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William J. Hughes Technical Center
Aviation Research Division
Atlantic City International Airport
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The Effect of Varying the Air Openings around the Sliding Platform in the Radiant Panel Insulation Test

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16. Abstract

A radiant panel insulation test round robin with 24 labs was conducted in 2015 and the test results varied considerably between labs. Dimension data about each apparatus was collected from each participating lab and the air openings around the sliding platform were identified as one possible cause of the test discrepancies. Preliminary studies were then conducted at the FAA Technical Center with four different insulation materials while varying the air openings. This testing found that certain materials failed more often when the openings were closed. A larger study was designed with four labs testing many parameters with the air gaps fully closed, partially open, and fully open. Each lab conducted a three-position calibration, measured the sliding platform top surface temperatures using a thermocouple array, and tested 20 samples of two different materials at each gap setting. Statistical analysis of variance was used to compare the material test data. Test results showed similar trends between all four labs for the calibration and surface temperature data, with mixed results for the material testing data. Minimum opening dimensions around the sliding platform were added to the Aircraft Materials Fire Test Handbook Revision 3 based on the results of this study.

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Acronyms

Acronym	Definition
FAA	Federal Aviation Administration
ANOVA	Analysis of Variance
FPM	Feet per minute
PEEK	Polyether ether ketone
IAMFTF	International Aircraft Materials Fire Test Forum
PCF	Pounds per cubic foot

Executive Summary

A radiant panel insulation test round robin with 24 labs was conducted in 2015, and the results showed a large variation between labs. Before testing, a survey was sent out to all participants, and data on each lab's radiant panel apparatus, including dimensions not listed in the materials fire test handbook, was collected. The largest variation in dimensions was found to be the openings around the sliding platform that can let in outside air. The heat produced from the electric radiant heat panel induces airflow through the apparatus, the amount of which can be affected by the size of the openings.

Preliminary studies were conducted at the FAA Technical Center to determine the effect of various air gaps around the sliding platform. The air gaps around the sliding platform varied in three different settings, and the standard test procedure for Chapter 23 of the Aircraft Materials Fire Test Handbook was used. When the gaps were fully closed off, calibrating the apparatus to the required heat flux of 1.50 Btu/ft^{2}s needed the lowest temperature set point of the electric radiant panel of any of the gap settings. The more the gaps were opened, the higher the radiant panel's temperature was needed to achieve proper calibration. Larger air openings also increased the air velocity exiting the chamber through the chimney. Material tests showed significantly more failures with a metalized PEEK insulation cover material when the gaps were closed compared to open.

A larger experiment was designed with four labs that would test their radiant panel apparatus at three air gap settings: fully closed, partially open, and fully open. At each gap setting, they would each run a three-position heat flux calibration, measure the surface temperature of the sliding platform with an array of 15 thermocouples, and test 20 samples of two different metalized PEEK insulation cover materials. Analysis of Variance was used to analyze the material test data.

For the three-position heat flux calibration on the fully closed setting, three out of the four labs were not within the specified range for positions one and/or two, and the fourth lab was right on the edge of the tolerance. All four labs were comfortably within range for the partially and fully open settings. For the surface temperatures, all four labs had the lowest temperatures with the fully closed setting and the highest with the fully open setting.

Two different types of metalized PEEK material were tested. The first was a robust material with only one failure out of 240 samples; however, it showed a significant difference in flame propagation length with different air gap settings in two out of four labs. The second material

had many more test failures and more varied results, with three out of four labs showing a significant difference in test results between gap settings.

Historically, the gaps around the sliding platform were never supposed to be completely closed, but it was never specified in the handbook. This testing showed that calibration is difficult to achieve with the gaps closed, it has the lowest surface temperatures, and material test results may not align with other gap settings. Therefore, minimum size openings around the sliding platform have been specified in handbook revision 3.

1 Introduction

The radiant panel insulation test is used to fire test insulation installed in hidden areas on commercial aircraft. It consists of an 18.5 ft^3 chamber with a platform that slides in and out to hold the test sample in place. Test samples are aircraft insulation materials sized to 23 by 12.5 inches for the most common test configuration. The electric radiant panel inside the chamber is rated at 7574 watts and is set at an angle of 30° from horizontal to supply radiant heat during testing. There is also a propane torch under the heat panel that is used to ignite the sample for 15 seconds during a test. Measurements of the after-flame time and flame propagation length of the test sample are taken. Smoke is exhausted out of the chamber on the opposite side. The heat created by the radiant panel induces air flow through the chamber by natural convection. A diagram is shown in Figure 1 and more details of the test method can be found in chapter 23 of the Aircraft Materials Fire Test Handbook (Federal Aviation Administration, 2020).

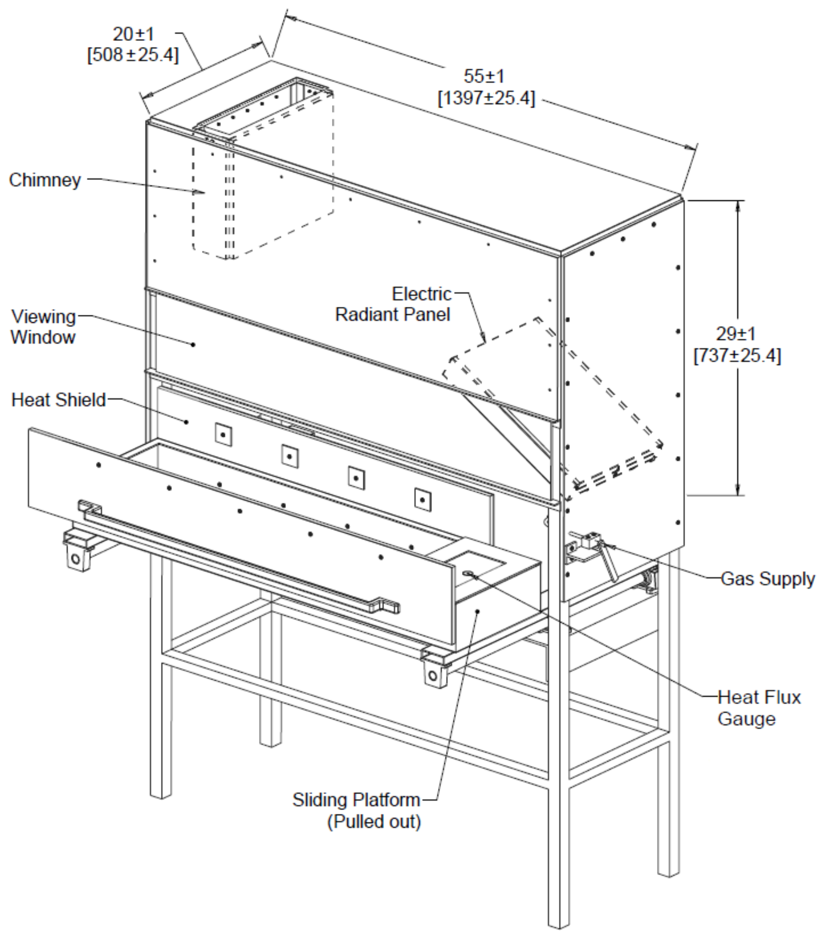

Figure 1. Diagram of the radiant panel insulation test apparatus

In the radiant panel insulation round robin of 2015, the 24 labs that participated had large variations in material test results. This could have been caused by several different factors, such as differences in heat flux gauges, the age of the electric radiant panels, variations in the ignitor from the manufacturing process or contaminants, or differences in the design of the test apparatus itself. Some of these variables have been previously studied such as variations in heat flux and flame length (Morgan, 2003).

Before the round robin testing, a survey was sent out to every lab to report all the dimensions of their radiant panel apparatus. Most of the dimensions that are specified in chapter 23 of the Aircraft Materials Fire Test Handbook (Federal Aviation Administration, 2020) were within spec for all the labs, but the handbook does not give details on every design aspect of the chamber. The survey asked participants to report the gaps between the sliding platform, or drawer, and the chamber walls that are open to the outside environment. These openings allow air to flow into the chamber from underneath while it is running.

The open areas around the drawer from every lab varied from zero to 308 in^2 with a wide variety of numbers in-between. For the FAA's apparatus, there was 124 in^2 of open area in its standard configuration. Differing amounts of cool air flowing into the chamber can potentially influence heat flux, the panel temperature set point, and the flame characteristics of the ignitor and material burning. This was identified as a possible cause of the poor reproducibility of the round robin test results, so we designed an experiment to quantify its effects.

2 Preliminary testing

Initial testing with the radiant panel apparatus at the FAA Technical Center involved conducting heat flux calibrations with the openings around the drawer in their normal setting, fully open, and fully closed. The blue arrows in Figure 2 show where room temperature air can enter the chamber around the drawer. However, there are no seals around the drawer, window, or any other part of the test apparatus, so even when in the fully closed setting, air can still enter the chamber. The dimensions of the openings around the drawer are summarized in Table 1. Since these dimensions were never specified in the rule or handbook, they vary substantially from machine to machine. For the FAA's apparatus, the fully open setting is as much as it can be opened without making major modifications.

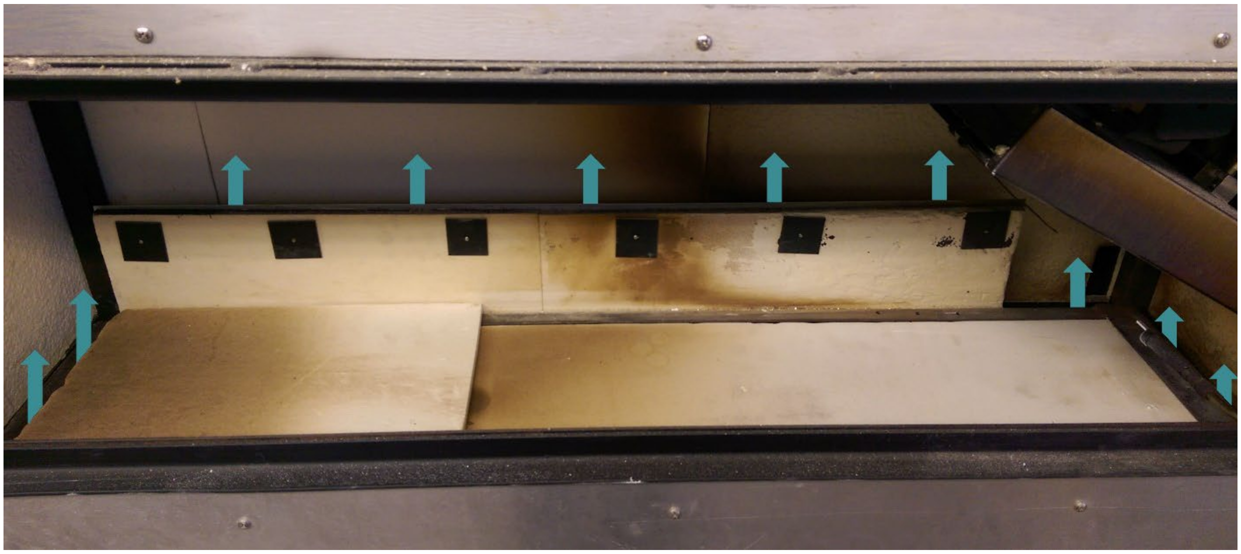

Figure 2. Blue arrows indicate where room temperature air enters the chamber

Table 1. The size of the openings around the drawer in each configuration

	Fully Closed (in)	Partial (in)	Fully Open (in)
Left	0	0.3125	2.125
Right	0	0.125	1.875
Front	0	0	0
Rear	0	2.25	2.25

The standard procedure (Federal Aviation Administration, 2020) for calibrating the radiant panel apparatus was used for all three configurations. The air gap, heat flux, radiant panel temperature set point, chamber temperature, and chimney air velocity were recorded. The velocity of the air exiting the chimney is not typically measured but was used in this testing to compare the change in airflow moving through the test apparatus. This was measured with a 3-inch diameter vane anemometer placed at the exit of the chimney averaged over three positions, centered, and the edge of the anemometer placed 1-inch from both the front and rear of the chimney. The results are summarized in Table 2. As the gaps were opened, the radiant panel needed to be set to a higher temperature in order to keep the heat flux constant. The set point increased from 1096°F when closed to 1137°F when opened. The velocity of the air through the chimney increased as well, from 205 FPM to 278 FPM. The increase of air moving through the chamber required more heat from the radiant panel in order to maintain standard conditions, which could potentially have an effect on test results.

Table 2. Preliminary calibration data

	Fully Closed	**Partial**	**Fully Open**
Open Area Around Drawer(in^2)	0	123.77	183.44
Panel Set Point (°F)	1096	1105	1137
Heat Flux (BTU/ft^2s)	1.501	1.502	1.495
Chamber Temperature(°F)	381	366	425
Chimney Air Velocity (FPM)	205	260	278

The radiant panel set point was also varied at the fully open setting in order to get a reading of heat flux with the panel at the same temperature set point as when fully closed. When at the panel set point of the fully closed setting, the heat flux for the fully open setting was only 1.398 Btu/ft2s and the chimney air velocity decreased to 245 FPM. A summary of the results is shown in Table 3.

Table 3. Calibration data with varied panel set point at fully open setting

Set Point (°F)	**1095**	**1110**	**1125**	**1137**
Heat Flux (BTU/ft^2s)	1.398	1.439	1.481	1.495
Chamber Temperature (°F)	385	395	410	425
Chimney (FPM)	245	255	268	278

Four different insulation samples were tested comparing the fully closed setting to the fully open setting. All of the insulation samples were composed of the same 0.34 pound per cubic foot (pcf) batting material and covered with different covering materials. Sample construction is described in chapter 23 of the Aircraft Materials Fire Test Handbook. (Federal Aviation Administration, 2020) Three of the cover materials were the same as was used in the round robin: metalized PEEK, metalized PEEK with metalized PEEK tape, and unmetalized PEEK. The fourth cover material was an unknown material that would shrink when heat was applied. In radiant panel insulation tests, flame propagation greater than 2 inches and/or after flame time greater than 3 seconds are considered a failure. These thresholds are shown by dashed lines in the test result graphs. The results for all four materials are shown in Figure 3, Figure 4, Figure 5, and Figure 6.

There were at least five samples tested of each material for each configuration. The metalized PEEK had the largest difference in test results, with four out of the five samples failing from both after flame time and flame propagation with the air gaps closed compared to no samples having any after flame time and only one failing for flame propagation with the gaps open. In observing the tests, it appeared that the extra airflow with the gaps open could have "blown out" the flame, while the flame was more stable and longer lasting when there was less airflow with the gaps closed.

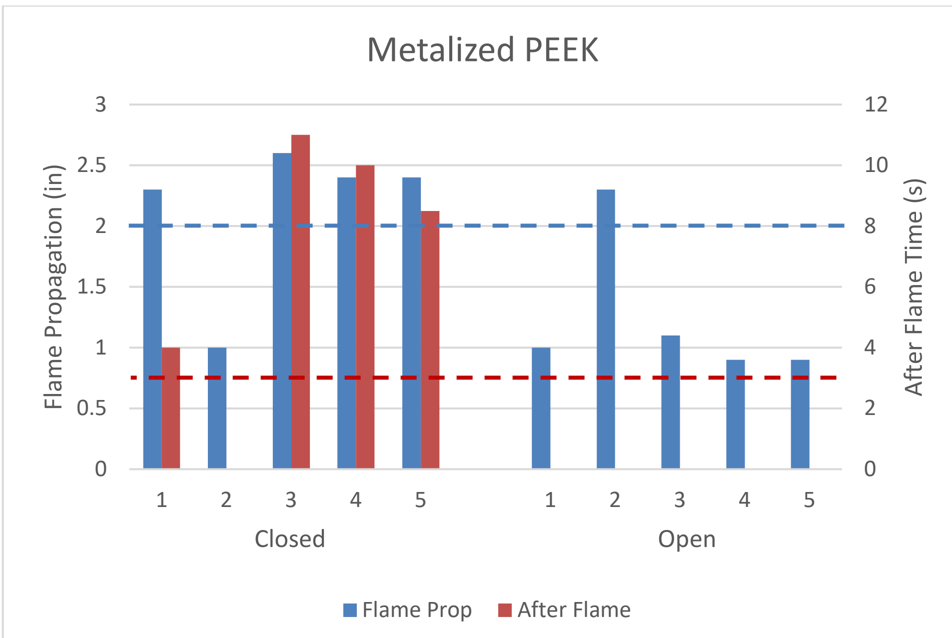

Figure 3. Metalized PEEK test results

The metalized PEEK material with metalized PEEK tape had similar results, as expected. Overall, the after-flame times were lower and there were no failures in either configuration, but four out of the five samples had after flame time with the gaps closed, while only one had after flame time with the gaps open.

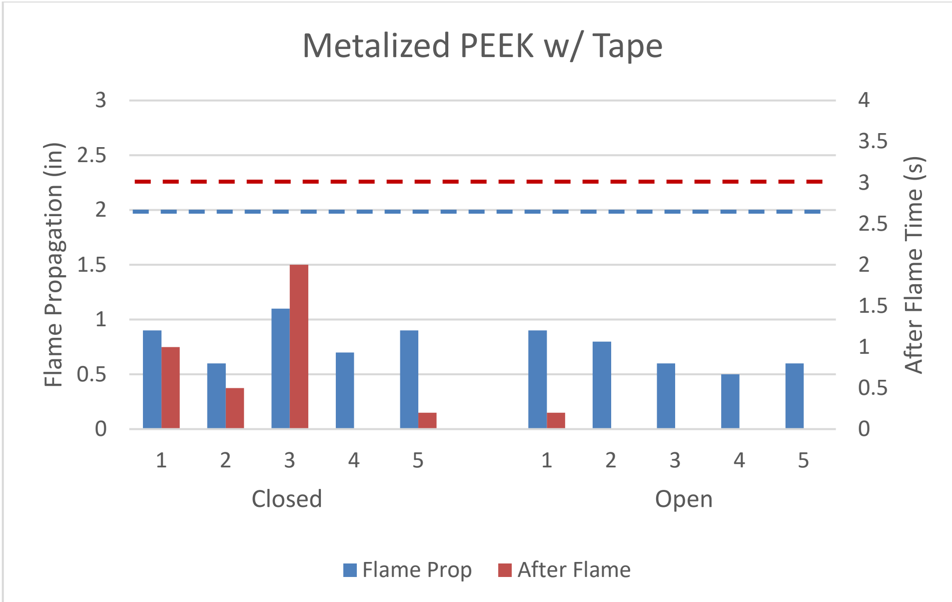

Figure 4. Metalized PEEK with metalized PEEK tape test results

With the unmetalized PEEK material, the change in air gaps had no significant impact on test results in this study.

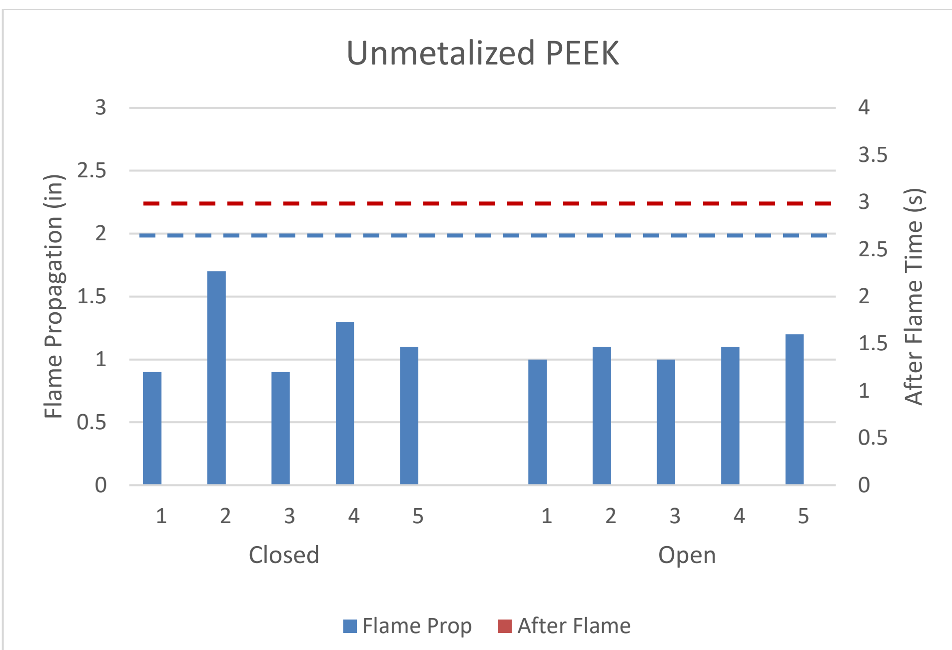

Figure 5. Unmetalized PEEK test results

The shrinking material did not show much difference in test results either. There was one sample with the air gaps closed that had an after-flame time of 2.8 seconds while all other samples had zero after flame time, but that was likely to be an anomaly based on the other results.

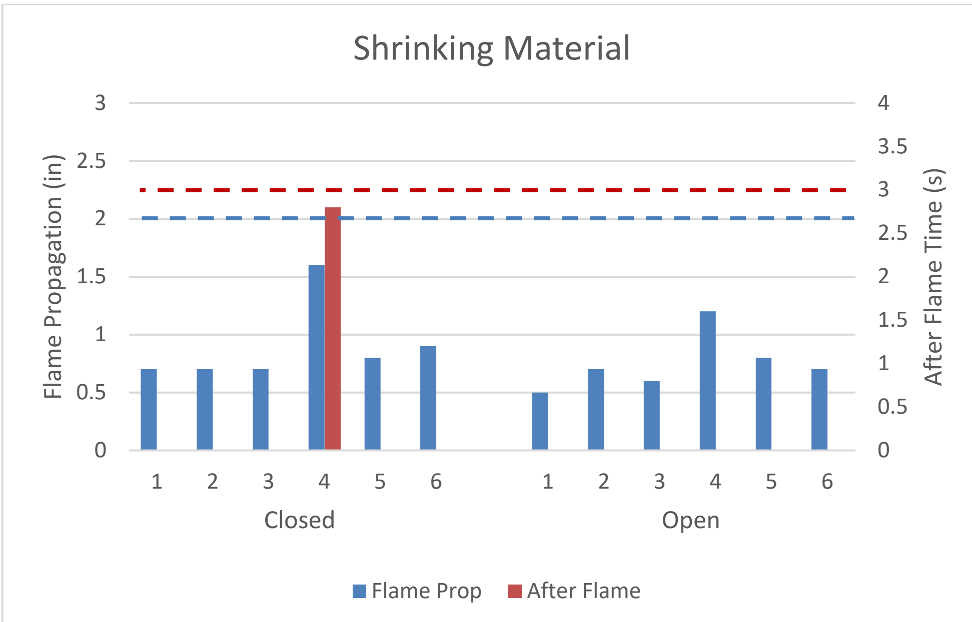

Figure 6. Shrinking material test results

3 Experimental setup

The results of the preliminary studies were discussed at the International Aircraft Materials Fire Test Forum (IAMFTF) and three other labs volunteered to participate in a larger study. The four labs involved in the study were the FAA Technical Center, The Boeing Company, Triumph Insulation Systems, and Damping Technologies, Inc. Two of the participating lab's radiant panel apparatuses were produced by the same company, and the other two were built in-house. This meant that the air gaps were not the same for the fully open setting, among other slight design differences.

Each lab in this experiment tested with the openings around their drawer in three different settings: fully closed, partially open, and fully open. Fully closed has all gaps around the drawer closed, partially open has a half inch gap on the left, right, and back sides, and fully open is as open as each apparatus can be without making major modifications. The fully open air gaps for each lab are shown in Table 4. Lab C has an asterisk for the right-side gap dimension because while there is a 3-inch gap between the edge of the drawer and the wall of the chamber, it is not fully open to the outside air. The 3-inch-wide area is blocked off near the bottom of the drawer but there are two smaller openings at the front and back of the chamber that can let fresh air inside. However, probably not as much air as if the full area was open.

Table 4. Fully open air gaps for each lab

	Lab A	**Lab B**	**Lab C**	**Lab D**
Right Gap (in)	1.875	2.5	3*	2.5
Left Gap (in)	2.125	2.25	4.375	2.5
Rear Gap (in)	2.25	1	1.2	0.5
Front Gap (in)	0	1.5	0	1.5
Total Area (in^2)	183.5	189	115	201.5

To conduct the full experiment, each lab ran the standard calibration procedure with the three-position heat flux check at each gap setting. All four lab's heat flux gauges were calibrated at the FAA Technical Center prior to testing to ensure they all had the same calibration. They were then asked to record the lab ambient temperature and humidity, radiant panel temperature set point, warm-up and stabilization time of the panel, the chamber temperature, and the air velocity at the exit of the chimney.

Then each lab measured the temperature at the top surface of the drawer with an array of 15 thermocouples coming through a half-inch sheet of Superwool 607 insulation board. The thermocouple array was built at the FAA Technical Center and then sent around to the other three labs to test. This eliminated any variables from using different thermocouples or building it with different dimensions. The dimensions of the thermocouple array are shown in Figure 7. Thermocouple number five is placed at the zero position and the other dimensions are based on that position. The actual array is shown in Figure 8 in the FAA's radiant panel apparatus. After calibrating to the standard 1.5 Btu/ft^{2}s heat flux and reaching steady state with the thermocouples in position, each lab recorded temperature data for 5 minutes three separate times at each gap setting.

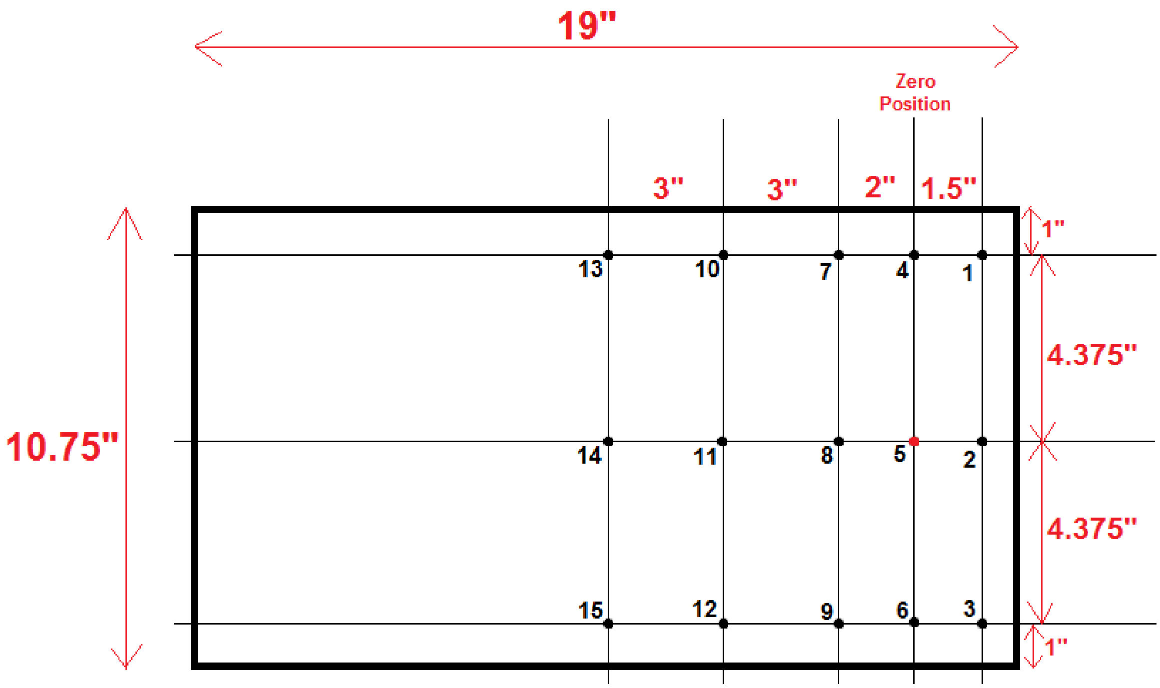

Figure 7. Thermocouple array dimensions

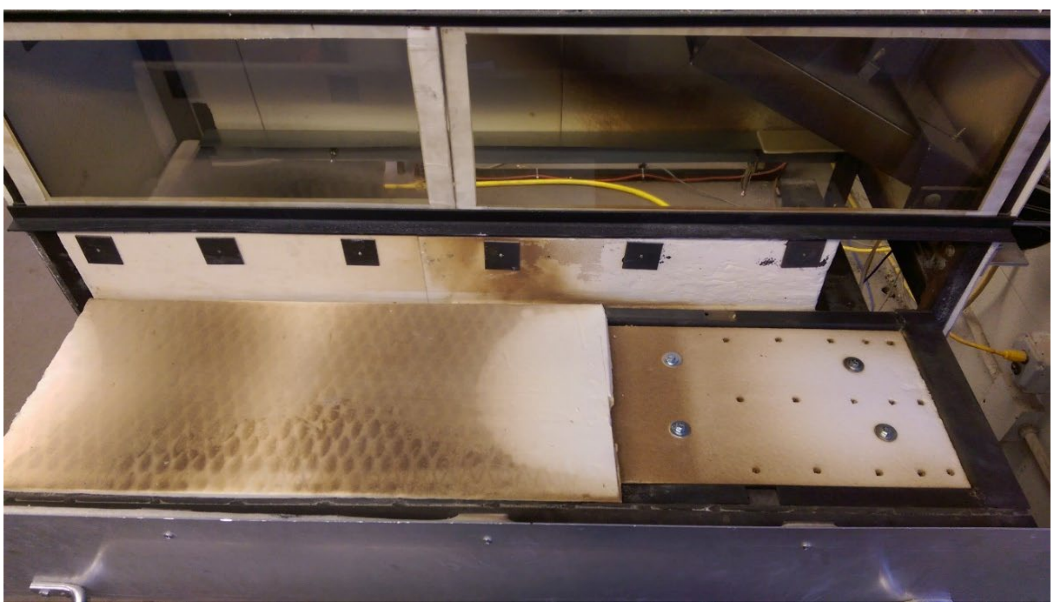
Figure 8. Thermocouple array picture

After this is completed, each lab tested 20 material samples at each gap configuration using the same metalized PEEK material as the previous round robin. The twenty-sample number comes from using one-way analysis of variance (ANOVA) which determined that would be the minimum number required to do useful statistically significant analysis. As seen in Figure 9, the analysis found that it would take 21 samples to detect a difference between the sample means of one standard deviation, 32 samples to detect 0.8 standard deviations, and 79 samples to detect 0.5 standard deviations. More than 20 samples than that would have been better able to detect smaller differences in test results, but getting supplied with more material and producing more samples would become a problem. Twenty samples for each of the three configurations for four labs is 240 total samples. After all labs complete their testing, Boeing completed the ANOVA and reported the results.

```
One-way ANOVA
Alpha = 0.05  Assumed standard deviation = 1

Factors: 1  Number of levels: 3

   Maximum    Sample   Target
Difference      Size   Power    Actual Power
       0.5        79   0.8      0.804941
       0.8        32   0.8      0.811864
       1.0        21   0.8      0.814770

The sample size is for each level.
```

Figure 9. ANOVA sample size required for a specified maximum difference

4 Results and discussion

4.1 Calibration testing

In calibration testing, all four labs required a much higher panel temperature set point when in the fully open configuration versus fully closed. The absolute temperature varied from lab to lab based on the panel resistance and the age of the panel, among other possible differences, but the important thing to consider is the required increase in temperature to make up for the increase in airflow into the chamber. The panel set points required to reach the 1.50 Btu/ft^{2}s calibration is shown in Figure 10.

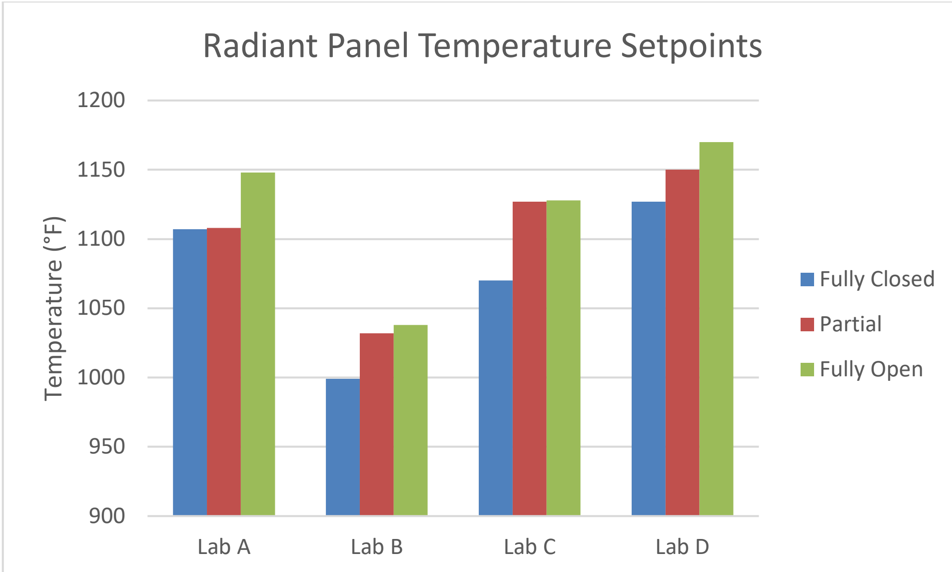

Figure 10. Radiant Panel temperature set points to reach calibration at each gap setting

The three-position calibration check showed some differences as well. In the fully open and partially open settings, all labs had their three-position check heat fluxes fall within the nominal range. For the fully closed setting, three out of the four labs had either positions 1 or 2 below the normal range. All of the heat flux measurements are shown in Table 5, with the anomalous values in red. Position one for lab A was slightly higher than normal but still technically within the nominal range. The fully closed setting consistently did not perform well in calibrating the apparatus.

The FAA Technical Center was the only lab to measure the velocity of the air exiting the chimney with an anemometer. When fully closed, the air velocity was 200 ft/min, partially open was 245 ft/min, and fully open was 287 ft/min. This is a similar result to the preliminary testing and is a good measurement of the higher airflow moving through the chamber, but unfortunately the other labs were not able to make the same measurement.

Table 5. Three-position check heat flux (Btu/ft2s)

		Fully Closed	Partial	Fully Open
Lab A	**Position 0**	1.497	1.499	1.506
	Position 1	1.520	1.511	1.503
	Position 2	1.430	1.440	1.440
Lab B	**Position 0**	1.50	1.50	1.50
	Position 1	1.43	1.47	1.46
	Position 2	1.35	1.43	1.41
Lab C	**Position 0**	1.50	1.50	1.50
	Position 1	1.43	1.50	1.50
	Position 2	1.43	1.45	1.44
Lab D	**Position 0**	1.50	1.50	1.50
	Position 1	1.36	1.48	1.50
	Position 2	1.37	1.42	1.42

Using the thermocouple array, the temperatures at the top surface of the drawer were measured over 5 minutes and averaged. The data was then linearly interpolated using MATLAB into heat maps, which are shown for every lab and setting in Figure 11. Every lab had the same trend in their temperature data. Fully closed had the lowest surface temperatures, partially open was in the middle, and fully open had the hottest temperatures. The hottest temperature measured for most of the configurations was either the zero position or 2 inches to the left of that.

While having the same basic trends between all the labs, the absolute temperatures varied quite a bit. For example, the average temperature measured at the fully open configuration varied from 374°F in the coolest lab to 455.7°F in the hottest lab. The age of the panels likely were a big cause of this discrepancy. The FAA Technical Center was the first lab to measure temperatures with the thermocouple array, and then measured again after getting the array back after the three other labs used it. In the meantime, the FAA replaced their panel with a brand new one a short period before using the thermocouple array a second time. The data displayed in Figure 11 is with the new panel.

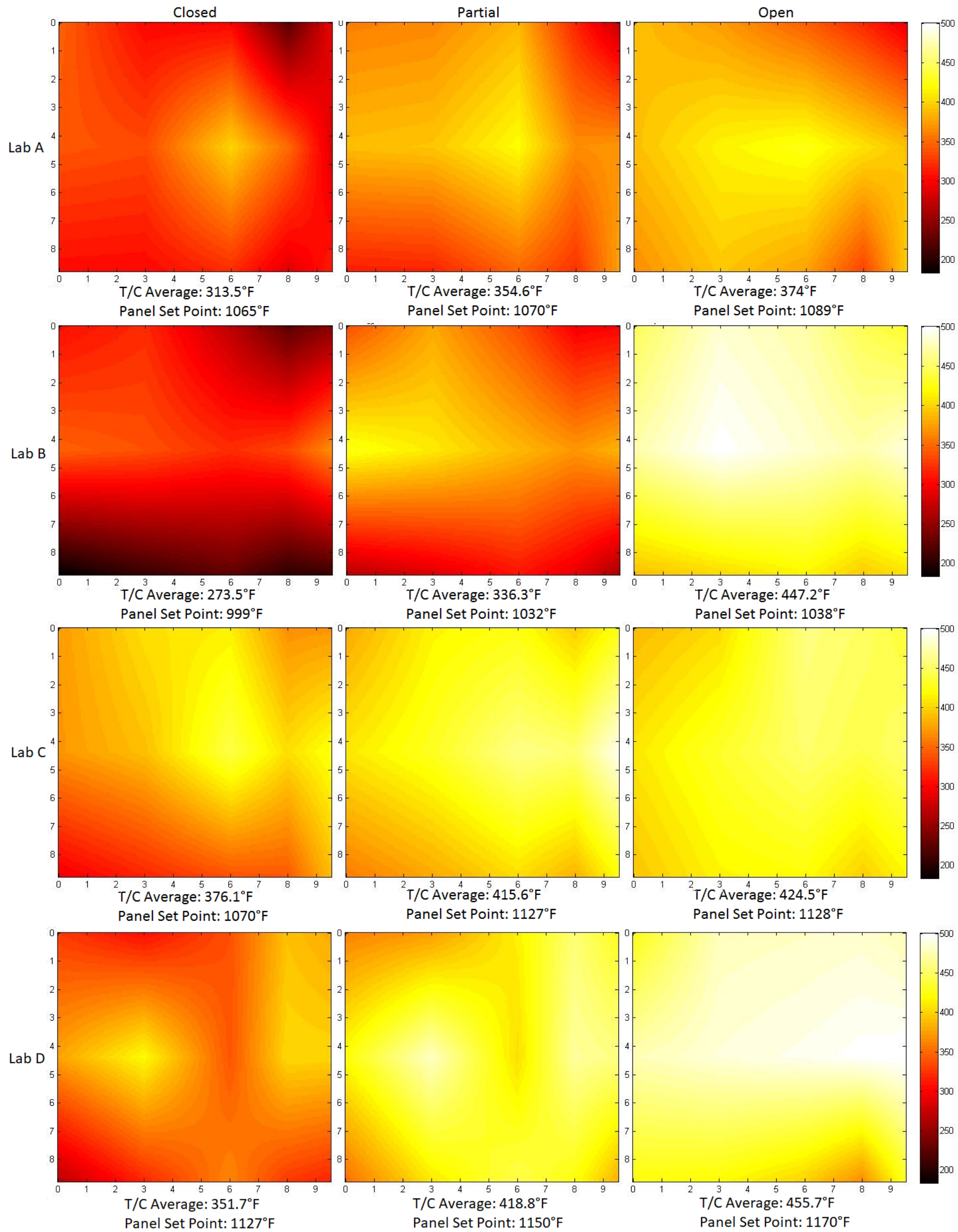

Figure 11. Heat maps from thermocouple array on top surface of drawer

The FAA originally tested with the thermocouple array before the dimensions of the partially open configuration were decided. Therefore, only the fully open and fully closed settings can be directly compared. The results are shown in Figure 12. With the old panel, the panel temperature set point and drawer surface temperatures were much higher, even though everything else was the same. The average surface temperature decreased from 393.2°F when closed and 415.9°F when open with an old panel to 313.5°F closed and 374°F open with a new panel. This shows that the both the electric panel and the amount of airflow into the chamber can have a large effect on surface temperatures even when heat flux is constant at the zero position.

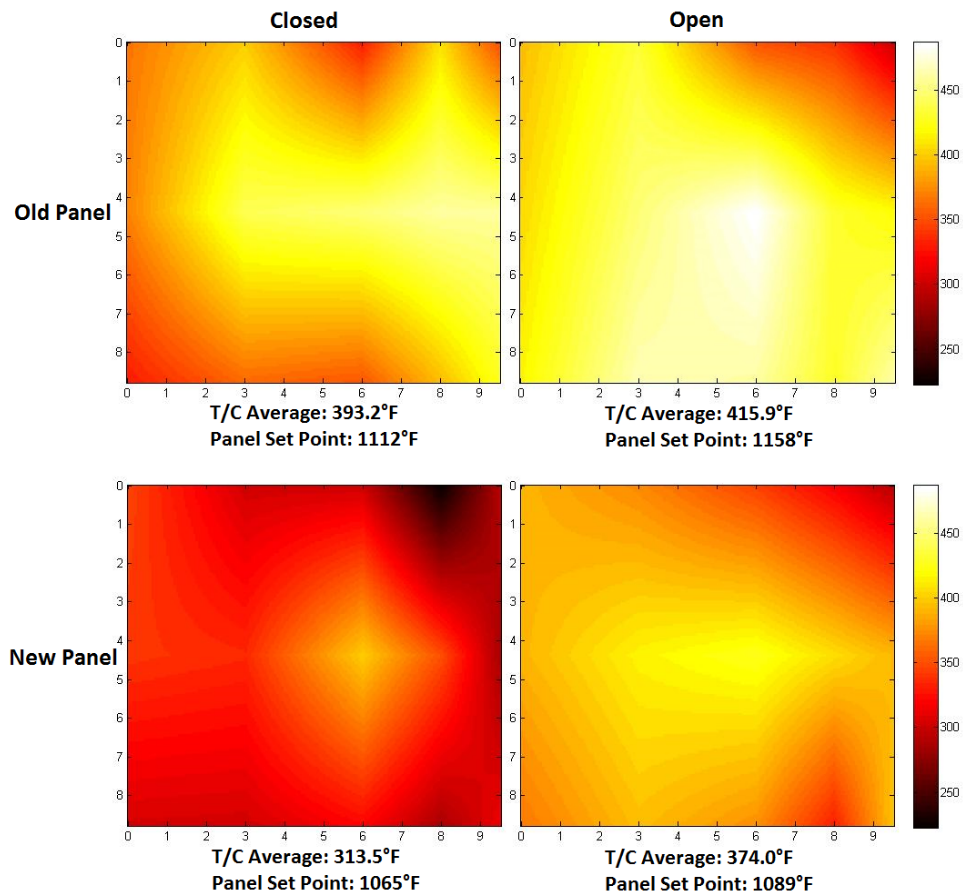

Figure 12. FAA's old panel compared to new panel

4.2 Insulation sample testing round 1

For material testing, each lab tested 20 samples of metalized PEEK at each of the three gap settings. This material came from the same supplier as the round robin metalized PEEK samples, but it was not the same material. The round robin material was more lustrous looking and may have had less flame retardant than the samples in this study. A picture comparing the two is shown in Figure 13. All testing proceeded as normal but the large differences in test results between the air gap configurations were not observed in this study.

Figure 13. Metalized PEEK from this study (left) and round robin (right)

All of the data from this study were compiled into box and whisker plots, with Figure 14 showing the flame propagation lengths and Figure 15 showing the after-flame time. The blue dashed line in Figure 14 indicates the threshold for failure due to flame propagation. In these graphs, the box spans from the first quartile to the third quartile with the middle line showing the median. The whiskers show the minimum and maximum and any dots outside of the whiskers are outliers. An outlier is defined as any number 1.5 times the inter-quartile range greater than the upper quartile or less than the lower quartile. The × symbol shows the mean.

In initial analysis, labs A and B had the lowest flame propagation length for the open setting, while labs C and D had the highest flame propagation length for the open setting. However, there was not much burning with this material in general, making comparisons more difficult. Only one sample out of the 240 tested by all the labs failed the two-inch flame propagation or three-second after flame time criteria. For after flame time, labs A, C, and D each only had one sample out of 60 have any after flame time and it occurred on the closed setting for all three. Lab B had much higher after flame times overall, and the open setting had less after flame time than the closed and partial settings.

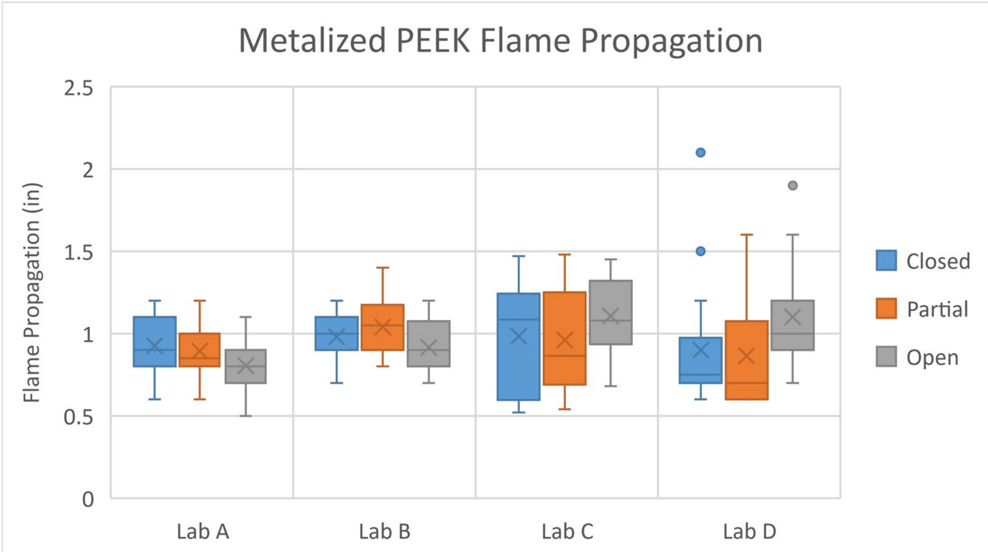

Figure 14. Box and whisker plot of flame propagation

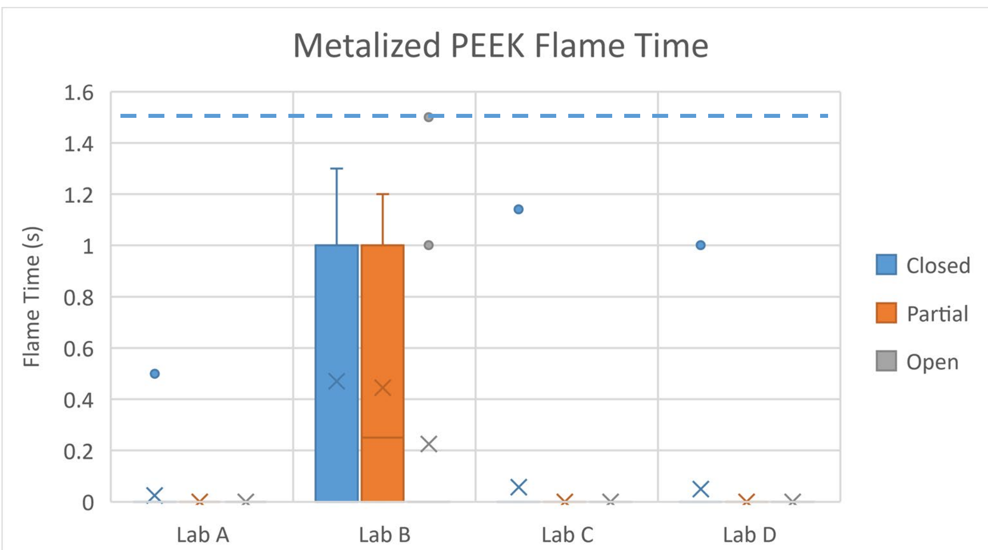

Figure 15. Box and whisker plot of after flame time

The ANOVA data for flame propagation for lab A is shown in Figure 16. The F statistic of 2.590 is less than the $F_{critical}$ value of 3.159 and the p-value of 0.084 is greater than 0.05, meaning the null hypothesis is accepted. Therefore, the different gap settings did not make a statistically significant difference at a 95% confidence level in this study. However, the p-value is still relatively low, so different types of analysis or a larger sample size may yield different results. For after flame time, it was not possible to conduct ANOVA since all values were zero except for one.

Descriptives - Flame Prop

Gap Setting	Mean	SD	N
closed	0.925	0.180	20
open	0.805	0.150	20
partial	0.895	0.188	20

ANOVA - Flame Prop

Cases	Sum of Squares	df	Mean Square	F	p	η²
Gap Setting	0.156	2	0.078	2.590	0.084	0.083
Residuals	1.717	57	0.030			

Note. Type III Sum of Squares

Figure 16. Lab A flame propagation length ANOVA

The ANOVA data for flame propagation length for lab B is shown in Figure 17. The F-statistic of 3.466 is greater than $F_{critical}$ and the p-value is less than 0.05, so the null hypothesis is rejected on both counts. Therefore, for lab B, the gap setting did make a significant difference with a 95% confidence level. Tukey analysis shows that the significant difference only came between the open and partial settings.

Descriptives - Flame Prop

Gap Setting	Mean	SD	N
Closed	0.980	0.147	20
Open	0.915	0.142	20
Partial	1.040	0.160	20

ANOVA - Flame Prop

Cases	Sum of Squares	df	Mean Square	F	p	η²
Gap Setting	0.156	2	0.078	3.466	0.038	0.108
Residuals	1.286	57	0.023			

Note. Type III Sum of Squares

Post Hoc Comparisons - Gap Setting

			95% CI for Mean Difference				
		Mean Difference	Lower	Upper	SE	t	p_{tukey}
Closed	Open	0.065	−0.049	0.179	0.047	1.369	0.364
	Partial	−0.060	−0.174	0.054	0.047	−1.263	0.422
Open	Partial	−0.125	−0.239	−0.011	0.047	−2.632	0.029*

* p < .05

Note. P-value and confidence intervals adjusted for comparing a family of 3 estimates (confidence intervals corrected using the tukey method).

Figure 17. Lab B flame propagation length ANOVA

The ANOVA data for after flame time for lab B is shown in Figure 18. The F-statistic of 1.426 is much less than $F_{critical}$ and the p-value of 0.249 is much greater than 0.05 so the null hypothesis is accepted. The different gap settings did not make any significant difference on flame time for lab B.

Descriptives - Flame Time

Gap Setting	Mean	SD	N
closed	0.470	0.545	20
open	0.225	0.472	20
partial	0.445	0.495	20

ANOVA - Flame Time

Cases	Sum of Squares	df	Mean Square	F	p	η²
Gap Setting	0.727	2	0.364	1.426	0.249	0.048
Residuals	14.529	57	0.255			

Note. Type III Sum of Squares

Figure 18. Lab B after flame time ANOVA

The ANOVA data for flame propagation length for lab C is shown in Figure 19. The F-statistic of 1.491 is much less than $F_{critical}$ and the p-value of 0.234 is much greater than 0.05 so the null hypothesis is accepted. The different gap settings did not make any significant difference on flame time for lab B. For after flame time, it was not possible to conduct ANOVA since all values were zero except for one.

Descriptives - Flame Prop

Gap Setting	Mean	SD	N
Closed	0.984	0.315	20
Open	1.105	0.227	20
Partial	0.961	0.303	20

ANOVA - Flame Prop

Cases	Sum of Squares	df	Mean Square	F	p	η²
Gap Setting	0.242	2	0.121	1.491	0.234	0.050
Residuals	4.621	57	0.081			

Note. Type III Sum of Squares

Figure 19. Lab C flame propagation length ANOVA

The ANOVA data for flame propagation for lab D is shown in Figure 20. The F statistic of 3.062 is slightly less than the $F_{critical}$ value of 3.159 and the p-value of 0.055 is slightly greater than 0.05, meaning the null hypothesis is accepted. Therefore, the different gap settings did not make a statistically significant difference at a 95% confidence level in this study. However, the p-value is just barely above the limit, so different types of analysis may yield different results. For after flame time, it was not possible to conduct ANOVA since all values were zero except for one.

Descriptives - Flame Prop

Gap Setting	Mean	SD	N
Closed	0.900	0.360	20
Open	1.100	0.301	20
Partial	0.865	0.308	20

ANOVA - Flame Prop

Cases	Sum of Squares	df	Mean Square	F	p	η^2
Gap Setting	0.643	2	0.321	3.062	0.055	0.097
Residuals	5.986	57	0.105			

Note. Type III Sum of Squares

Figure 20. Lab D flame propagation length ANOVA

For the two labs with results that were very close to showing a statistically significant difference, labs A and D, additional analysis was performed using Bayesian ANOVA. Rather than the all-or-none approach of typical ANOVA ($p < 0.05$ being the cutoff), a Bayesian ANOVA works differently. In the Bayesian framework, knowledge about parameters and hypotheses is updated as a function of predictive success – hypotheses that predicted the observed data relatively well receive a boost in credibility, whereas hypotheses that predicted the data relatively poorly suffer a decline. (van den Bergh, et al., 2019) The prior knowledge from the preceding data set is used to predict the succeeding data and the Bayes factor is updated based on the relative predictive performance. The knowledge is continuously updated on a learning cycle to determine which model is most likely.

The Bayesian ANOVA on lab A flame propagation length is shown in Figure 21. The Bayes factor (BF_M) is 1.118 for the Null model, meaning that it is 1.118 times more likely that the gap setting does not cause a statistically significant difference in test results. A Bayes factor of 1 means there is no evidence in either direction, while a Bayes factor from 1 to 3 means there is anecdotal evidence for the result.

Model Comparison

Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
Null model	0.500	0.528	1.118	1.000	
Gap Setting	0.500	0.472	0.894	0.894	0.012

Figure 21. Lab A flame propagation length Bayesian ANOVA

For Lab D, the Bayesian ANOVA actually does flip the results in favor of the gap setting making a difference in test results, shown in Figure 22. The BF_M is 1.256; meaning is 1.256 times more likely that the gap setting does have a significant effect. For a point of comparison with a more definitive result, the Bayes factor for lab B's flame propagation is 1.677.

Model Comparison

Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
Gap Setting	0.500	0.557	1.256	1.000	
Null model	0.500	0.443	0.796	0.796	0.005

Figure 22. Lab D flame propagation length Bayesian ANOVA

Overall, changing the openings around the drawer made a significant (greater than one standard deviation) difference with Lab B, a smaller difference with lab D, and no difference with labs A and C. However, the material tested was not as sensitive to changes as materials used previously and only one sample out of 240 failed the chapter 23 radiant panel insulation test. Because the material did not perform as hoped, all of the material testing was repeated for a second round of testing using a more sensitive material that better matched the 2015 round robin metalized PEEK material.

4.3 Insulation sample testing round 2

The results from round two of this testing resulted in much higher flame propagation lengths and after flame times overall than round one. The box and whisker plots of flame propagation lengths and after flame times are shown in Figure 23 and Figure 24. The blue and red dashed lines indicate the failure thresholds due to flame propagation length and after flame time, respectively. Due to a mistake in testing, lab D was not able to produce data for the partial setting. Labs A and B had the highest flame propagation lengths and after flame times for the closed setting, lab C was relatively close for all three settings with partial having the highest flame propagation and closed having the highest after flame, and lab D had the higher flame propagation and after flame with the open setting. The numbers of material failures for each lab and setting are shown in Table 6.

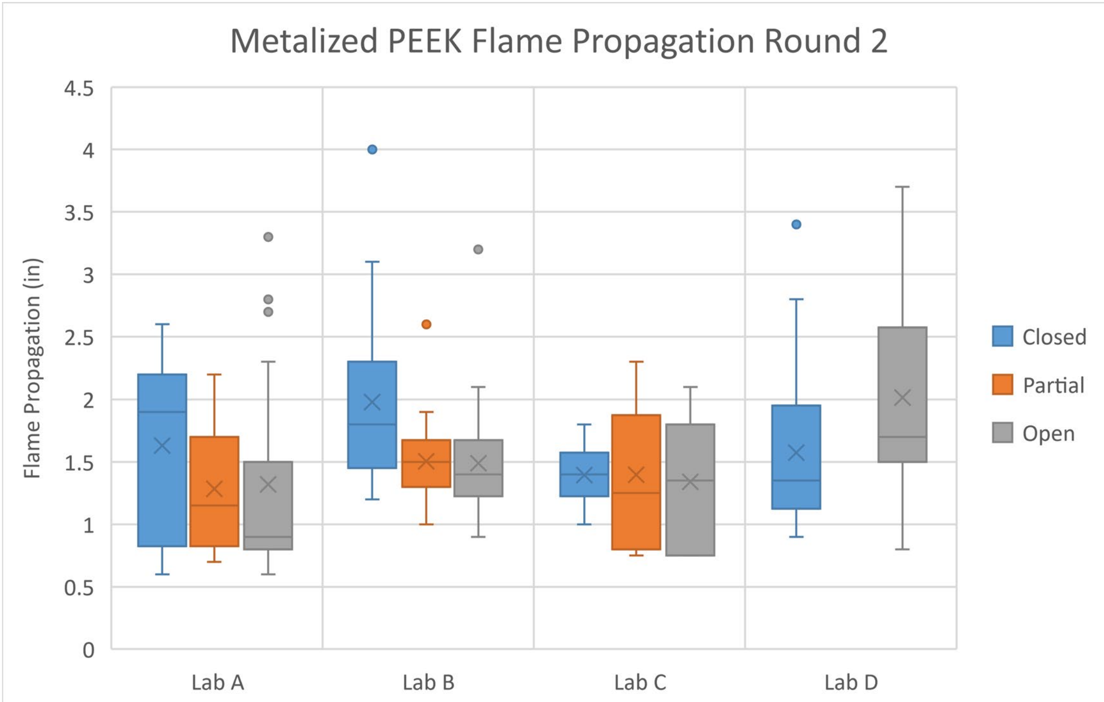

Figure 23. Box and whisker plot of round two flame propagation

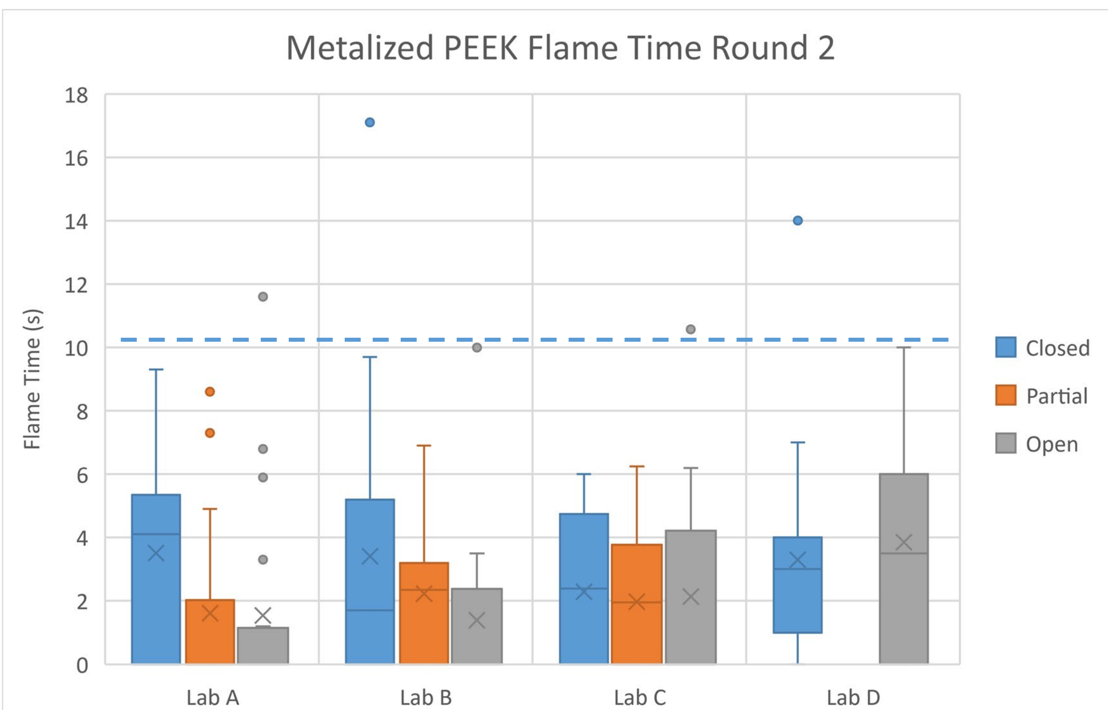

Figure 24. Box and whisker plot of round two flame time

Table 6. Round two material failures for each lab and configuration

	Lab A	Lab B	Lab C	Lab D
Closed	12	9	7	8
Partial	4	6	8	-
Open	4	4	7	10

The ANOVA for round two of flame propagation lengths and after flame times for lab A are shown in Figure 25. For flame propagation, the F-statistic of 1.590 is much less than the $F_{critical}$ value and the p-value of 0.213 is greater than 0.05, so changing the gap settings did not make a statistically significant difference. For flame time, the F-statistic of 2.968 is less than $F_{critical}$ and the p-value of 0.059 is greater than 0.05, so this just barely missed the cutoff for a statistically significant difference. The mean flame time for the closed setting was more than double that of the open and partial settings, but the large standard deviations meant that the differences could not be confirmed.

Descriptives -

	Flame Prop			Flame Time	
Gap Setting	Mean	SD	N	Mean	SD
closed	1.630	0.706	20	3.505	2.950
open	1.320	0.809	20	1.540	3.095
partial	1.285	0.457	20	1.610	2.617

ANOVA - Flame Prop

Cases	Sum of Squares	df	Mean Square	F	p	η²
Gap Setting	1.442	2	0.721	1.590	0.213	0.053
Residuals	25.860	57	0.454			

Note. Type III Sum of Squares

ANOVA - Flame Time

Cases	Sum of Squares	df	Mean Square	F	p	η²
Gap Setting	49.714	2	24.857	2.968	0.059	0.094
Residuals	477.435	57	8.376			

Note. Type III Sum of Squares

Figure 25. Lab A round two flame propagation and flame time ANOVA

The ANOVA for round two of flame propagation lengths and after flame times for lab B are shown in Figure 26. For flame propagation, F-statistic of 5.270 is greater than $F_{critical}$ and the p-value of 0.008 is less than 0.05, so there is a statistically significant difference at a 95%

confidence level. Using Tukey analysis, both the open and partial settings were significantly different from the closed setting. For after flame time, the F-statistic of 2.078 is less than $F_{critical}$ and the p-value of 0.135 is greater than 0.05, so there was no statistically significant difference.

Descriptives -

	Flame Prop			Flame Time	
Gap Setting	Mean	SD	N	Mean	SD
closed	1.980	0.708	20	3.405	4.447
open	1.490	0.495	20	1.390	2.395
partial	1.505	0.371	20	2.225	2.019

ANOVA - Flame Prop

Cases	Sum of Squares	df	Mean Square	F	p	η^2
Gap Setting	3.106	2	1.553	5.270	0.008	0.156
Residuals	16.799	57	0.295			

Note. Type III Sum of Squares

Post Hoc Comparisons - Gap Setting

			95% CI for Mean Difference				
		Mean Difference	Lower	Upper	SE	t	p_{tukey}
closed	open	0.490	0.077	0.903	0.172	2.854	0.016*
	partial	0.475	0.062	0.888	0.172	2.767	0.021*
open	partial	−0.015	−0.428	0.398	0.172	−0.087	0.996

* p < .05

Note. P-value and confidence intervals adjusted for comparing a family of 3 estimates (confidence intervals corrected using the tukey method).

ANOVA - Flame Time

Cases	Sum of Squares	df	Mean Square	F	p	η^2
Gap Setting	40.999	2	20.500	2.078	0.135	0.068
Residuals	562.225	57	9.864			

Note. Type III Sum of Squares

Figure 26. Lab B round two flame propagation and flame time ANOVA

The ANOVA for round two of flame propagation lengths and after flame times for lab C are shown in Figure 27. For both flame propagation and after flame time, there were very small F-statistics and very large p-values, meaning that this testing strongly confirmed no statistical difference in gap settings for this material for lab C.

Descriptives -	Flame Prop			Flame Time	
Gap Setting	Mean	SD	N	Mean	SD
closed	1.395	0.233	20	2.287	2.215
open	1.340	0.500	20	2.138	2.985
partial	1.397	0.563	20	1.980	2.137

ANOVA - Flame Prop

Cases	Sum of Squares	df	Mean Square	F	p	η^2
Gap Setting	0.042	2	0.021	0.102	0.903	0.004
Residuals	11.800	57	0.207			

Note. Type III Sum of Squares

ANOVA - Flame Time

Cases	Sum of Squares	df	Mean Square	F	p	η^2
Gap Setting	0.946	2	0.473	0.077	0.926	0.003
Residuals	349.324	57	6.128			

Note. Type III Sum of Squares

Figure 27. Lab C round two flame propagation and flame time ANOVA

Lab D was not able to test the partial setting because of a testing error, so the $F_{critical}$ value becomes 4.10. The ANOVA for round two flame propagation lengths and after flames times are shown in Figure 28. For flame propagation, the F-statistic of 3.799 is less than $F_{critical}$ and the p-value of 0.059 is greater than 0.05, so the gap setting did not make a statistically significant difference in flame propagation. For after flame time, the F-statistic is very small, and p-value is large so there was no significant effect on flame time.

Descriptives - Gap Setting	Flame Prop Mean	SD	N	Flame Time Mean	SD
closed	1.575	0.648	20	3.300	3.262
open	2.015	0.774	20	3.850	3.468

ANOVA - Flame Prop

Cases	Sum of Squares	df	Mean Square	F	p	η²
Gap Setting	1.936	1	1.936	3.799	0.059	0.091
Residuals	19.363	38	0.510			

Note. Type III Sum of Squares

ANOVA - Flame Time

Cases	Sum of Squares	df	Mean Square	F	p	η²
Gap Setting	3.025	1	3.025	0.267	0.608	0.007
Residuals	430.750	38	11.336			

Note. Type III Sum of Squares

Figure 28. Lab D round two flame propagation and flame time ANOVA

Bayesian ANOVA was conducted for some of the borderline test results for round two as well. For lab A, this analysis is shown in Figure 29. The Bayes factor is 1.174 for the gap setting meaning is 1.174 times more likely that the gap setting has a significant effect.

Model Comparison

Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
Gap Setting	0.500	0.540	1.174	1.000	
Null model	0.500	0.460	0.852	0.852	0.005

Figure 29. Lab A round two flame time Bayesian ANOVA

For lab D, the Bayesian ANOVA for flame propagation length is shown in Figure 30. The Bayes factor is 1.348 leaning towards the gap setting having a significant effect on test results. For a point of comparison with a more definitive result, the Bayes factor for lab B's flame propagation is 5.992.

Model Comparison

Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
Gap Setting	0.500	0.574	1.348	1.000	
Null model	0.500	0.426	0.742	0.742	0.004

Figure 30. Lab D round two flame propagation Bayesian ANOVA

Overall, for round two of testing, changing the gap setting made a large difference with lab B, a smaller difference with labs A and D, and no difference with lab C. Lab C had the smallest open area around its sliding platform, so there was the least variation in the apparatus from fully open to fully closed. Also, most of the open area was on the left side of Lab C's chamber, away from the radiant panel and ignitor. Testing with this round 2 insulation sample produced more variety in test results, which produced larger standard deviations, meaning there needed to be a more considerable difference in the sample to have a statistically significant result.

4.4 Analysis

Considering all the data gathered as a whole, the fully closed setting did not perform well and should be eliminated as a possible radiant panel apparatus configuration. The original radiant panel apparatus for testing aircraft insulation was based on the test method ASTM E648 for floor covering systems and specified that, "The free, or air access, area around the platform shall be in the range from 2300 to 3225 cm^2 (356 to 500 $in.^2$). (ASTM Committee E05.22, 2014)" Therefore, it was never supposed to be fully closed off historically, and the data in this experiment showed that the fully closed setting did not perform well. Three out of the four labs were not able to calibrate the three positions of the heat flux gauge in the specified range in the fully closed setting, and the fourth was right on the borderline. It also produced the lowest surface temperatures for all four labs.

In material testing, the gap setting significantly differed in test results for one lab, with a smaller difference for two labs and no difference for one lab. The sample size required a relatively large difference of one standard deviation to be statistically significant, and a larger sample size would have been more sensitive to changes. Many other factors can affect material test results as well, such as the age of the panel, the condition of the ignitor, and even the operators themselves. However, the test results from this experiment show that the air gaps around the drawer have the ability to make a difference, albeit possibly not as large of a difference as other factors. Therefore, the FAA added to the radiant panel insulation section of the Aircraft Materials Fire Test Handbook, Revision 3, that there must be a minimum opening of 0.5 inch on the rear and 0.25 inch on both sides of the sliding platform, as shown in Figure 31 (Marker, 2019).

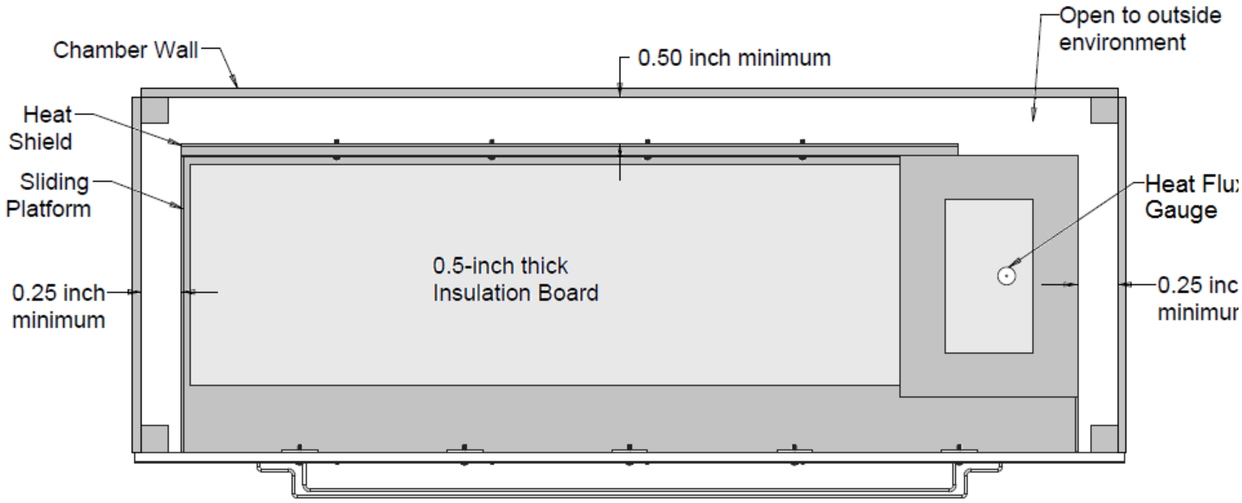

Figure 31. Opening around sliding platform in handbook, revision 3

5 Summary of results

When conducting the standard radiant panel insulation heat flux calibration at the zero position, all four labs required the highest panel temperature set point when the air gaps around the sliding platform were fully open and the lowest set point when fully closed. For the three-position check calibration, when the gaps were closed, three of the four labs were outside the specifications for positions one and/or two, and the fourth lab was right on the borderline for position one. The other two gap settings were in the correct range for all three positions for all four labs.

An array of 15 thermocouples was used to measure temperatures at the top surface of the sliding platform. All four labs had the highest average temperature when the air gaps were open and the lowest when they were closed. The temperatures between labs showed some variation, but all showed the same trend. Further testing by the FAA showed that the age of a panel could have a large effect on temperatures.

Two rounds of material testing were completed with two variations of metalized PEEK cover material over the same batting material. Each lab tested 20 samples for each gap configuration. The analysis required a difference in test results of about one standard deviation in order to detect a statistically significant result. The material in round one was robust and had only one failure out of 240 samples, meaning it was a poor material to show a difference in test results. Still, one lab showed the gap setting causing a statistically significant difference in test results, one lab showed a smaller difference, and two labs showed no difference. The material in round two was more flammable, and there was a significant difference for one lab, a smaller difference for two labs, and no difference for one lab. The closed setting had the most material failures overall.

6 Conclusion

Preliminary studies with the radiant panel insulation test at the FAA Technical Center showed that the air openings around the sliding platform could significantly affect test results. Four labs were involved in an experiment designed to quantify the effects of changing the air gaps around the sliding platform from fully closed off to as open as possible without making major modifications to each lab's apparatus.

The fully closed configuration was the only setting unable to calibrate correctly with the three-position check. It also consistently had the lowest temperatures at the top surface of the sliding platform. Material testing showed mixed results, with some labs showing much bigger differences in test results than others. Historically, the gaps around the sliding platform were never supposed to be closed. Therefore, limits were placed on the minimum openings required around the sliding platform in the Aircraft Materials Fire Test Handbook, Revision 3.

7 References

ASTM Committee E05.22. (2014). E648 − 14c Standard Test Method for Critical Radiant Flux of Floor-Covering Systems Using a Radiant Heat Energy Source. West Conshohocken, PA: ASTM International.

Federal Aviation Administration. (2020). Chapter 23 Test Method to Determine the Flammability and Flame Propagation Characteristics of Thermal/Acoustic Insulation Materials. In *Aircraft Materials Fire Test Handbook* (pp. 23-1 to 23-10). Washington, D.C.: U.S. Department of Transportation.

Marker, T. R. (2019). DOT/FAA/TC-17/55 Aircraft Materials Fire Test Handbook, Revision 3. Atlantic City, NJ: Federal Aviation Administration.

Morgan, S. W. (2003). Boeing Design of Experiment (DoE) on Radiant Heat Test. *International Aircraft Materials Fire Test Forum.* Atlantic City, NJ: Boeing.

van den Bergh, D., van Doorn, J., Marsman, M., Draws, T., van Kesteren, E.-J., Derks, K., . . . Wagenmakers, E.-J. (2019). *A Tutorial on Conducting and Interpreting a Bayesian ANOVA in JASP.* Amsterdam, The Netherlands: University of Amsterdam.