Radiant Panel Update

Presented to: International Aircraft Materials Fire Test Working Group Meeting
By: Steven Rehn
Date: 6/7/2017
Introduction

• Round Robin results from 2016 varied widely
• Biggest difference between machines was the gaps around the drawer which allows outside air to flow in
• There is nothing in the rule about what size these gaps should be
Previous Testing

• Used metalized PEEK material with too much flame retardant so there was almost no flame propagation or after flame time on any test

• Results presented in March 2017 were inconclusive
Air Flow Study

• Experiment to determine the effect these air gaps have on this test method
• Goal is to change the handbook to make test results more repeatable across all labs
• Changes will likely involve standardizing the size of the air gaps around the drawer
• This experiment will determine how best to do that
Air Flow Study

• **Conduct tests with 3 different air gap levels**
  – Fully open (different for each lab)
  – Partially open (1/2” gap in back and both sides)
  – Fully closed

• **Place array of thermocouples in the retaining frame to test how material temperature changes**

• **Material tests with Metalized PEEK** – 20 samples per air gap setting for each lab

• **Four participating labs:**
  – FAA Technical Center – Steve Rehn
  – Boeing – Randy Smith
  – Damping Technologies Inc. (DTI) – Kris Notestine
  – Triumph Insulation Systems (TIS) – Brad Gustavesen
Air Flow Study

- Array of 15 thermocouples placed inside retaining frame
- Tested at each air-gap configuration
- Calibrated with calorimeter to 1.5 Btu/ft²s each time
- Temperature averaged over 5 minute period
- Array sent around to each lab so there were no differences in thermocouples
Air Flow Study
Air Flow Study
### Fully Open

Left: 2.125”

Rear: 2.25”

Right: 1.875”

<table>
<thead>
<tr>
<th></th>
<th>FAA (in)</th>
<th>DTI (in)</th>
<th>Boeing (in)</th>
<th>TIS (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Gap (in)</td>
<td>1.875</td>
<td>3</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Left Gap (in)</td>
<td>2.125</td>
<td>8.3</td>
<td>2.5</td>
<td>2.25</td>
</tr>
<tr>
<td>Rear Gap (in)</td>
<td>2.25</td>
<td>1.2</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>Front Gap (in)</td>
<td>0</td>
<td>0</td>
<td>1.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Partially Open

½” Gap on each side

Left  Rear  Right
Fully Closed

Left

Rear

Right
Fully Closed - DTI
Air Flow Study
Boeing

T/C Average: 351.7°F
Panel Set Point: 1185°F
3 Position Check:
Set Point: 1127°F
Position 0: 1.50 Btu/ft²s
Position 1: 1.36 Btu/ft²s
Position 2: 1.37 Btu/ft²s

T/C Average: 418.8°F
Panel Set Point: 1185°F
3 Position Check:
Set Point: 1150°F
Position 0: 1.50 Btu/ft²s
Position 1: 1.48 Btu/ft²s
Position 2: 1.42 Btu/ft²s

T/C Average: 455.7°F
Panel Set Point: 1185°F
3 Position Check:
Set Point: 1170°F
Position 0: 1.50 Btu/ft²s
Position 1: 1.50 Btu/ft²s
Position 2: 1.42 Btu/ft²s
T/C Average: 376.1°F
Panel Set Point: 1070°F
3 Position Check:
Position 0: 1.50 Btu/ft²s
Position 1: 1.43 Btu/ft²s
Position 2: 1.43 Btu/ft²s

T/C Average: 415.6°F
Panel Set Point: 1127°F
3 Position Check:
Position 0: 1.50 Btu/ft²s
Position 1: 1.50 Btu/ft²s
Position 2: 1.45 Btu/ft²s

T/C Average: 424.5°F
Panel Set Point: 1128°F
3 Position Check:
Position 0: 1.50 Btu/ft²s
Position 1: 1.50 Btu/ft²s
Position 2: 1.44 Btu/ft²s
FAA

Radiant Panel Insulation Test Update

<table>
<thead>
<tr>
<th>Condition</th>
<th>T/C Average</th>
<th>Panel Set Point</th>
<th>Panel Set Point</th>
<th>3 Position Check</th>
<th>3 Position Check</th>
<th>3 Position Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed</td>
<td>313.5°F</td>
<td>1065°F</td>
<td>1107°F</td>
<td>(old panel)</td>
<td>(old panel)</td>
<td>(old panel)</td>
</tr>
<tr>
<td>Partial</td>
<td>354.6°F</td>
<td>1070°F</td>
<td>1108°F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open</td>
<td>374.0°F</td>
<td>1089°F</td>
<td>1148°F</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Position 0: 1.497 Btu/ft²s
Position 1: 1.520 Btu/ft²s
Position 2: 1.430 Btu/ft²s

T/C Average: 313.5°F
Panel Set Point: 1065°F
3 Position Check: (old panel)
Set Point: 1107°F
Position 0: 1.497 Btu/ft²s
Position 1: 1.520 Btu/ft²s
Position 2: 1.430 Btu/ft²s

T/C Average: 354.6°F
Panel Set Point: 1070°F
3 Position Check: (old panel)
Set Point: 1108°F
Position 0: 1.499 Btu/ft²s
Position 1: 1.511 Btu/ft²s
Position 2: 1.440 Btu/ft²s

T/C Average: 374.0°F
Panel Set Point: 1089°F
3 Position Check: (old panel)
Set Point: 1148°F
Position 0: 1.506 Btu/ft²s
Position 1: 1.503 Btu/ft²s
Position 2: 1.440 Btu/ft²s
Triumph

Closed

T/C Average: 273.5°F
Panel Set Point: 999°F
3 Position Check:
Position 0: 1.50 Btu/ft²s
Position 1: 1.43 Btu/ft²s
Position 2: 1.35 Btu/ft²s

Partial

T/C Average: 336.3°F
Panel Set Point: 1032°F
3 Position Check:
Position 0: 1.50 Btu/ft²s
Position 1: 1.47 Btu/ft²s
Position 2: 1.43 Btu/ft²s

Open

T/C Average: 447.2°F
Panel Set Point: 1038°F
3 Position Check:
Position 0: 1.50 Btu/ft²s
Position 1: 1.46 Btu/ft²s
Position 2: 1.41 Btu/ft²s
FAA Panel Comparison

- ~2 year old panel ran at higher set point and produced higher temperatures at the surface of the test sample
- Both calibrated at 1.50 Btu/ft\(^2\)s
- It’s been observed that panels get hotter over time and eventually need to be replaced
Material Tests

• 20 Metalized PEEK samples per gap setting per lab (60 samples per lab)
• Tested fully closed, partially open, and fully open
• Boeing was not able to test partially open
Boeing Results

Boeing - Fully Closed

Boeing - Fully Open
DTI Results

DTI - Fully Closed

DTI - Partially Open

After Flame (s)
Flame Propagation (in)

DTI - Partially Open

After Flame (s)
Flame Propagation (in)
FAA Results

FAA - Fully Closed

FAA - Partially Open

FAA - Fully Open

Flame Propagation (in)
After Flame (s)
FP Fail
AF Fail
Triumph Results

Triumph - Fully Closed

Triumph - Partially Open

Triumph - Fully Open
Boeing Statistical Analysis

- Sent test results to Boeing as planned
- Analysis of Variance (ANOVA) and Median testing as appropriate at 5% significance level
- Determine if changing air gaps made significant difference in test results
- Compared flame propagation, after flame time, and pass/fail numbers
Radiant Panel Gap Analysis

- **Analysis Overview**
  - Experimental “power”
    - Why did we use 20 insulation blankets for each gap setting??
  - Evaluation of continuous variables (burn length, after-flame time)
    - For a given gap setting (closed, partial, original), determine if results from the different labs (Boeing, DTI, FAA, Triumph) can be considered from the same population. If so…
    - Combine the data for each gap setting and then compare the results from each gap setting to the other gap settings to determine if there are differences
      - Perform separate analyses for “Burn Length” and “After Flame Time”
  - Evaluation of pass/fail data (binominal data)
    - Consider results from the perspective of “pass/fail” with respect to the 14 CFR 25.856(a) requirements
  - Evaluation of variation
    - Is there any difference in the variation of results (burn length, after-flame time) as a function of gap setting?
Radiant Panel Gap Analysis

### Experimental “Power”

- Experimental Power = the likelihood an experiment can detect a significant effect or difference when such an effect or difference truly exists
  - Similar to “resolving power” in optical instruments (telescopes, microscopes): the ability of an instrument to resolve 2 points which are closely spaced
    - Optical resolving power .....\( R = \frac{1.22 \lambda}{2n \sin \theta} \) (\( R \) = minimum distance b/resolvable points, ....)
  - Best “lever” to increase “experimental power” is sample size
- Numerically...
  - Sample size of 20 insulation blankets per gap setting was selected to achieve
    - Power of 0.8 for a ....
    - detectable difference between gap settings of 1.0 standard deviations with a ...
    - significance level of 0.05

### Key Point

- FTWG radiant panel expt is largely insensitive to measurement differences which are <1 std dev
  - Burn Length std dev: ~0.5-0.6 inches
  - After Flame Time std dev: ~2-3 seconds
Radiant Panel Gap Analysis

**Overview**

- Gap setting data summarized by lab

**REFERENCE**

**Boxplot**

A graphical summary of the distribution of a sample that shows its shape, central tendency, and variability.

The default boxplot display consists of the following:

1. **Outlier (•)** – Observation that is beyond the upper or lower whisker
2. **Upper whisker** – Extends to the maximum data point within 1.5 box heights from the top of the box
3. **Interquartile range box** – Middle 50% of the data
   - Top line – Q3 (third quartile). 75% of the data are less than or equal to this value.
   - Middle line – Q2 (median). 50% of the data are less than or equal to this value.
   - Bottom line – Q1 (first quartile). 25% of the data are less than or equal to this value.
4. **Lower whisker** – Extends to the minimum data point within 1.5 box heights from the bottom of the box
Radiant Panel Gap Analysis

- Overview
  - Lab data summarized by gap setting

**Impact of Radiant Panel Gap Setting on Burn Length**

**Impact of Radiant Panel Gap Setting on After Flame Time**

**Boxplot**

A graphical summary of the distribution of a sample that shows its shape, central tendency, and variability.

The default boxplot display consists of the following:

1. **Outlier** (*) – Observation that is beyond the upper or lower whisker
2. **Upper whisker** – Extends to the maximum data point within 1.5 box heights from the top of the box
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Radiant Panel Gap Analysis

- **Burn Length/After Flame Time vs. Gap Setting**
  - ANOVA showed for a given gap setting, data from all labs can be considered from a single population
    - After Flame Time better “behaved” than Burn Length
      - Analysis in “Backup” section of presentation
    - Result: Combine data from all labs for subsequent analysis
      - Analysis on following slides
Radiant Panel Gap Analysis

- **Burn Length vs. Gap Setting (All Labs Combined)**

  Source | DF | Adj SS | Adj MS | F-Value | P-Value
  --- | --- | --- | --- | --- | ---
  Gap Setting | 2 | 2.129 | 1.0645 | 2.74 | 0.067
  Error | 217 | 84.233 | 0.3882 |  |  
  Total | 219 | 86.362 |  |  |

  Grouping Information Using the Tukey Method and 95% Confidence

  Gap Setting | N | Mean | Grouping
  --- | --- | --- | ---
  Closed | 80 | 1.6450 | A
  Original | 80 | 1.5413 | A
  Partial | 60 | 1.3958 | A

  Means that do not share a letter are significantly different.

- **Not Normal**

- **Confirmed by median test**

- **Mood median test for Burn Length (in)**

  Chi-Square = 1.89 | DF = 2 | P = 0.390

  Individual 95.0% CIs

  Gap Setting | N≤ | N> | Median | Q3-Q1 |-----------|--------
  --- | --- | --- | --- | --- | --- | ---
  Closed | 41 | 39 | 1.50 | 0.88 | (---*----)
  Partial | 36 | 24 | 1.40 | 0.80 | (----------)
  Original | 49 | 31 | 1.75 | 0.60 | (----------)

  Overall median = 1.50

**Conclusion:** No statistical difference in Burn Length as a function of gap setting (closed, partial, original).
Radiant Panel Gap Analysis

- **After Flame Time vs. Gap Setting (All Labs Combined)**

  Source        DF   Adj SS  Adj MS  F-Value  P-Value  
  Gap Setting    2    55.84  27.920   3.16    0.045  
  Error         217   1918.97    8.843  
  Total         219   1974.81  

Grouping Information Using the Tukey Method and 95% Confidence

<table>
<thead>
<tr>
<th>Gap Setting</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed</td>
<td>80</td>
<td>3.124</td>
<td>A</td>
</tr>
<tr>
<td>Original</td>
<td>80</td>
<td>2.229</td>
<td>A</td>
</tr>
<tr>
<td>Partial</td>
<td>60</td>
<td>1.938</td>
<td>A</td>
</tr>
</tbody>
</table>

Means that do not share a letter are significantly different.

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### Residual Plots for After Flame Time vs Gaps (All Labs Combined)

- Normal Probability Plot
- Versus Fits
- Histogram
- Versus Order

Not Normal

---

### Mood median test for After Flame (sec)

Chi-Square = 5.27  DF = 2  P = 0.072

- Individual 95.0% CIs
- Overall median = 1.67

---

**Conclusion:** No statistical difference in After Flame Time as a function of gap setting (closed, partial, original).
Pass/Fail Analysis

14 CFR 25.856(a)

14 CFR Part 25 Appendix F
Part VI (h) “Requirements” (1) & (2)
Radiant Panel Gap Analysis

### Analysis of “Failures” by Gap Setting (All Labs Combined)

- “Failure”
  - Assume certification testing. Failure = exceeding allowable burn length (2 inches), after flame time (3 seconds), or both

<table>
<thead>
<tr>
<th>Gap Setting</th>
<th>Lab</th>
<th>Closed</th>
<th>Partial</th>
<th>Original</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boeing</td>
<td>8</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DTI</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>FAA</td>
<td>12</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Triumph</td>
<td>9</td>
<td>6</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gap Setting</td>
<td>2</td>
<td>23.49</td>
<td>11.746</td>
<td>2.16</td>
<td>0.177</td>
</tr>
<tr>
<td>Error</td>
<td>8</td>
<td>43.42</td>
<td>5.427</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>10</td>
<td>66.91</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Grouping Information Using the Tukey Method & 95% Confidence

Gap Setting | N | Mean | Grouping |
-----------|---|------|----------|
Closed     | 4 | 9.00 | A        |
Original   | 4 | 6.25 | A        |
Partial    | 3 | 5.67 | A        |

Means that do not share a letter are significantly different.

**Conclusion:** No statistical difference in “Failures” as a function of gap setting (closed, partial, original).
Analysis of Variation by Gap Setting
Radiant Panel Gap Analysis

- **Analysis of Variation by Gap Setting (All Labs Combined)**
  - Use “interquartile range” (IQR) as measure of variation
    - IQR = Q3 – Q1 --> Difference between 3rd Quartile (75% of data) and 1st Quartile (25% of data)
    - Shows the “spread” of the middle 50% of the data for a given series of measurements
    - More “robust” measurement of variation than standard deviation, i.e. IQR is less susceptible to outliers

---

**Boxplot**

A graphical summary of the distribution of a sample that shows its shape, central tendency, and variability. The default boxplot display consists of the following:

1. **Outlier (•)** – Observation that is beyond the upper or lower whisker
2. **Upper whisker** – Extends to the maximum data point within 1.5 box heights from the top of the box
3. **Interquartile range box** – Middle 50% of the data
   - Top line – Q3 (third quartile). 75% of the data are less than or equal to this value.
   - Middle line – Q2 (median). 50% of the data are less than or equal to this value.
   - Bottom line – Q1 (first quartile). 25% of the data are less than or equal to this value.
4. **Lower whisker** – Extends to the minimum data point within 1.5 box heights from the bottom of the box
Radiant Panel Gap Analysis

- **Burn Length IQR (All Labs Combined)**

<table>
<thead>
<tr>
<th>Lab</th>
<th>Closed</th>
<th>Partial</th>
<th>Original</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boeing</td>
<td>0.825</td>
<td>1.075</td>
<td></td>
</tr>
<tr>
<td>DTI</td>
<td>0.350</td>
<td>1.075</td>
<td>1.050</td>
</tr>
<tr>
<td>FAA</td>
<td>1.375</td>
<td>0.875</td>
<td>0.700</td>
</tr>
<tr>
<td>Triumph</td>
<td>0.850</td>
<td>0.375</td>
<td>0.450</td>
</tr>
</tbody>
</table>

  **Boxplot of Burn Length IQR (in)**

  **Source** | DF | Adj SS | Adj MS | F-Value | P-Value |
  -----------|----|--------|--------|---------|---------|
  Gap Setting | 2  | 0.00964| 0.004822| 0.04    | 0.964   |
  Error      | 8  | 1.05547| 0.131934|         |         |
  Total      | 10 | 1.06511|         |         |         |

  **Grouping Information Using the Tukey Method and 95% Confidence**

<table>
<thead>
<tr>
<th>Gap Setting</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed</td>
<td>4</td>
<td>0.850</td>
<td>A</td>
</tr>
<tr>
<td>Original</td>
<td>4</td>
<td>0.819</td>
<td>A</td>
</tr>
<tr>
<td>Partial</td>
<td>3</td>
<td>0.775</td>
<td>A</td>
</tr>
</tbody>
</table>

  Means that do not share a letter are significantly different.

  **Conclusion:** No statistical difference in Burn Length IQR as a function of gap setting (closed, partial, original).
Radiant Panel Gap Analysis

- **After Flame Time IQR (All Labs Combined)**

<table>
<thead>
<tr>
<th>Lab</th>
<th>Closed</th>
<th>Partial</th>
<th>Original</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boeing</td>
<td>3.000</td>
<td>6.000</td>
<td></td>
</tr>
<tr>
<td>DTI</td>
<td>4.742</td>
<td>3.770</td>
<td>4.213</td>
</tr>
<tr>
<td>FAA</td>
<td>5.350</td>
<td>2.025</td>
<td>1.150</td>
</tr>
<tr>
<td>Triumph</td>
<td>5.200</td>
<td>3.200</td>
<td>2.375</td>
</tr>
</tbody>
</table>

Source        DF  Adj SS  Adj MS  F-Value  P-Value
---            --  -----  ------  --------  -------
Gap Setting    2   4.798  2.399   1.03    0.400
Error         8   18.613 2.327
Total         10  23.410

Grouping Information Using the Tukey Method and 95% Confidence

<table>
<thead>
<tr>
<th>Gap Setting</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed</td>
<td>4</td>
<td>4.573</td>
<td>A</td>
</tr>
<tr>
<td>Original</td>
<td>4</td>
<td>3.43</td>
<td>A</td>
</tr>
<tr>
<td>Partial</td>
<td>3</td>
<td>2.998</td>
<td>A</td>
</tr>
</tbody>
</table>

Means that do not share a letter are significantly different.

**Conclusion:** No statistical difference in After Flame Time IQR as a function of gap setting (closed, partial, original).
Burn Length Data by Gap Setting
Radiant Panel Gap Analysis

- **Closed Gaps—Burn Length**

Source | DF | Adj SS | Adj MS | F-Value | P-Value
---|---|---|---|---|---
Lab | 3 | 3.597 | 1.1990 | 3.25 | 0.026
Error | 76 | 28.001 | 0.3684 | |
Total | 79 | 31.598 | |

Grouping Information Using the Tukey Method and 95% Confidence

<table>
<thead>
<tr>
<th>Lab</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triumph</td>
<td>20</td>
<td>1.980</td>
<td>A</td>
</tr>
<tr>
<td>FAA</td>
<td>20</td>
<td>1.630</td>
<td>A B</td>
</tr>
<tr>
<td>Boeing</td>
<td>20</td>
<td>1.575</td>
<td>A B</td>
</tr>
<tr>
<td>DTI</td>
<td>20</td>
<td>1.3950</td>
<td>B</td>
</tr>
</tbody>
</table>

Means that do not share a letter are significantly different.

Boxplot of Burn Length (in)

Mood median test for Burn Length (in)
Chi-Square = 12.56  DF = 3  P = 0.006

<table>
<thead>
<tr>
<th>Lab</th>
<th>N&lt;=</th>
<th>N&gt;</th>
<th>Median</th>
<th>Q3-Q1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boeing</td>
<td>13</td>
<td>7</td>
<td>1.35</td>
<td>0.82</td>
</tr>
<tr>
<td>DTI</td>
<td>15</td>
<td>5</td>
<td>1.40</td>
<td>0.35</td>
</tr>
<tr>
<td>FAA</td>
<td>8</td>
<td>12</td>
<td>1.90</td>
<td>1.38</td>
</tr>
<tr>
<td>Triumph</td>
<td>5</td>
<td>15</td>
<td>1.80</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Individual 95.0% CIs

Overall median = 1.50
Radiant Panel Gap Analysis

- **Partial Gaps—Burn Length**

  Source | DF | Adj SS | Adj MS | F-Value | P-Value | P-Value
  --- | --- | --- | --- | --- | --- | ---
  Lab | 2 | 0.4841 | 0.2420 | 1.10 | 0.341 | 0.341
  Error | 57 | 12.5924 | 0.2209 |  |  |  
  Total | 59 | 13.0765 |  |  |  |  

  Grouping Information Using the Tukey Method and 95% Confidence

  | Lab | N | Mean | Grouping |
  --- | --- | --- | --- |
  Triumph | 20 | 1.5050 | A |
  DTI | 20 | 1.398 | A |
  FAA | 20 | 1.285 | A |

  Means that do not share a letter are significantly different.

  Not Normal

  Test for Equal Variances: Burn Length (in) vs Lab
  Multiple comparison intervals for the standard deviation, $\alpha = 0.05$

  If intervals do not overlap, the corresponding stdevs are significantly different.
Radiant Panel Gap Analysis

- **Original Gaps—Burn Length**

  Source | DF | Adj SS | Adj MS | F-Value | P-Value |
  --- | --- | --- | --- | --- | --- |
  Lab | 3 | 6.330 | 2.1101 | 4.83 | 0.004 |
  Error | 76 | 33.228 | 0.4372 | 0.4372 |
  Total | 79 | 39.559 | 0.4372 |

Grouping Information Using the Tukey Method and 95% Confidence

Lab       N   Mean  Grouping
Boeing   20  2.015  A
Triumph  20  1.490  A B
DTI      20  1.340    B
FAA      20  1.320    B

Means that do not share a letter are significantly different.

**Not Normal**

**Confirmed by median test**

---

Test for Equal Variances: Original Gaps Burn Length (in) vs Lab
Multiple comparison intervals for the standard deviation, $\alpha = 0.05$

If intervals do not overlap, the corresponding stdevs are significantly different.
After Flame Time Data by Gap Setting
Radiant Panel Gap Analysis

- **Closed Gaps—After Flame Time**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab</td>
<td>3</td>
<td>19.11</td>
<td>6.371</td>
<td>0.58</td>
<td>0.631</td>
</tr>
<tr>
<td>Error</td>
<td>76</td>
<td>836.57</td>
<td>11.008</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>79</td>
<td>855.69</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

  Grouping Information Using the Tukey Method and 95% Confidence

<table>
<thead>
<tr>
<th>Lab</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAA</td>
<td>20</td>
<td>3.505</td>
<td>A</td>
</tr>
<tr>
<td>Triumph</td>
<td>20</td>
<td>3.405</td>
<td>A</td>
</tr>
<tr>
<td>Boeing</td>
<td>20</td>
<td>3.300</td>
<td>A</td>
</tr>
<tr>
<td>DTI</td>
<td>20</td>
<td>2.287</td>
<td>A</td>
</tr>
</tbody>
</table>

  Means that do not share a letter are significantly different.

Not Normal

Mood median test for After Flame (sec)
Chi-Square = 3.60   DF = 3   P = 0.308

Individual 95.0% CIs

<table>
<thead>
<tr>
<th>Lab</th>
<th>N ≤</th>
<th>N &gt;</th>
<th>Median</th>
<th>Q3–Q1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boeing</td>
<td>8</td>
<td>12</td>
<td>3.00</td>
<td>3.00</td>
</tr>
<tr>
<td>DTI</td>
<td>13</td>
<td>7</td>
<td>2.38</td>
<td>4.74</td>
</tr>
<tr>
<td>FAA</td>
<td>8</td>
<td>12</td>
<td>4.10</td>
<td>5.35</td>
</tr>
<tr>
<td>Triumph</td>
<td>11</td>
<td>9</td>
<td>1.70</td>
<td>5.20</td>
</tr>
</tbody>
</table>

Overall median = 2.94
Radiant Panel Gap Analysis

- **Partial Gaps—After Flame Time**

  Grouping Information Using the Tukey Method and 95% Confidence

<table>
<thead>
<tr>
<th>Lab</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triumph</td>
<td>20</td>
<td>2.225</td>
<td>A</td>
</tr>
<tr>
<td>DTI</td>
<td>20</td>
<td>1.980</td>
<td>A</td>
</tr>
<tr>
<td>FAA</td>
<td>20</td>
<td>1.610</td>
<td>A</td>
</tr>
</tbody>
</table>

  Means that do not share a letter are significantly different.

  ![Residual Plots for Partial Gaps After Flame (sec)](image)

  ![Histograms](image)

  Mood median test for After Flame (sec)
  
  Chi-Square = 2.80  DF = 2  P = 0.247

  Individual 95.0% CIs

<table>
<thead>
<tr>
<th>Lab</th>
<th>N&lt; N&gt;</th>
<th>Median</th>
<th>Q3-Q1</th>
</tr>
</thead>
<tbody>
<tr>
<td>DTI</td>
<td>9</td>
<td>1.95</td>
<td>3.77</td>
</tr>
<tr>
<td>FAA</td>
<td>13</td>
<td>0.00</td>
<td>2.03</td>
</tr>
<tr>
<td>Triumph</td>
<td>8</td>
<td>2.35</td>
<td>3.20</td>
</tr>
</tbody>
</table>

  Overall median = 1.30

  [Not Normal Confirmed by median test]
Radiant Panel Gap Analysis

- **Original Gaps—After Flame Time**

  **Source** | **DF** | **Adj SS** | **Adj MS** | **F-Value** | **P-Value**
  --- | --- | --- | --- | --- | ---
  Lab | 3 | 76.29 | 25.431 | 2.81 | 0.045
  Error | 76 | 688.85 | 9.064 |  | 
  Total | 79 | 765.15 |  |

Grouping Information Using the Tukey Method and 95% Confidence

<table>
<thead>
<tr>
<th>Lab</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
<th>Confirmed by median test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boeing</td>
<td>20</td>
<td>3.850</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>DTI</td>
<td>20</td>
<td>2.138</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>FAA</td>
<td>20</td>
<td>1.540</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>Triumph</td>
<td>20</td>
<td>1.390</td>
<td>A</td>
<td></td>
</tr>
</tbody>
</table>

Means that do not share a letter are significantly different.

---

**Not Normal**

**Test for Equal Variances: After Flame (sec) vs Lab**

Multiple comparison intervals for the standard deviation, $\alpha = 0.05$

<table>
<thead>
<tr>
<th>Lab</th>
<th>Multiple Comparisons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boeing</td>
<td>P-Value 0.663</td>
</tr>
<tr>
<td>DTI</td>
<td>P-Value 0.291</td>
</tr>
<tr>
<td>FAA</td>
<td></td>
</tr>
<tr>
<td>Triumph</td>
<td></td>
</tr>
</tbody>
</table>

If intervals do not overlap, the corresponding stdevs are significantly different.
Individial Lab Analysis
Radiant Panel Gap Analysis

- **FAA: After Flame Time**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>P-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gap Setting</td>
<td>2</td>
<td>49.71</td>
<td>24.857</td>
<td>2.97</td>
<td>0.059</td>
</tr>
<tr>
<td>Error</td>
<td>57</td>
<td>477.44</td>
<td>8.376</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>59</td>
<td>527.15</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Gap Setting  N  Mean  StDev  95% CI
Closed 20 3.505 2.950 (2.209, 4.801)
Partial 20 1.610 2.617 (0.314, 2.906)
Original 20 1.540 3.095 (0.244, 2.836)

Pooled StDev = 2.89414

Grouping Information Using the Tukey Method and 95% Confidence

<table>
<thead>
<tr>
<th>Gap Setting</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>95% CI</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed</td>
<td>20</td>
<td>3.505</td>
<td>2.950</td>
<td>(2.209, 4.801)</td>
<td>A</td>
</tr>
<tr>
<td>Partial</td>
<td>20</td>
<td>1.610</td>
<td>2.617</td>
<td>(0.314, 2.906)</td>
<td>A</td>
</tr>
<tr>
<td>Original</td>
<td>20</td>
<td>1.540</td>
<td>3.095</td>
<td>(0.244, 2.836)</td>
<td>A</td>
</tr>
</tbody>
</table>

Means that do not share a letter are significantly different.

Mood median test for After Flame (sec)
Chi-Square = 6.96  DF = 2  P = 0.031

Individual 95.0% CIs

<table>
<thead>
<tr>
<th>Gap Setting</th>
<th>N≤</th>
<th>N&gt;</th>
<th>Median</th>
<th>Q3-Q1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed</td>
<td>6</td>
<td>14</td>
<td>4.10</td>
<td>5.35</td>
</tr>
<tr>
<td>Partial</td>
<td>12</td>
<td>8</td>
<td>0.00</td>
<td>2.03</td>
</tr>
<tr>
<td>Original</td>
<td>14</td>
<td>6</td>
<td>0.00</td>
<td>1.15</td>
</tr>
</tbody>
</table>

Overall median = 0.50

Not confirmed by median test
Borderline difference with Closed performing worse than Partial and Original (which are “equivalent”).
Radiant Panel Gap Analysis

**Triumph: Flame Propagation Length**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>P-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gap Setting</td>
<td>2</td>
<td>3.106</td>
<td>1.5532</td>
<td>5.27</td>
<td>0.008</td>
</tr>
<tr>
<td>Error</td>
<td>57</td>
<td>16.800</td>
<td>0.2947</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>59</td>
<td>19.906</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Gap Setting | N | Mean | StDev | 95% CI                  |
------------|---|------|-------|-------------------------|
Closed      | 20| 1.980| 0.708 | (1.737, 2.223)          |
Partial     | 20| 1.505| 0.370 | (1.2619, 1.7481)        |
Original    | 20| 1.490| 0.495 | (1.247, 1.733)          |

Pooled StDev = 0.542889

Grouping Information Using the Tukey Method and 95% Confidence

<table>
<thead>
<tr>
<th>Gap Setting</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed</td>
<td>20</td>
<td>1.980</td>
<td>A</td>
</tr>
<tr>
<td>Partial</td>
<td>20</td>
<td>1.505</td>
<td>B</td>
</tr>
<tr>
<td>Original</td>
<td>20</td>
<td>1.490</td>
<td>B</td>
</tr>
</tbody>
</table>

Means that do not share a letter are significantly different.

Mood median test for Flame Propagation Length (in)
Chi-Square = 8.40   DF = 2   P = 0.015

<table>
<thead>
<tr>
<th>Gap Setting</th>
<th>N&lt;</th>
<th>N&gt;</th>
<th>Median</th>
<th>Q3–Q1</th>
<th>Individual 95.0% CIs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed</td>
<td>5</td>
<td>15</td>
<td>1.80</td>
<td>0.85</td>
<td>(---*-----------------)</td>
</tr>
<tr>
<td>Partial</td>
<td>11</td>
<td>9</td>
<td>1.50</td>
<td>0.37</td>
<td>(-----*--              )</td>
</tr>
<tr>
<td>Original</td>
<td>14</td>
<td>6</td>
<td>1.40</td>
<td>0.45</td>
<td>(-----*----            )</td>
</tr>
</tbody>
</table>

Overall median = 1.55

Confirmed by median test

\[ d = \frac{(1.98 - 1.4975)}{0.542889} = 0.89 \]
Conclusion

• Thermocouple array showed lowest temperatures when fully closed
• Temperature increased with more airflow allowed into chamber
• Fully closed performed poorly in 3 position calibration check
• Fully closed had the most combined failures
• No statistical difference between labs and air gap settings
  – Analysis was only good up to 1 standard deviation difference
  – Large variance in test data
• Comparing individual labs showed a few statistical differences between closed and fully open
Questions?

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