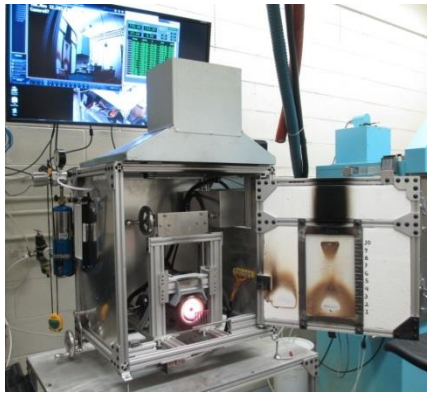
Development of a Flame Propagation Test Apparatus for Inaccessible Area Materials

Federal Aviation Administration





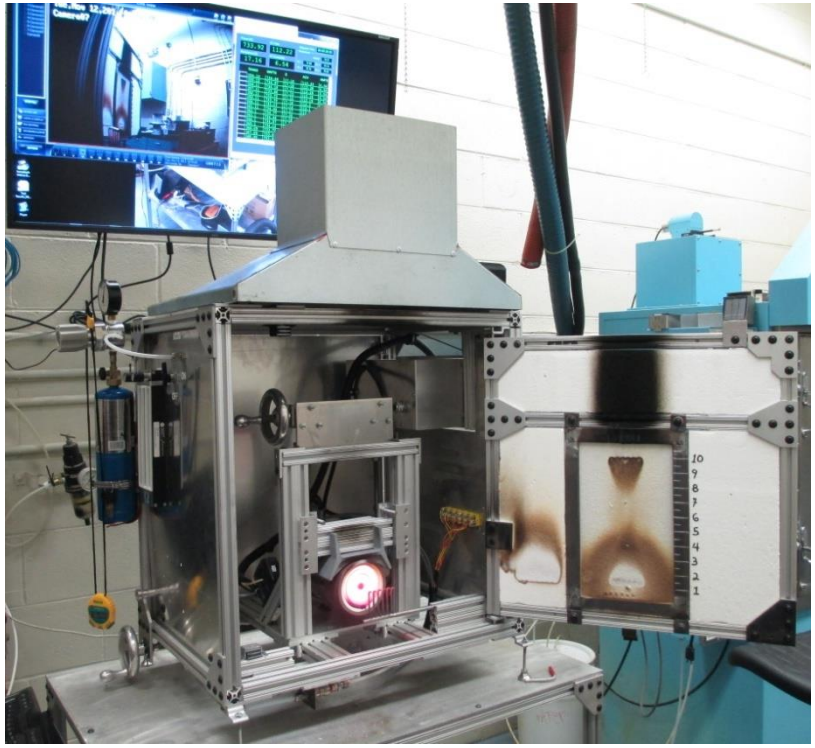
Presented to: IAMFTWG
By: Robert I. Ochs
Date: June 25-26, 2014, Solothurn, Switzerland

Introduction

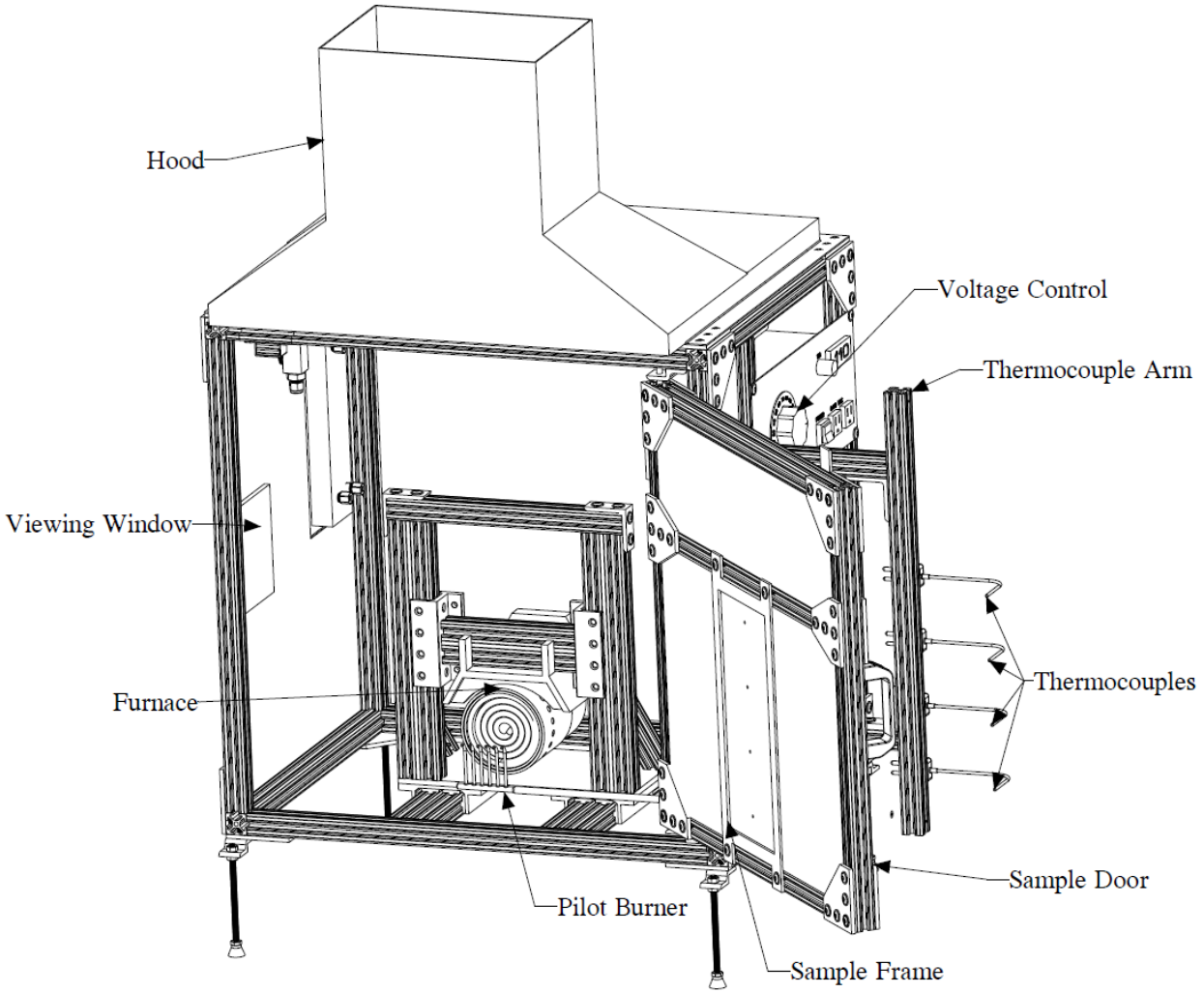
- Carbon fiber composites are being used more frequently in aerospace applications
  - Increased strength
  - Lower density
  - Better corrosion resistance
- New designs of commercial transport airplanes include primary and secondary structure constructed from carbon fiber composites
- Current FAR's do not require flammability testing for fuselage skins or structures, as traditional designs are inherently non-flammable
  - Special Conditions for certification of fire resistance of composite fuselage
  - Must demonstrate level of safety equivalent to or better than traditional constructions
- To continue with the FAA's efforts to enhance in-flight fire safety, materials in inaccessible areas of the cabin should meet a flammability test based on the "block of foam" fire source

Objective

- Design, construct, and evaluate a new flame propagation test method
  - Determine effectiveness of evaluating flame propagation
  - Determine level of repeatability and reproducibility
- Deliver new test method to FAA Transport Directorate for use in certification of novel design airplanes
  - Inclusion in next-generation fire test requirements
  - Possibly replace current Special Conditions requirements
- Attempt to test other inaccessible area materials on same apparatus
  - Wire insulation
  - Ducts, hoses

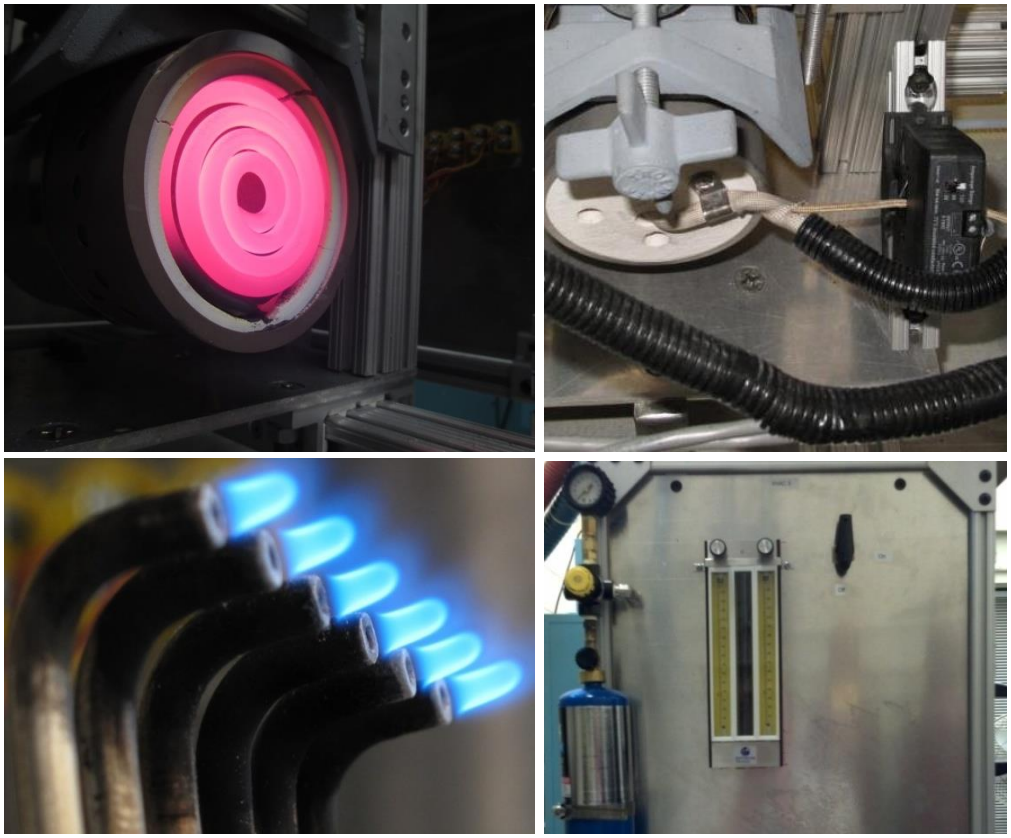


Vertical Flame Propagation Test Apparatus



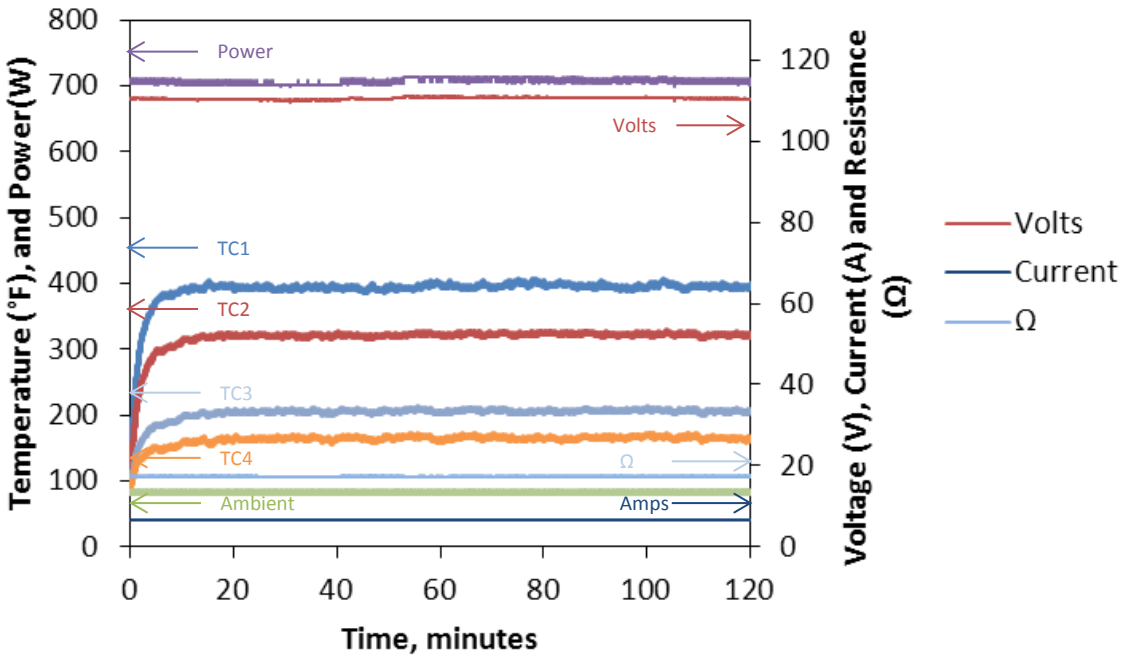
Vertical Flame Propagation Test Apparatus

- Vertically-mounted coil furnace
  - 120V, 875W
  - Monitoring AC voltage and current, calculating input power, coil resistance
  - Adjust power with variable AC transformer
- Multi-flamelet pilot flame
  - Pre-mixed propane/air flame
  - Controlled with mixing type flowmeters



Steady State Conditions

- Thermocouples indicate equilibrium within chamber
- Can be used to determine steady-state condition to compare test conditions from other tests
- Voltage is very steady during extended periods of time
  - Average 110.5 V
  - Std Dev 0.07
  - % SD 0.06
- Fluctuation of TC readings at steady state indicate relative level of turbulence



$$\textit{Ohm's Law}$$

$$R = \frac{V}{I}$$

$$P = IV$$

$$\textit{110 Volts} * \textit{6.42 Amps} = \textit{707 Watts}$$

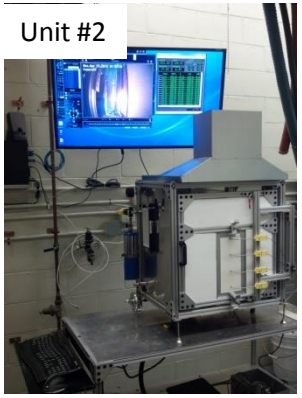
$$\textit{110 Volts} / \textit{6.42 Amps} = \textit{17.13 } \Omega$$

Apparatus Reproducibility

- A series of tests will be performed to determine the reproducibility of the test apparatus
- An array of materials will be tested on each machine:
  - Glass/epoxy: 10 tests
  - ACF1 8ply: 6 tests
  - FRV: 3 tests
  - 3KPW/TCR (woven CF)
    - 4, 8, 12, 16 ply: 3 tests each
  - T700/TC250 (uni tape CF, 250°F cure epoxy)
    - 4, 8, 12, 16 ply: 3 tests each
  - T700/TC350 (uni tape CF, 350°F cure epoxy)
    - 4, 8, 12, 16 ply: 3 tests each
  - 55 tests total
- Each machine will be tested in two laboratories
  - FAATC: B203
  - FAATC: B277
- Machines will also be shipped to outside labs to confirm reproducibility

Unit #1

Unit #2



Unit #3

203

277

Federal Aviation Administration

Test Matrix

Apparatus	B203	B277	Away
1	Glass/Epoxy: 10 ACF1-8 ply: 6 FRV: 3 3KPW/TCR: 3x(4, 8, 12, 16 ply, 12 tests) T700/TC250: 3x(4, 8, 12, 16 ply, 12tests) T700/TC350: 3x(4, 8, 12, 16 ply, 12tests)	Glass/Epoxy: 10 ACF1-8 ply: 3 FRV: 3 3KPW/TCR: 3x(4, 8, 12, 16 ply, 12 tests) T700/TC250: 3x(4, 8, 12, 16 ply, 12tests) T700/TC350: 3x(4, 8, 12, 16 ply, 12tests)	Glass/Epoxy: 10 ACF1-8 ply: 3 FRV: 3 3KPW/TCR: 3x(4, 8, 12, 16 ply, 12 tests) T700/TC250: 3x(4, 8, 12, 16 ply, 12tests) T700/TC350: 3x(4, 8, 12, 16 ply, 12tests)
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Description of Analysis

Measured Burn Length

Repeatability for Each Lab/Unit

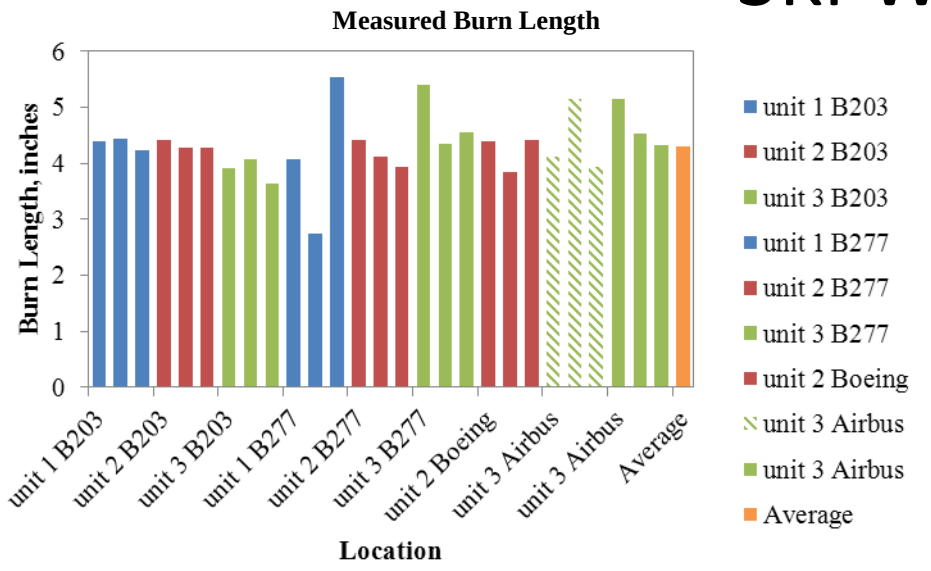
Date	Unit	Location	Test	Material	Plies / Thickness	Identifier	After Flame	Burn Length	Burn Width	Average BL @ LOC	STDEV @ LOC	%SD @ LOC
6/11/2013	1	203	T2	3KPW	4 PLY	unit 1 B203	39	4.397	2.555			
6/11/2013	1	203	T3	3KPW	4 PLY	unit 1 B203	45	4.447	2.641			
6/11/2013	1	203	T4	3KPW	4 PLY	unit 1 B203	40	4.232	2.453	4.36	0.11	3%
6/18/2013	2	203	T2	3KPW	4 PLY	unit 2 B203	47	4.421	2.512			
6/18/2013	2	203	T3	3KPW	4 PLY	unit 2 B203	43	4.281	2.541			
6/18/2013	2	203	T4	3KPW	4 PLY	unit 2 B203	40	4.271	2.698	4.32	0.08	2%
6/24/2013	3	203	T19	3KPW	4 PLY	unit 3 B203	40	3.919	2.442			
6/24/2013	3	203	T20	3KPW	4 PLY	unit 3 B203	43	4.078	2.428			
6/24/2013	3	203	T21	3KPW	4 PLY	unit 3 B203	32	3.638	2.47	3.88	0.22	6%
9/30/2013	1	277	11	3KPW	4 PLY	unit 1 B277	40	4.077	2.54			
9/30/2013	1	277	12	3KPW	4 PLY	unit 1 B277	4	2.746	2.575			
9/30/2013	1	277	13	3KPW	4 PLY	unit 1 B277	66	5.535	3	4.12	1.39	34%
9/16/2013	2	277	36	3KPW	4 PLY	unit 2 B277	38	4.409	2.577			
9/16/2013	2	277	37	3KPW	4 PLY	unit 2 B277	32	4.109	2.545			
9/16/2013	2	277	38	3KPW	4 PLY	unit 2 B277	30	3.926	2.558	4.15	0.24	6%
9/24/2013	3	277	9	3KPW	4 PLY	unit 3 B277	69	5.4	2.578			
9/24/2013	3	277	10	3KPW	4 PLY	unit 3 B277	41	4.354	2.632			
9/24/2013	3	277	11	3KPW	4 PLY	unit 3 B277	42	4.548	2.728	4.77	0.56	12%
3/18/2014	2	Boeing		3KPW	4 PLY	unit 2 Boeing	50	4.39	2.55			
3/18/2014	2	Boeing		3KPW	4 PLY	unit 2 Boeing	39	3.85	2.41			
3/18/2014	2	Boeing		3KPW	4 PLY	unit 2 Boeing	53	4.41	2.38	4.22	0.32	8%
4/1/2014	3	Airbus		3KPW	4 PLY	unit 3 Airbus	43	4.11	2.33			
4/1/2014	3	Airbus		3KPW	4 PLY	unit 3 Airbus	56	5.15	2.375			
4/1/2014	3	Airbus		3KPW	4 PLY	unit 3 Airbus	40	3.93	2.47	4.40	0.66	15%
4/3/2014	3	Airbus		3KPW	4 PLY	unit 3 Airbus	65	5.14	2.33			
4/3/2014	3	Airbus		3KPW	4 PLY	unit 3 Airbus	53	4.54	3.04			
4/3/2014	3	Airbus		3KPW	4 PLY	unit 3 Airbus	38	4.33	3.01	4.67	0.42	9%
					Average		42.88	4.31	2.59			
					Standard Deviation		13.21	0.56	0.19			
					% SD		31%	13%	7%			10%

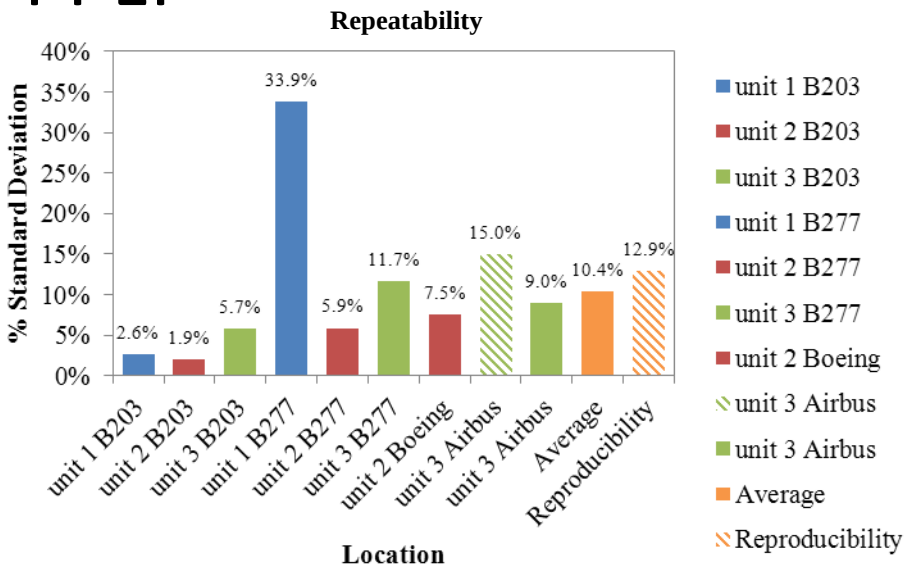
Average Burn Length

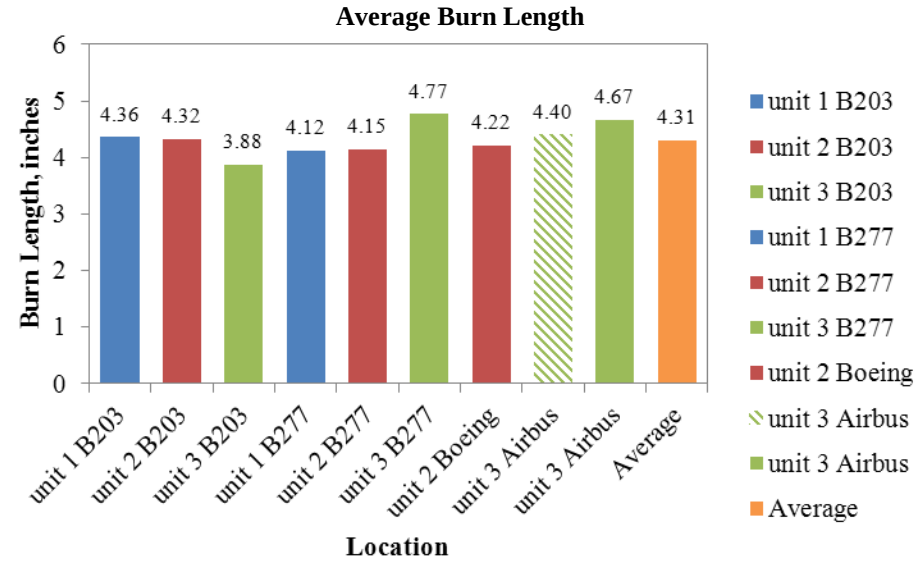
Reproducibility

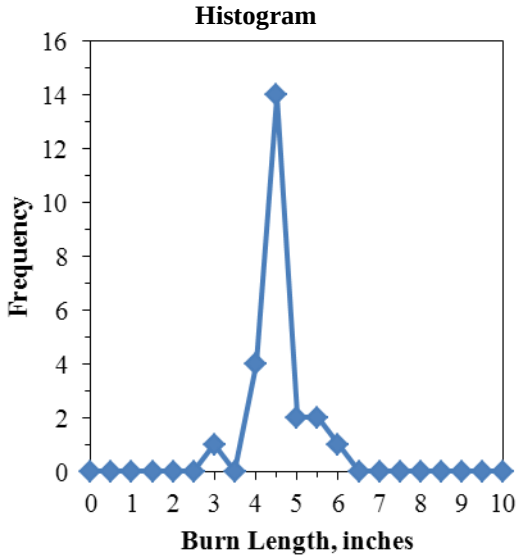
Average Repeatability

Comparative Test Series Results
3KPW-4 PLY

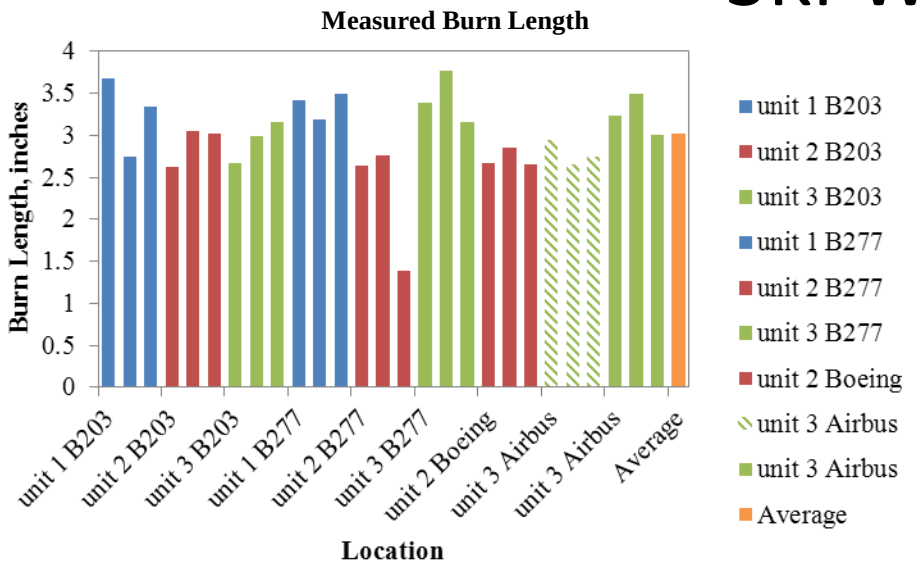


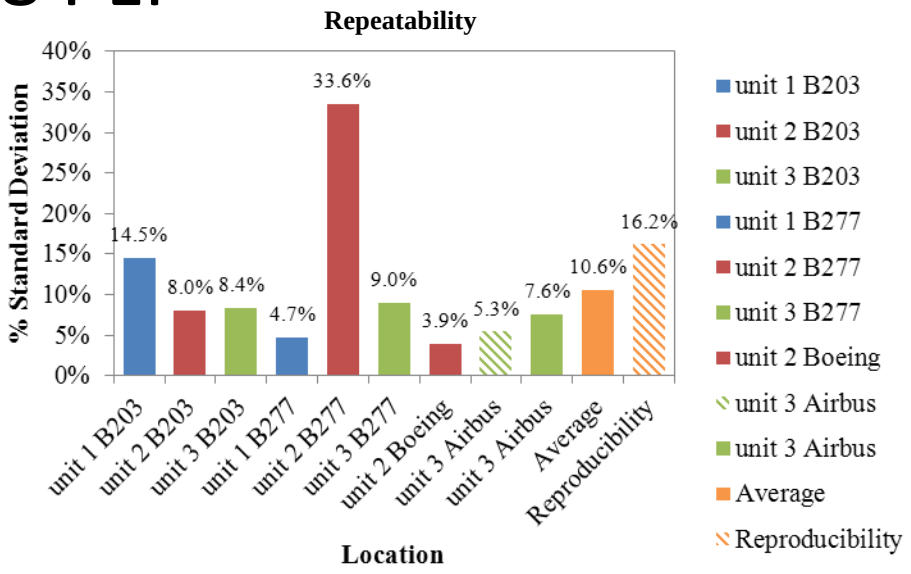


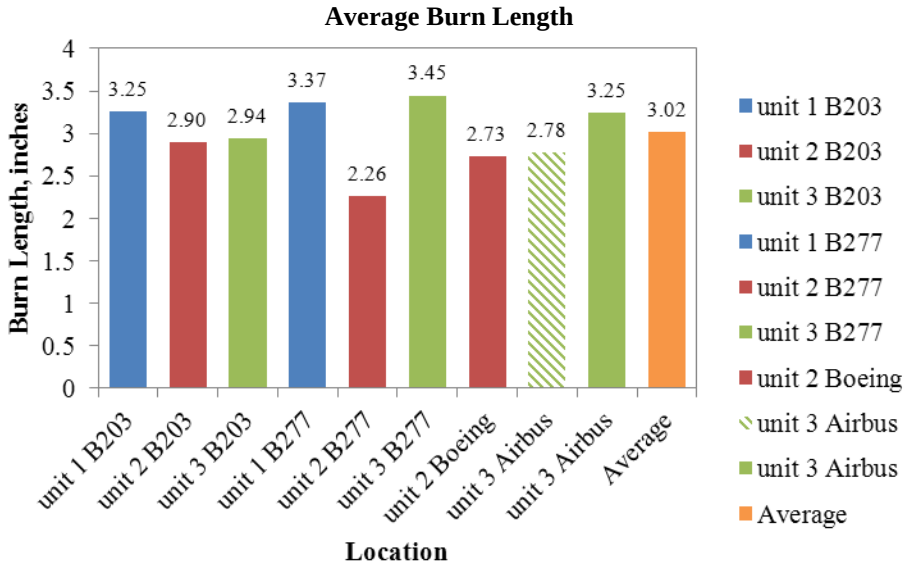


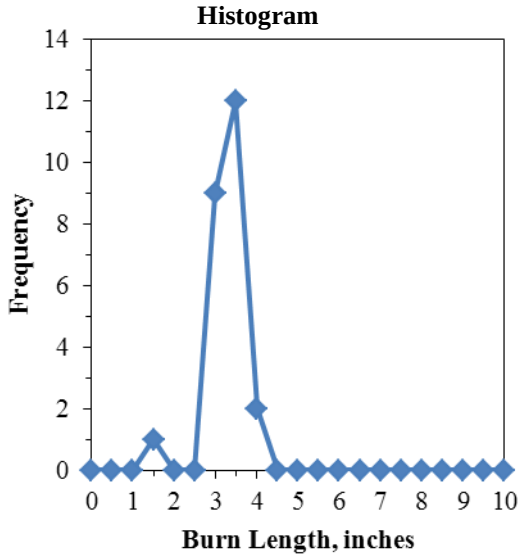


Comparative Test Series Results
3KPW-8 PLY

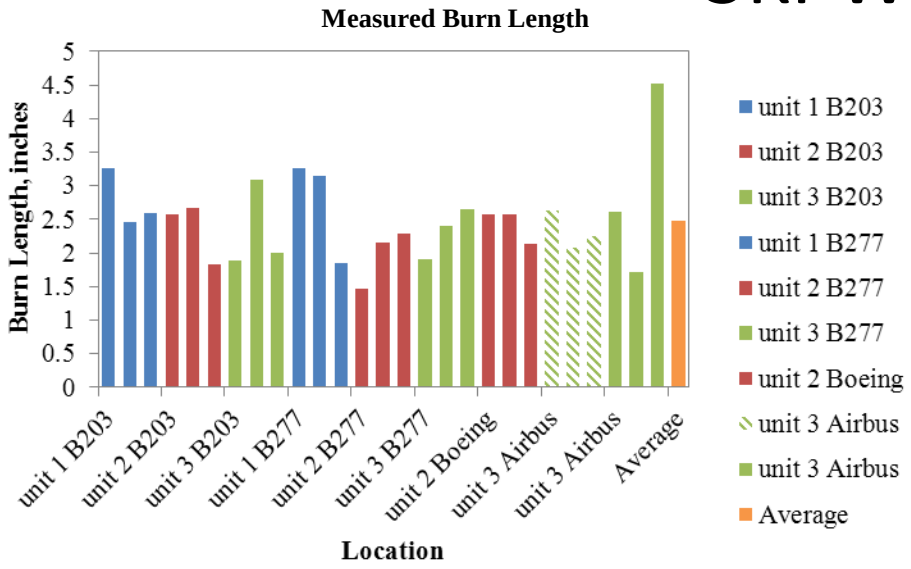


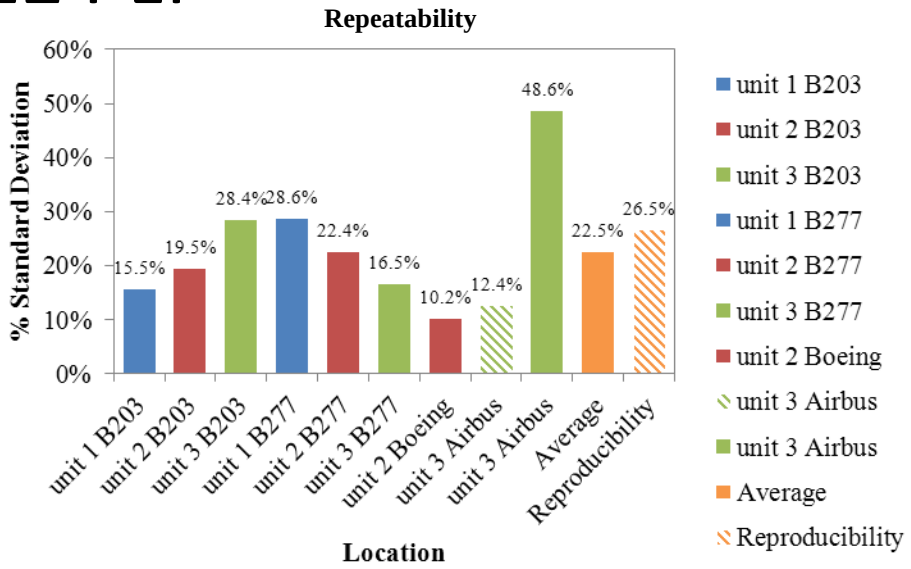


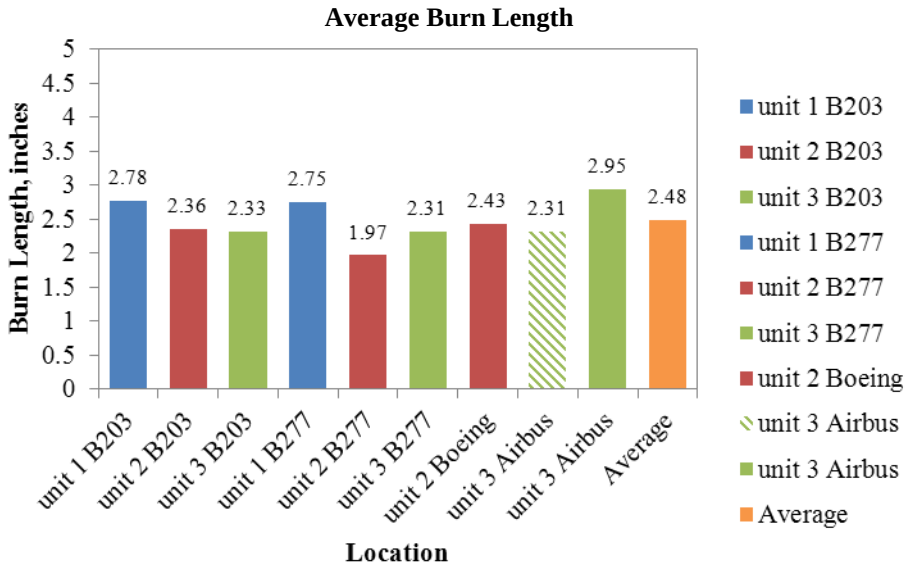


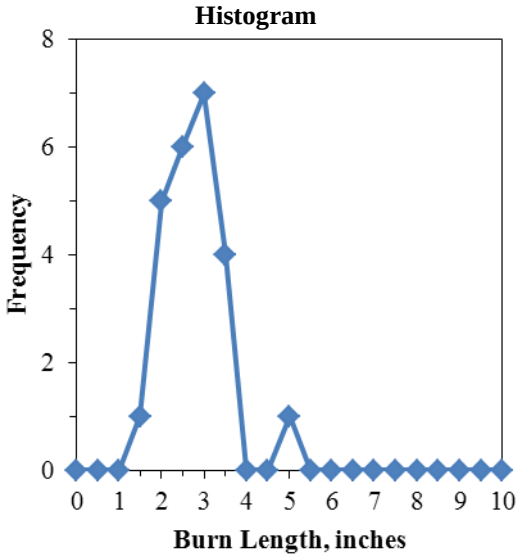


Comparative Test Series Results
3KPW-12 PLY

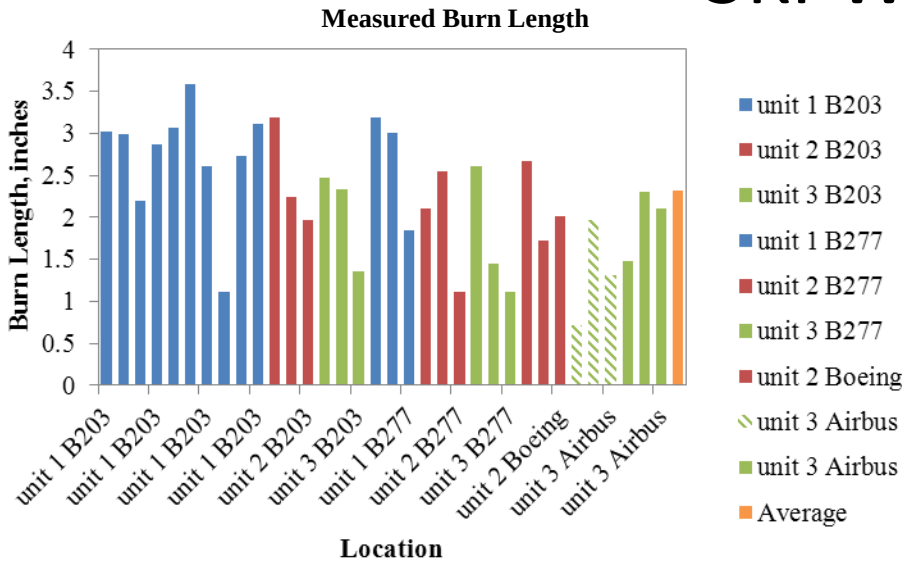


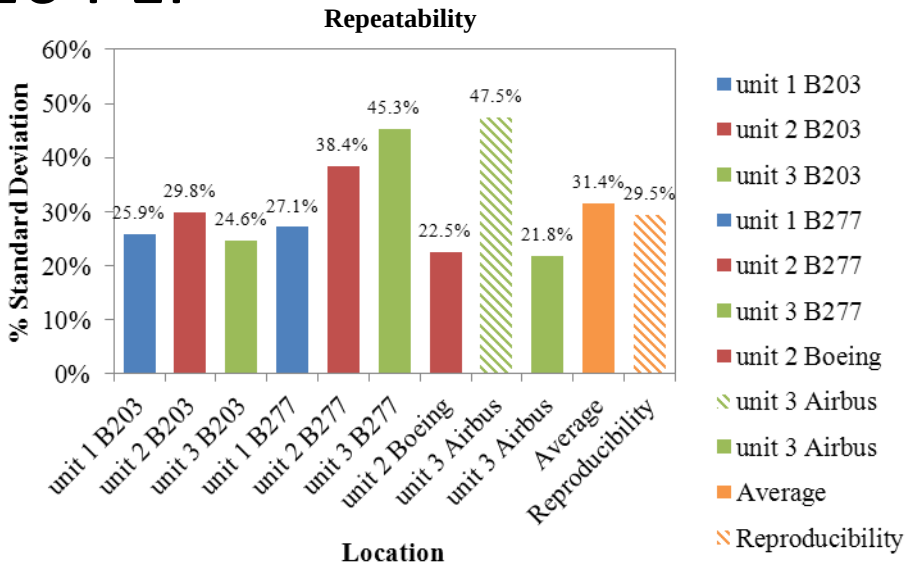


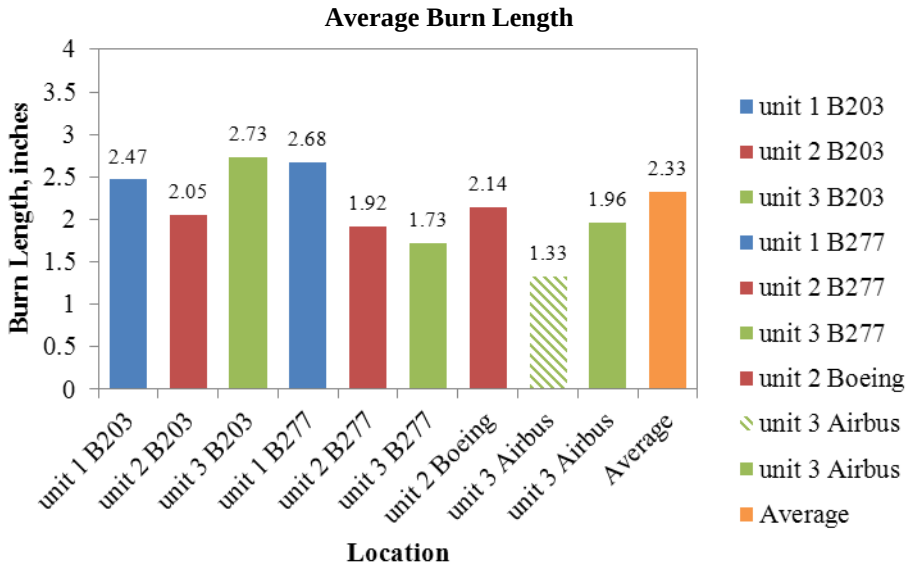


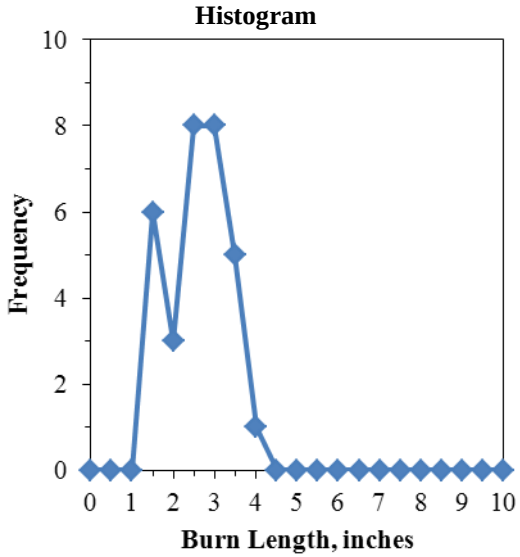


Comparative Test Series Results
3KPW-16 PLY

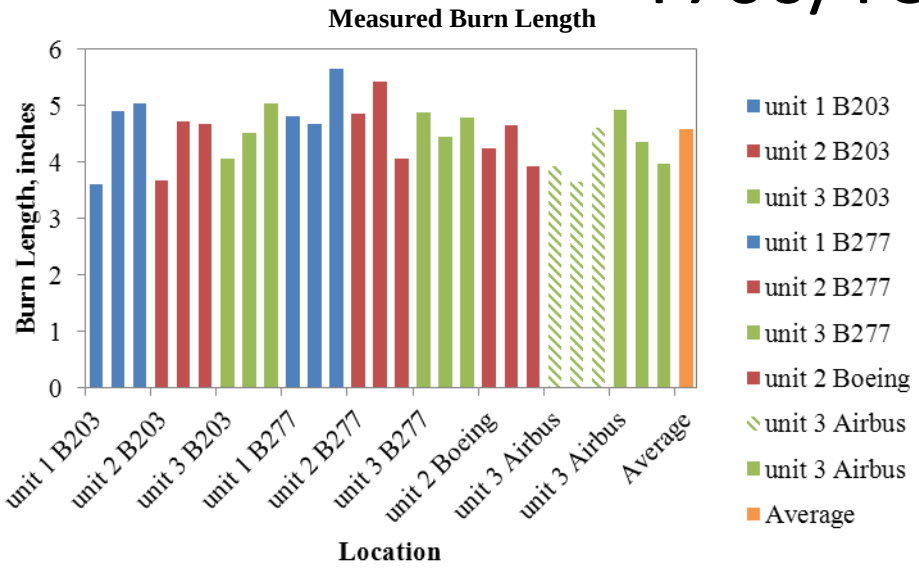


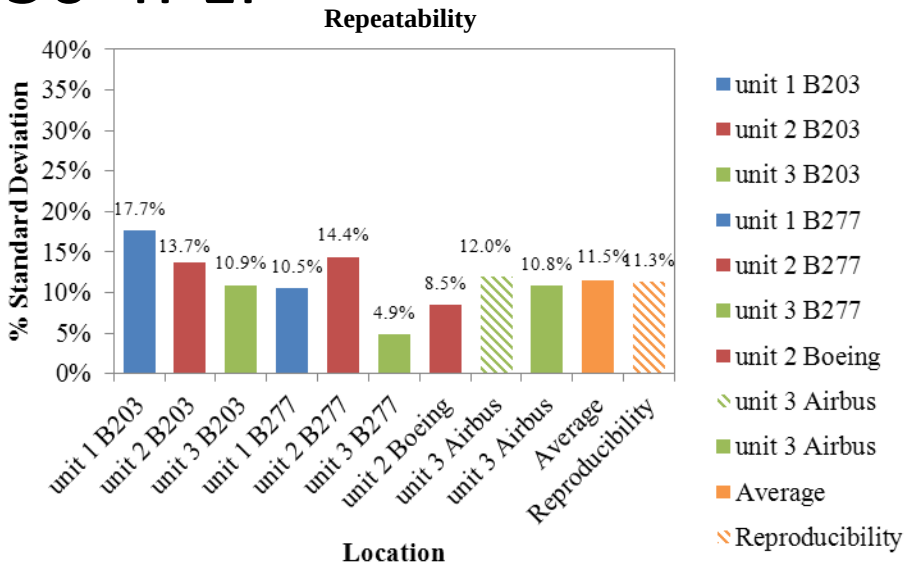


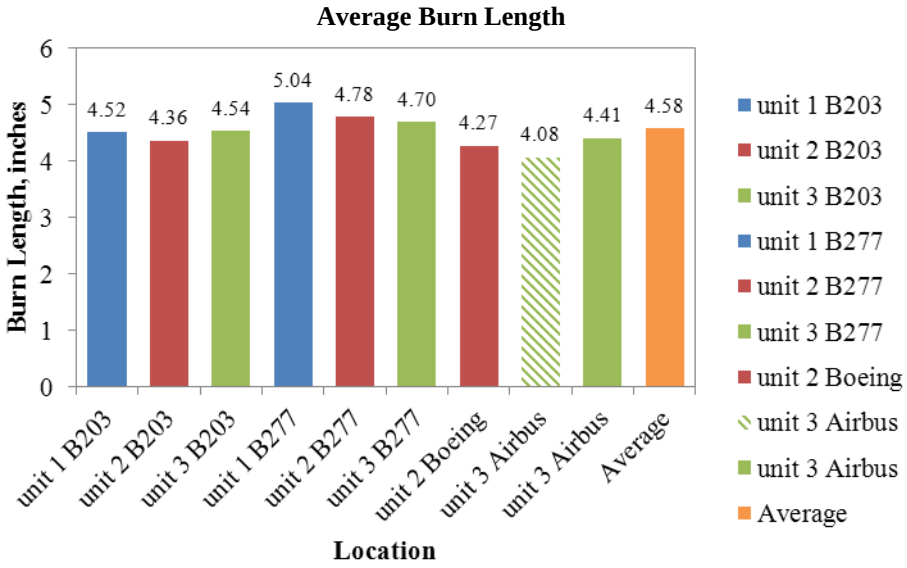


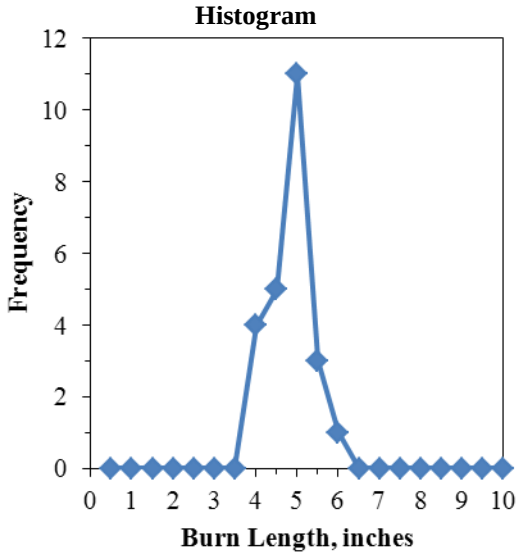


Comparative Test Series Results
T700/TC250 4PLY

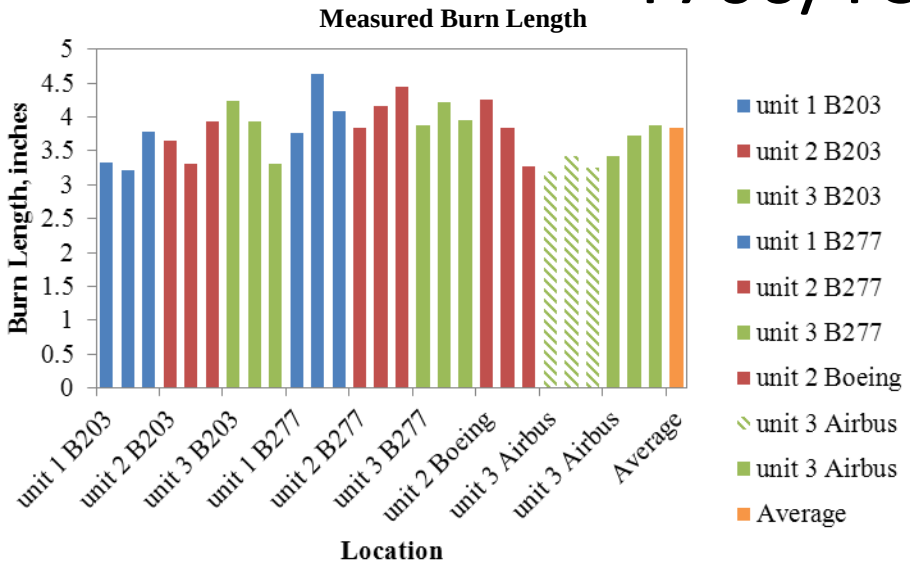


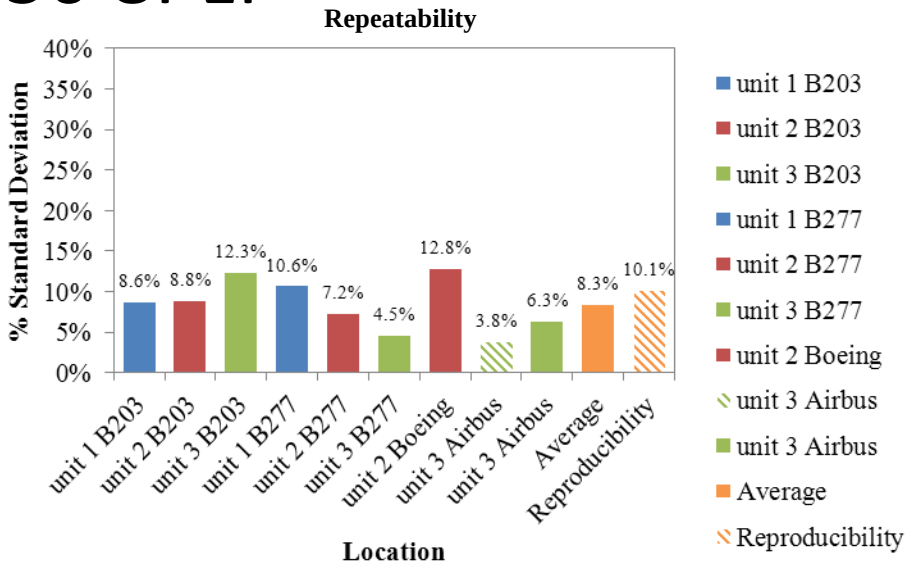


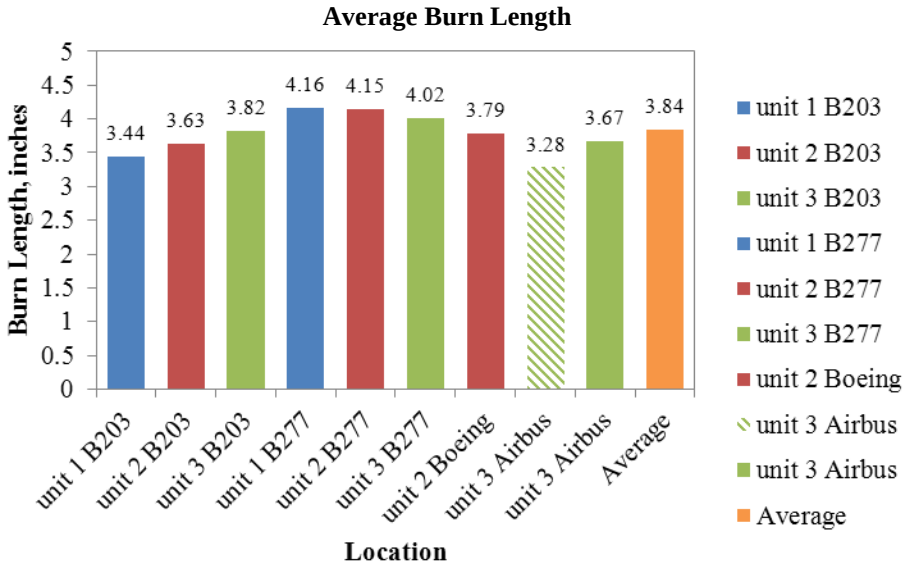


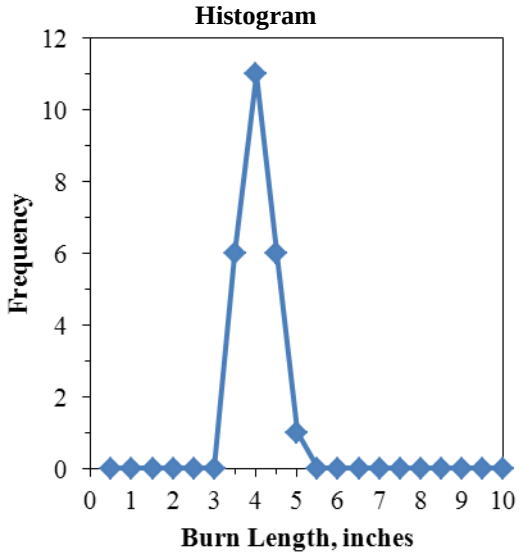


Comparative Test Series Results
T700/TC250 8PLY

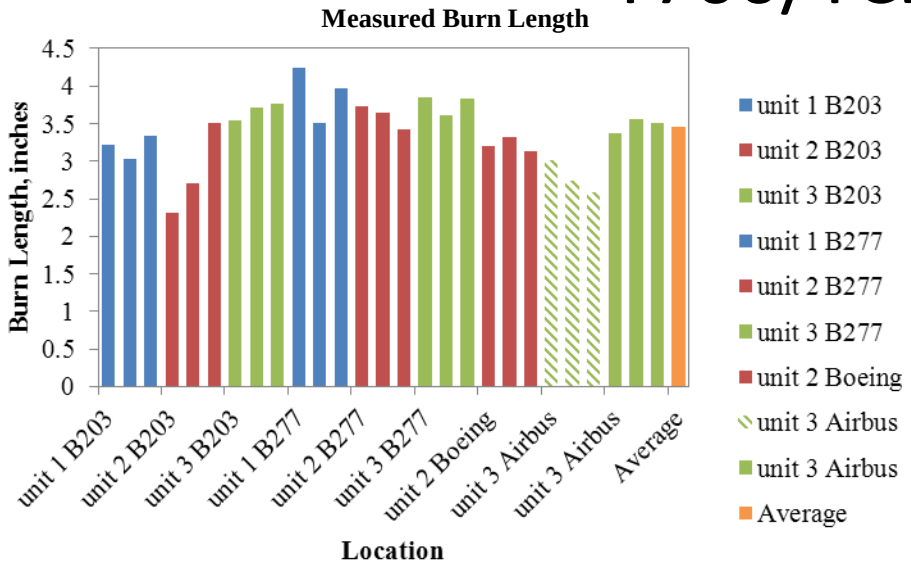


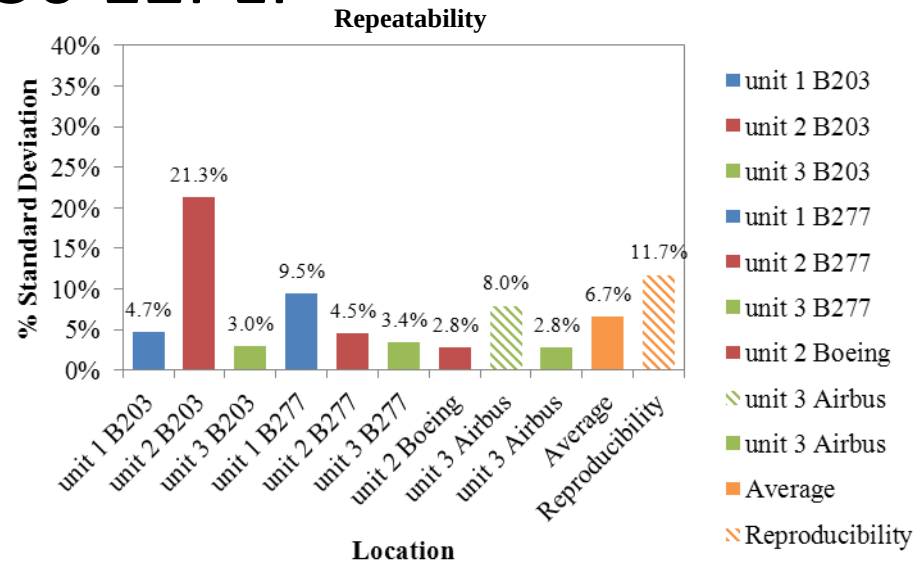


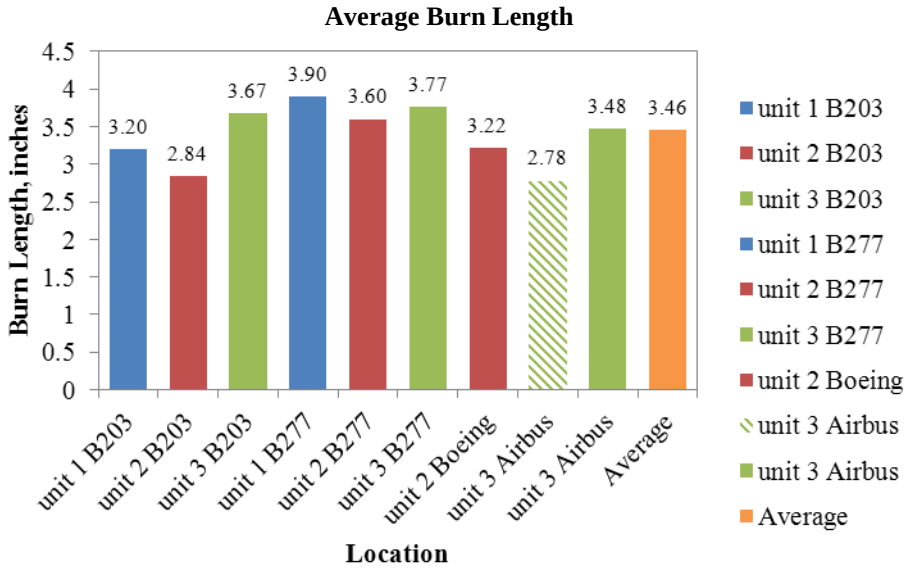


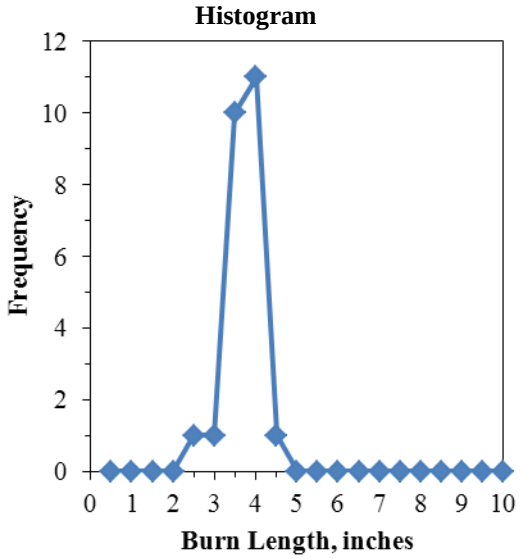


Comparative Test Series Results
T700/TC250 12PLY

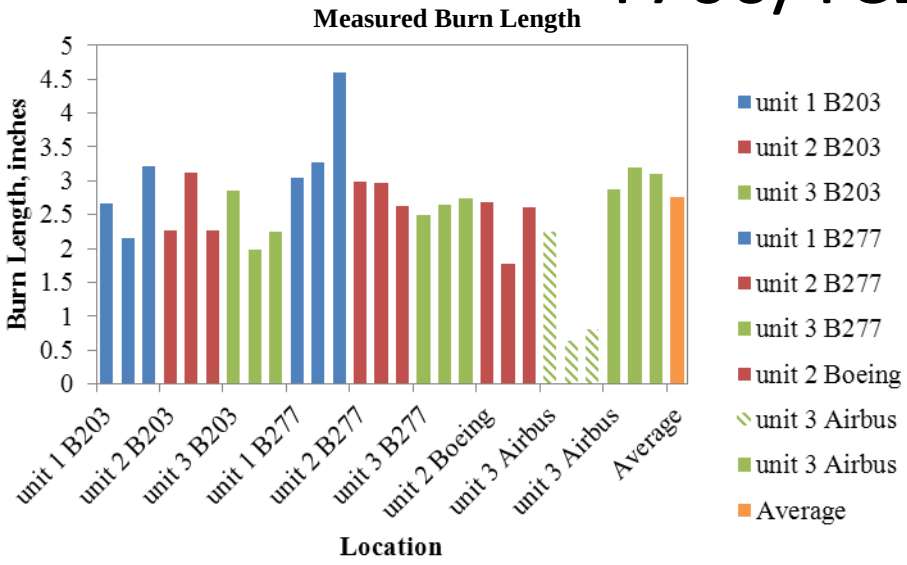


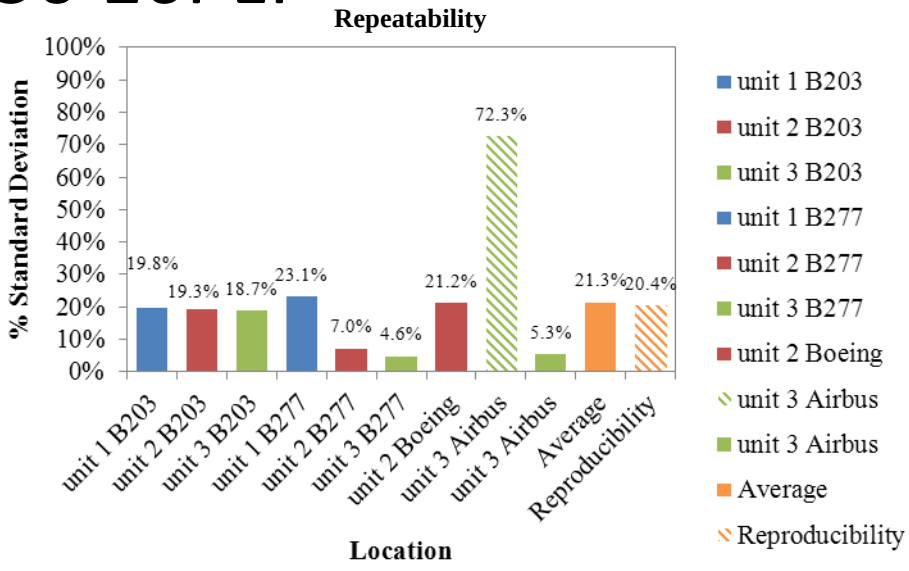


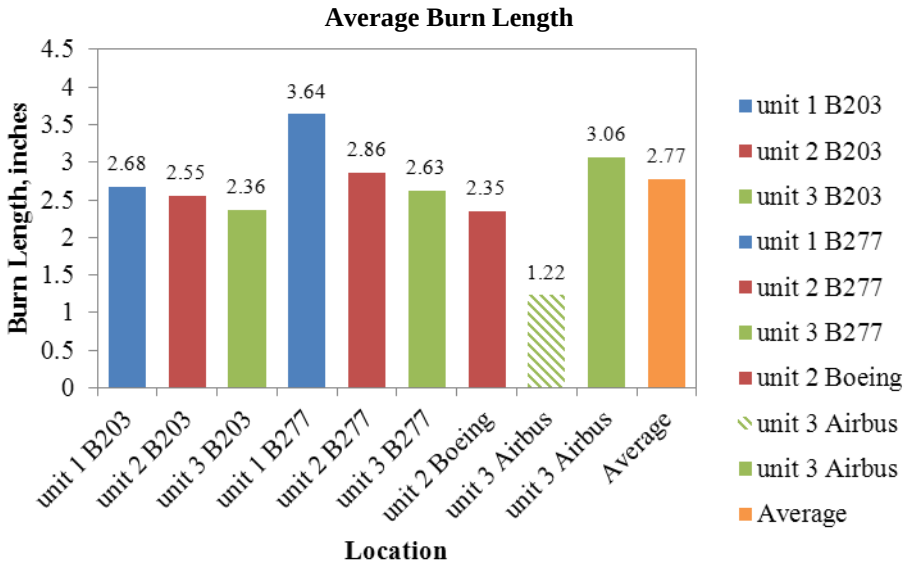


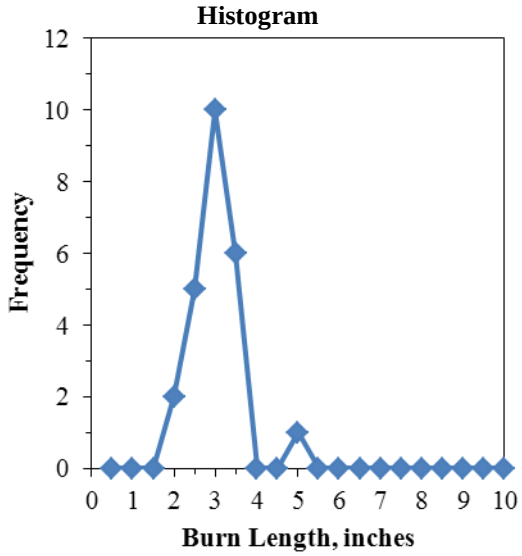


Comparative Test Series Results
T700/TC250 16PLY

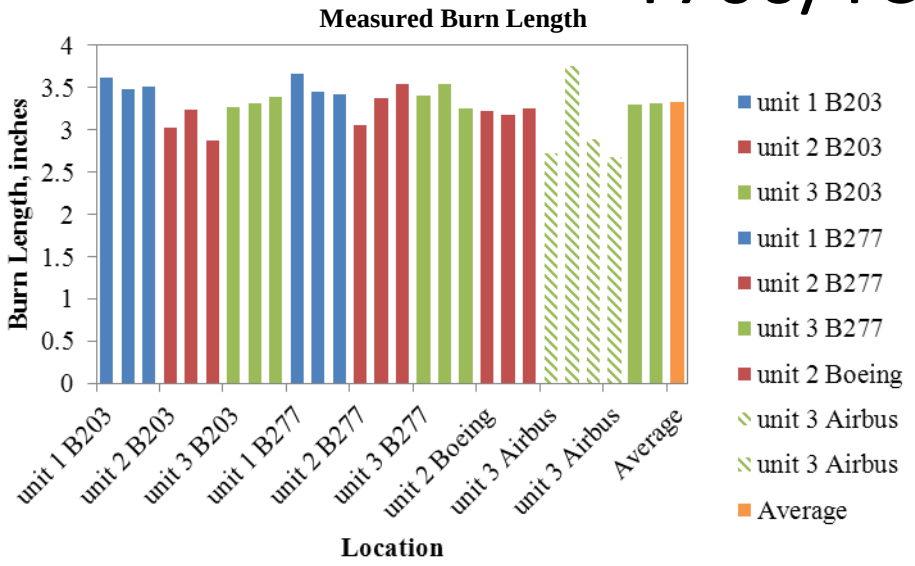


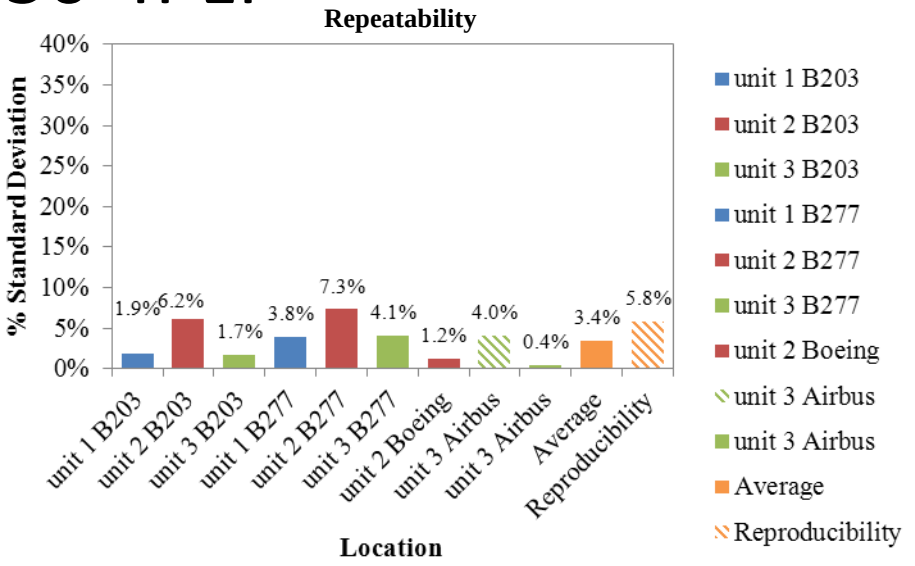


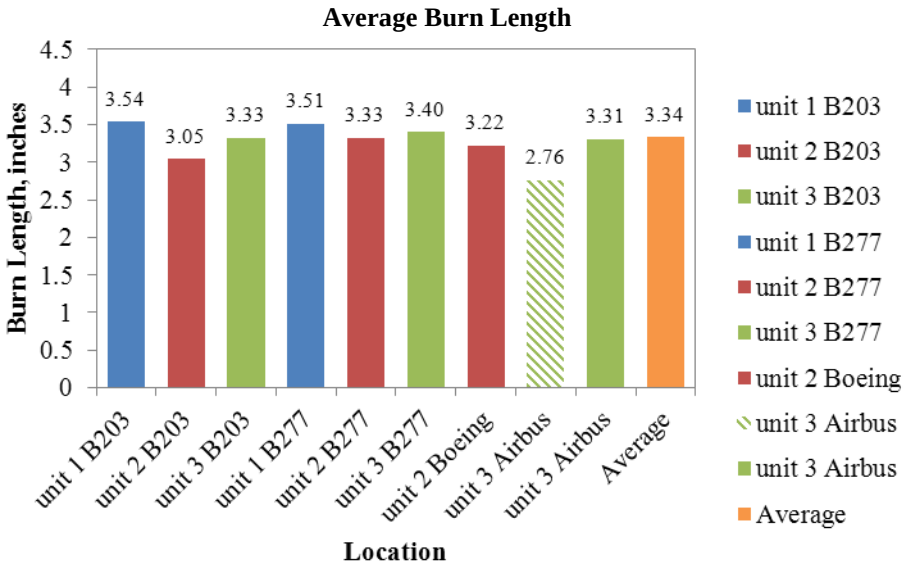


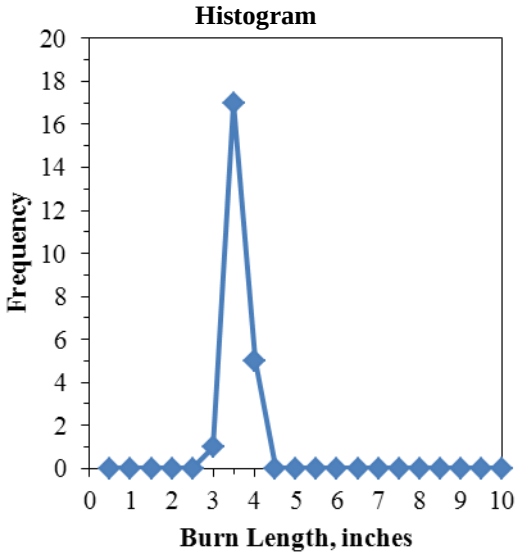


Comparative Test Series Results
T700/TC350 4PLY

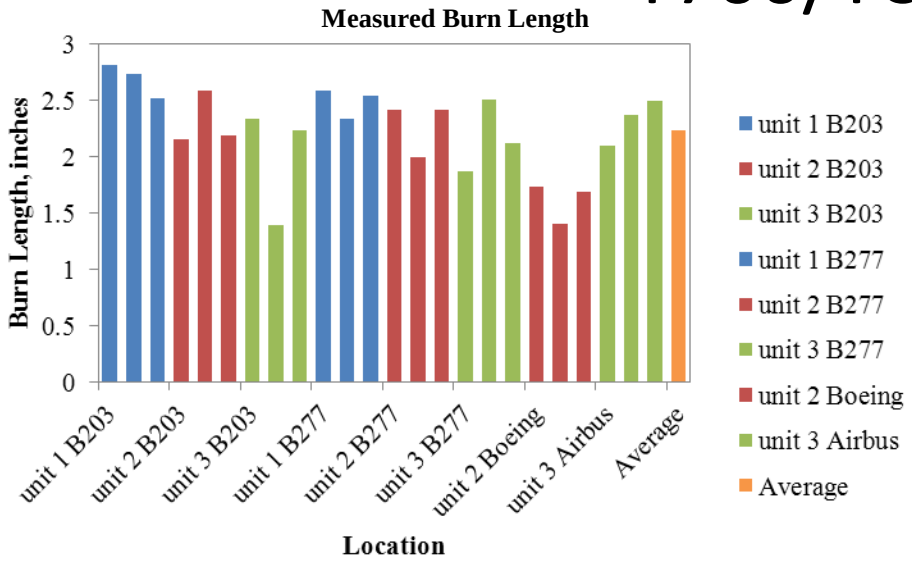


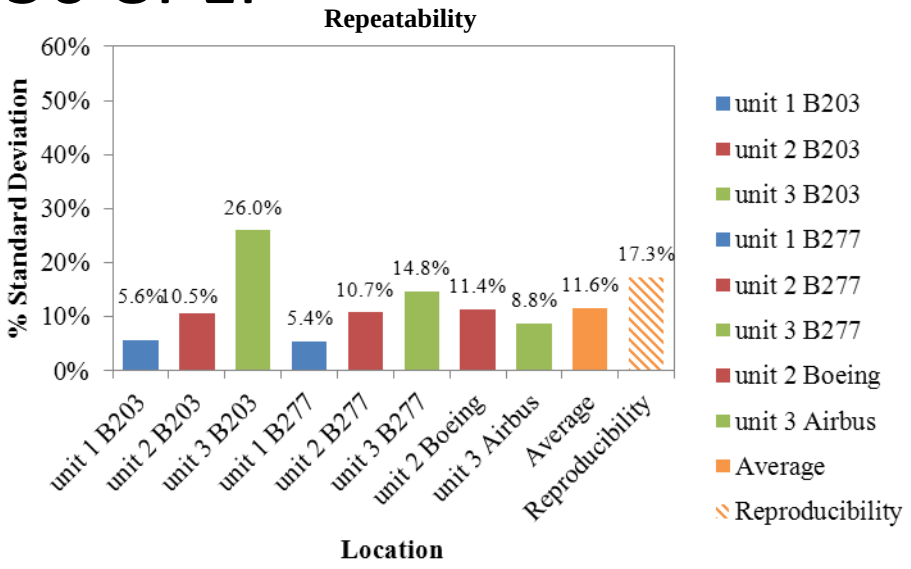


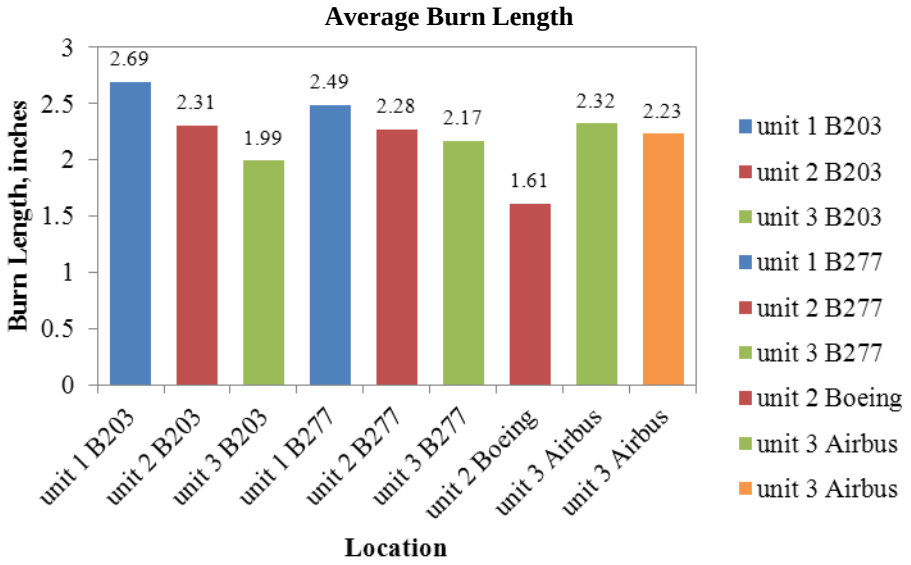


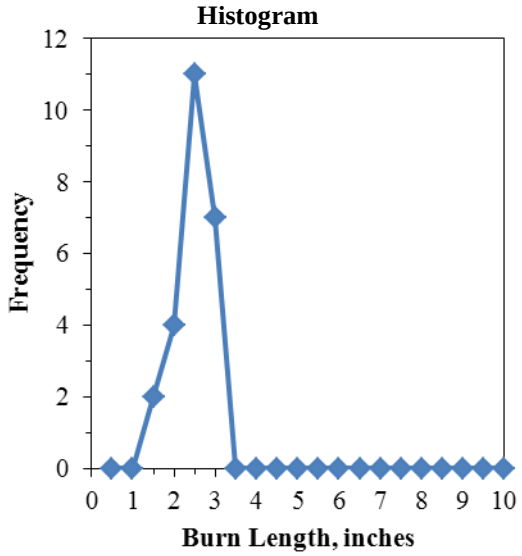


Comparative Test Series Results
T700/TC350 8PLY



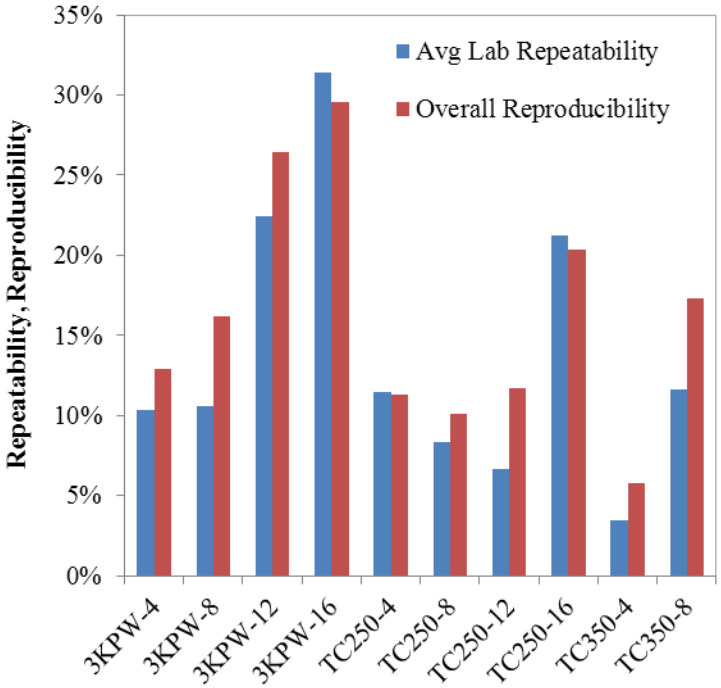






Overall Results

Sample Type	Average Repeatability	Overall Material Reproducibility
3KPW-4	10.35%	12.91%
3KPW-8	10.56%	16.16%
3KPW-12	22.45%	26.47%
3KPW-16	31.44%	29.52%
TC250-4	11.49%	11.29%
TC250-8	8.33%	10.07%
TC250-12	6.66%	11.73%
TC250-16	21.26%	20.36%
TC350-4	3.42%	5.75%
TC350-8	11.64%	17.31%
Average	13.76%	16.16%



Comparative Test Series Summary

- Good agreement was found between labs and machines, though highly dependent on material type/thickness
- Good repeatability (avg. 14%) was found within each lab/machine combination, though highly dependent on material type/thickness
- Good reproducibility (avg. 16%) was found for each material considering all lab/machine combinations, though highly dependent on material type/thickness
- Furnace alignment found to be very critical to achieving proper burn lengths

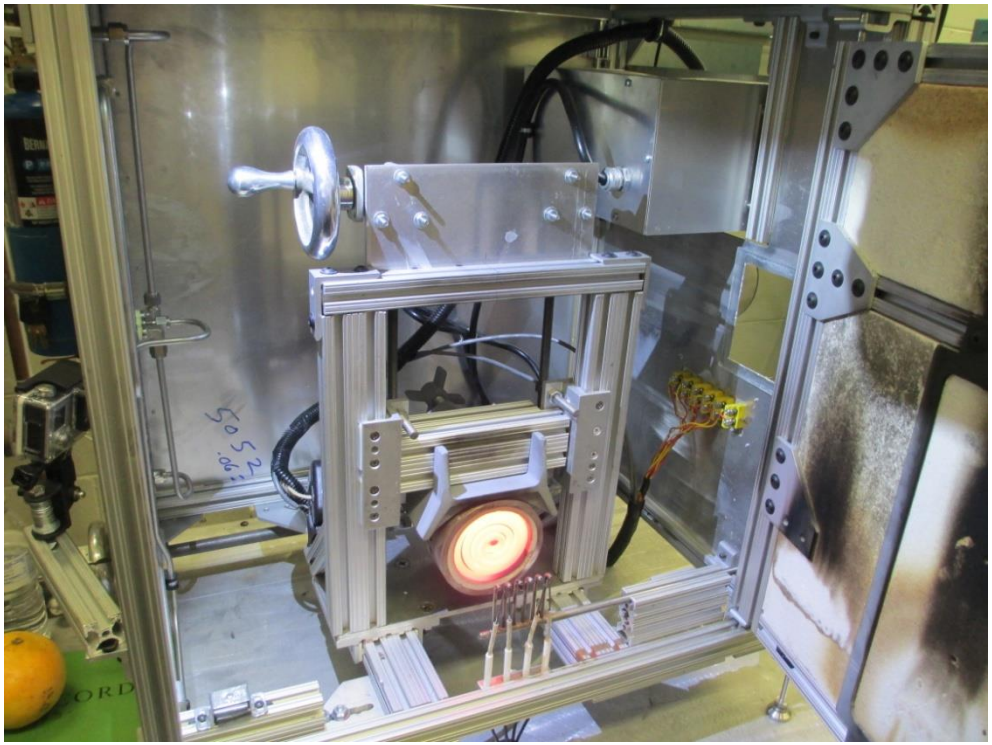
Follow-On Items from Lab Visits

- Add viewing windows for observation of test in event of video failure
- Develop method to re-ignite pilot flame in the event of a material that blows out flames
- Determine if a method can be used to eliminate backside smoke from entering room
- Determine if a damper can be installed in the exhaust hood in order to regulate the airflow leaving the chamber

Windows & Lighting

Left

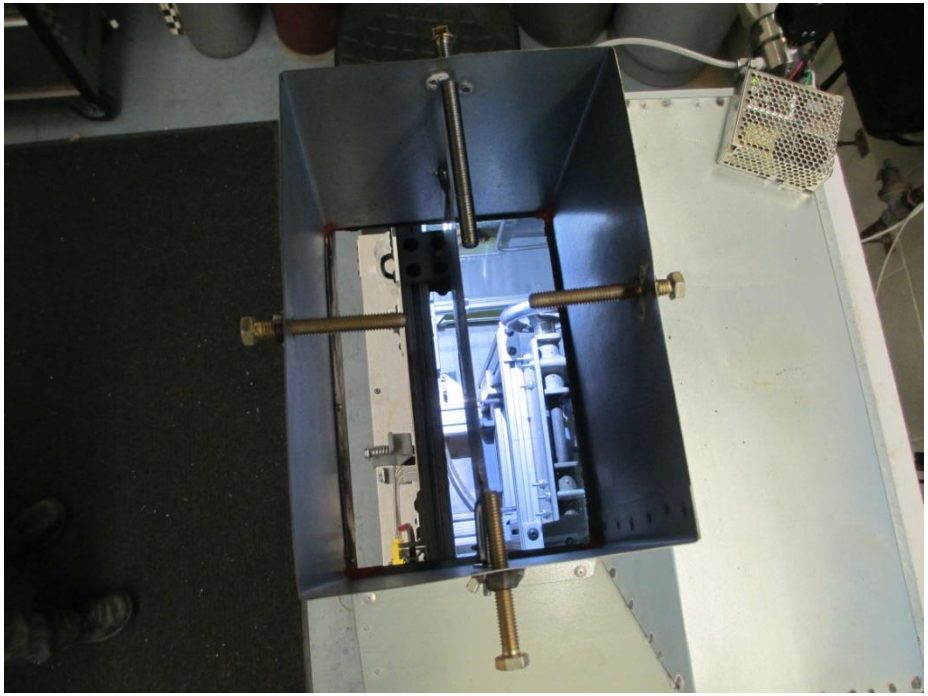
Right

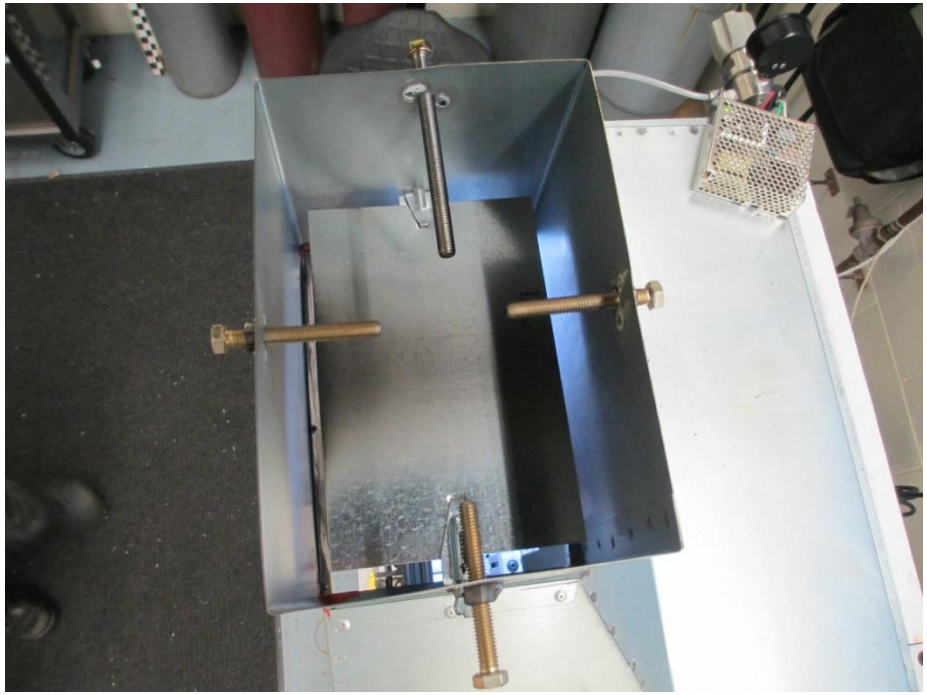


Federal Aviation Administration

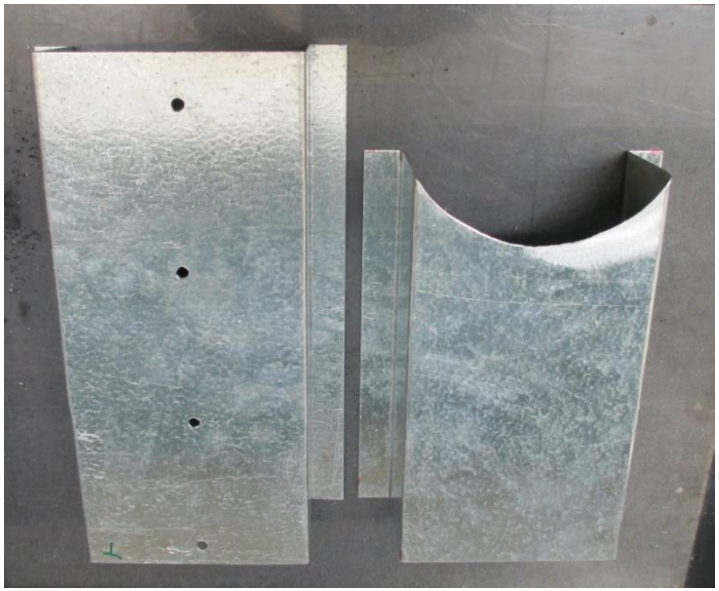
Reignition System

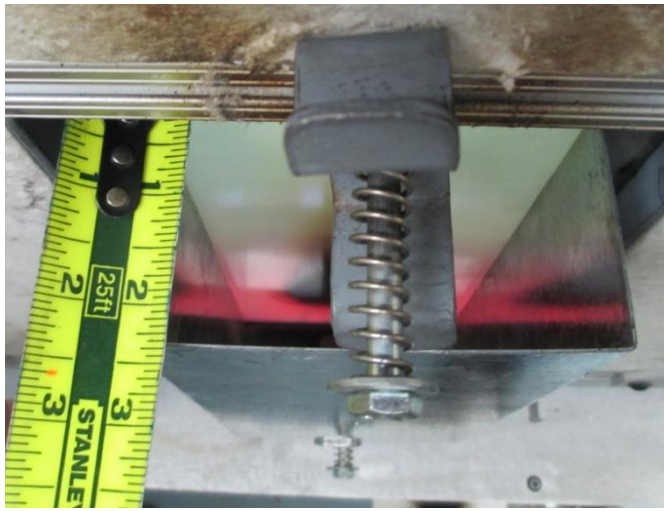
Damper & Integrated Velocity Measurement Location



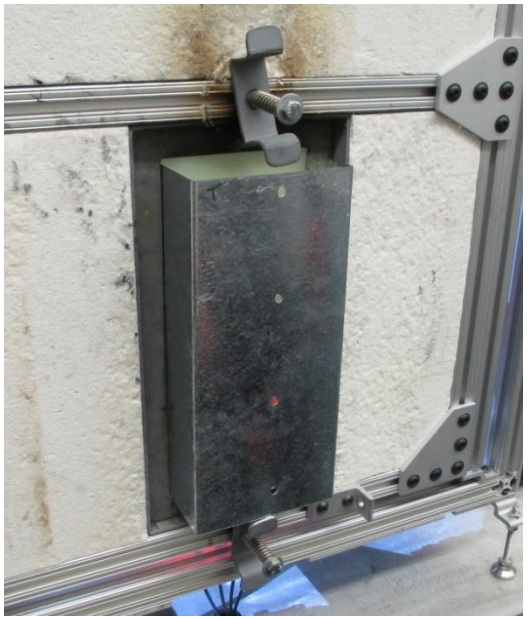


Chimneys

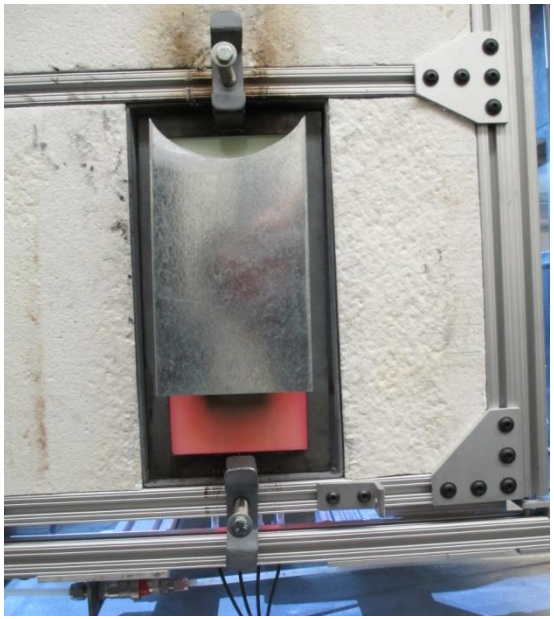




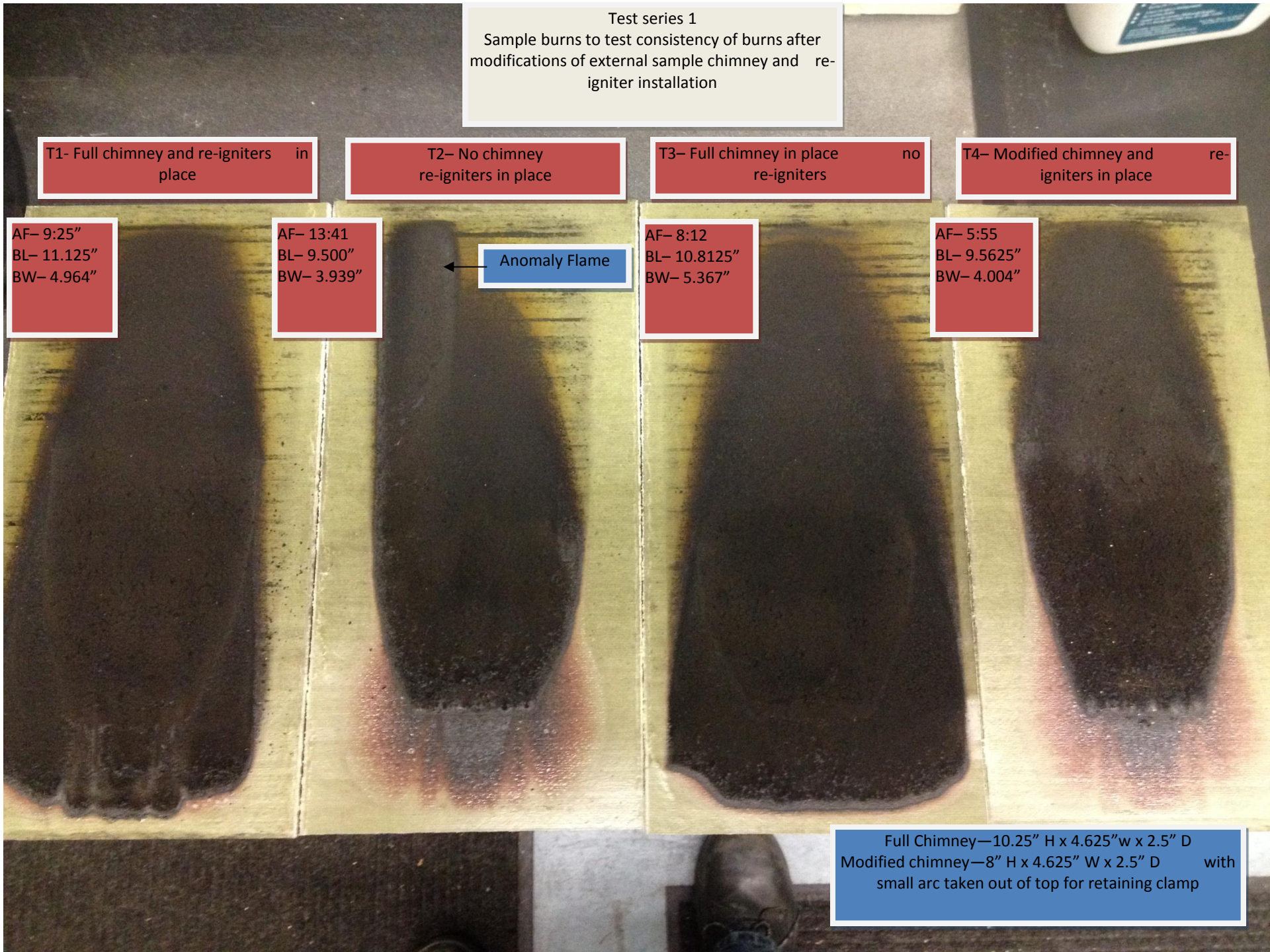
Full Chimney

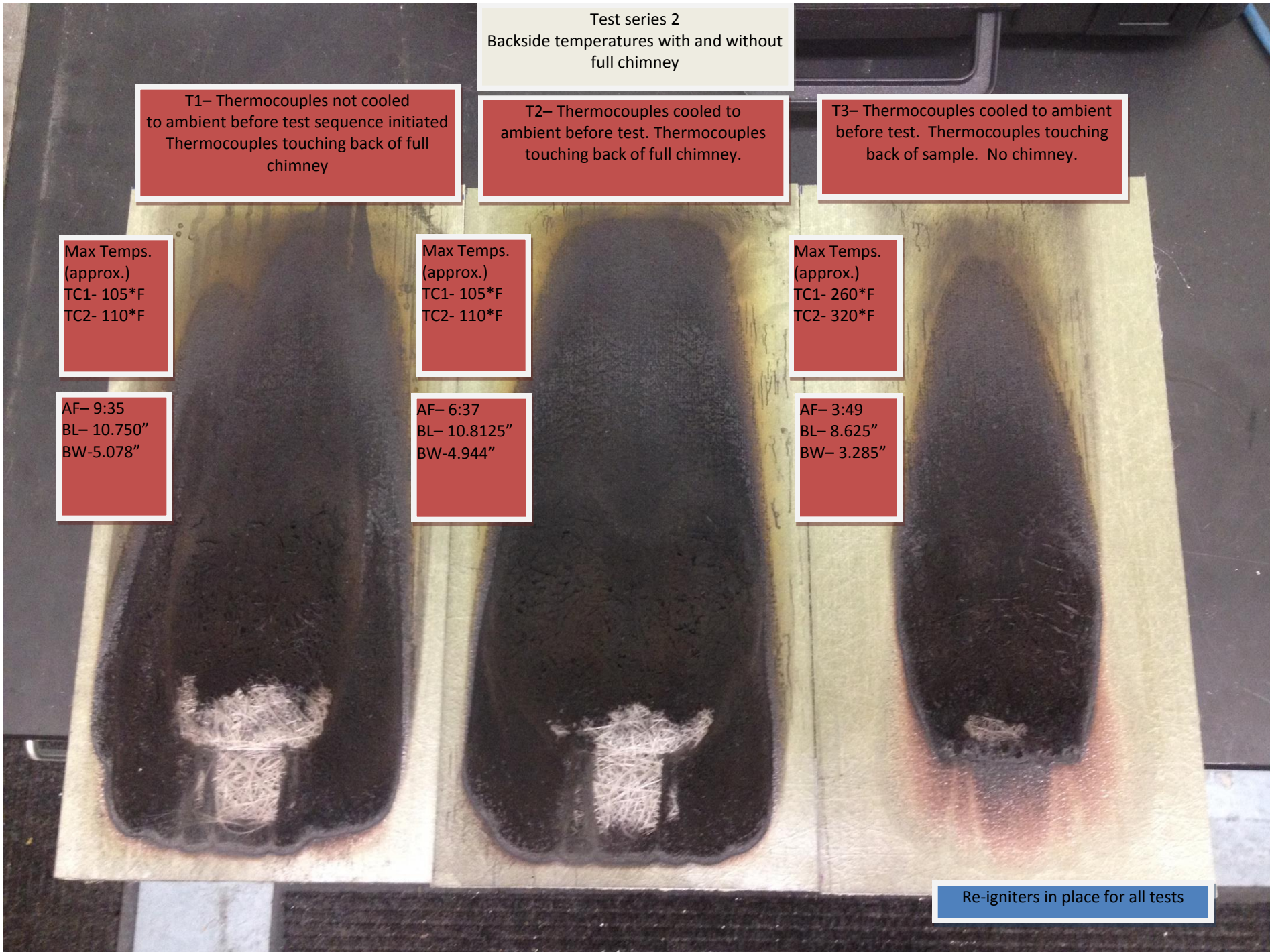


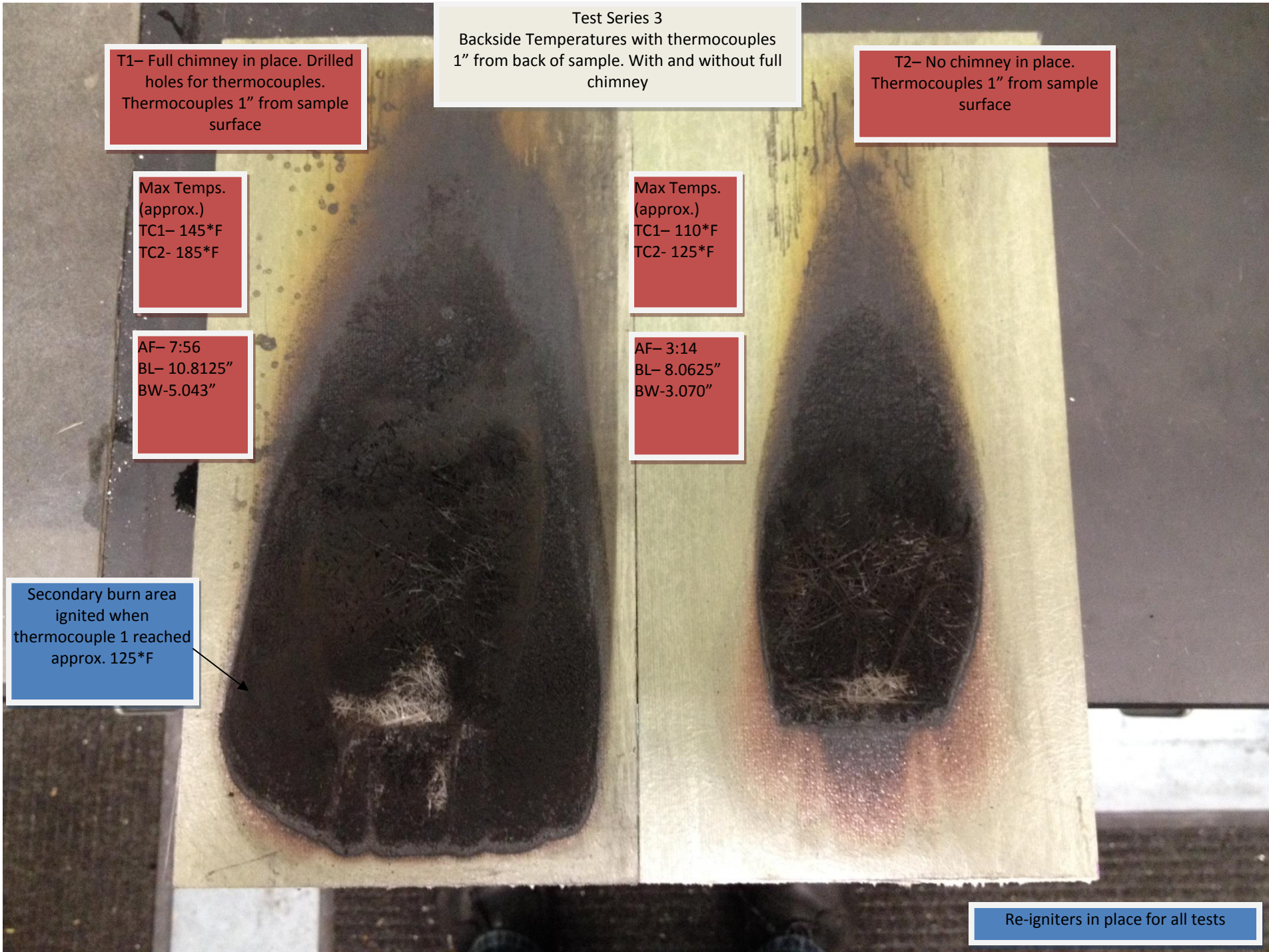
Partial Chimney



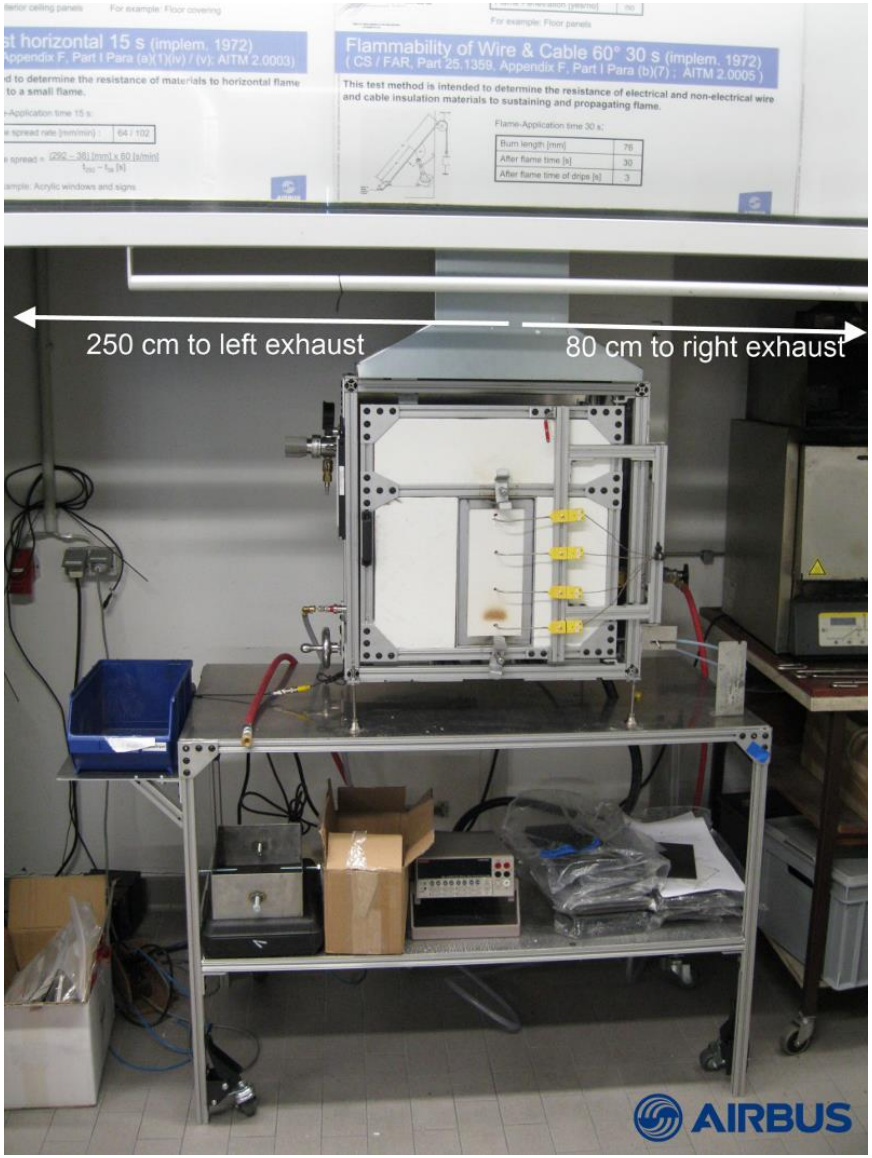
Test series 1
Sample burns to test consistency of burns after modifications of external sample chimney and re-igniter installation

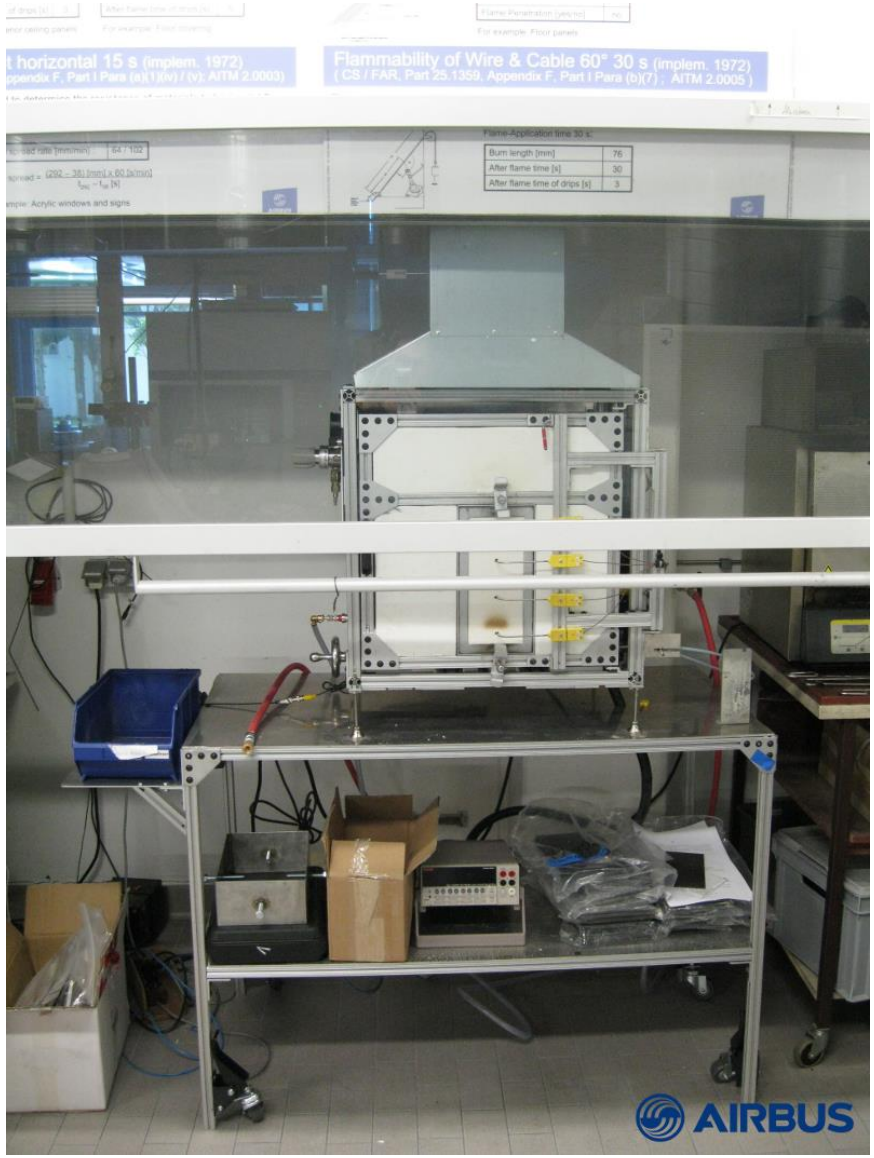



Test series 2
Backside temperatures with and without full chimney
T1– Thermocouples not cooled to ambient before test sequence initiated Thermocouples touching back of full chimney
T2– Thermocouples cooled to ambient before test. Thermocouples touching back of full chimney.
T3– Thermocouples cooled to ambient before test. Thermocouples touching back of sample. No chimney.
Max Temps. (approx.)
TC1- 105*F
TC2- 110*F
AF– 9:35
BL– 10.750”
BW-5.078”
Max Temps. (approx.)
TC1- 105*F
TC2- 110*F
AF– 6:37
BL– 10.8125”
BW-4.944”
Max Temps. (approx.)
TC1- 260*F
TC2- 320*F
AF– 3:49
BL– 8.625”
BW– 3.285”
Re-igniters in place for all tests

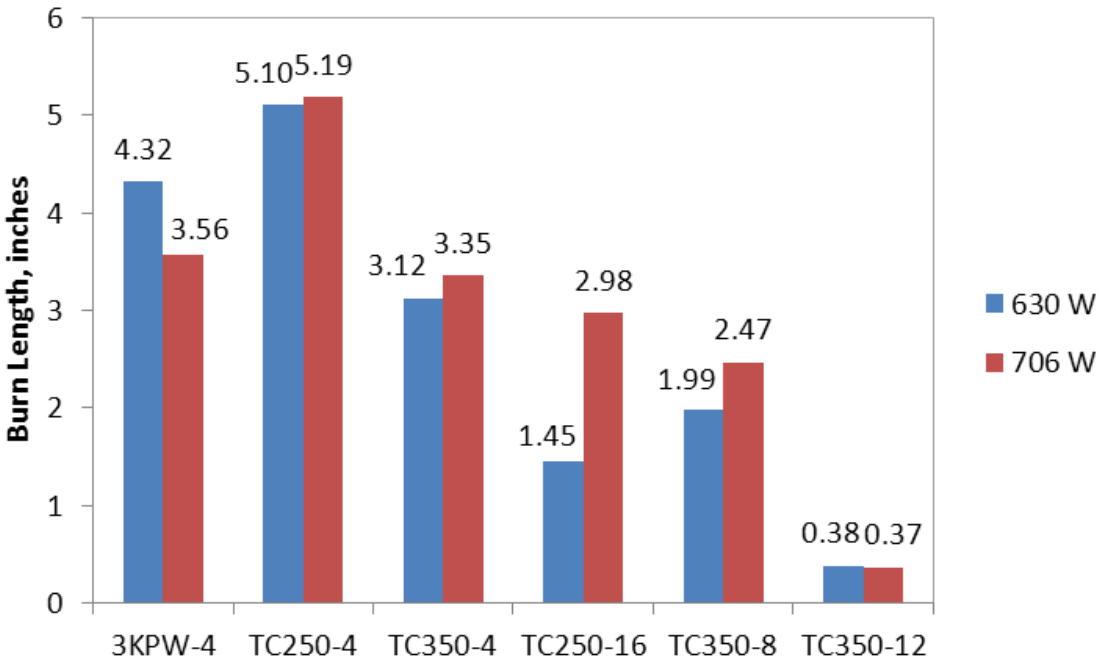

Test Series 3
Backside Temperatures with thermocouples 1” from back of sample. With and without full chimney
T1– Full chimney in place. Drilled holes for thermocouples. Thermocouples 1” from sample surface
T2– No chimney in place. Thermocouples 1” from sample surface
Max Temps. (approx.)
TC1– 145*F
TC2- 185*F
AF– 7:56
BL– 10.8125”
BW-5.043”
Max Temps. (approx.)
TC1– 110*F
TC2- 125*F
AF– 3:14
BL– 8.0625”
BW-3.070”
Secondary burn area ignited when thermocouple 1 reached approx. 125*F
Re-igniters in place for all tests

Backside Smoking & Off-gassing: Possible Solution





Influence of Furnace Power



- Thin samples *relatively* insensitive to a 75W decrease (106 Volts vs. 100 Volts) in furnace power
- Thicker samples that do burn are very sensitive to 75W decrease in furnace power

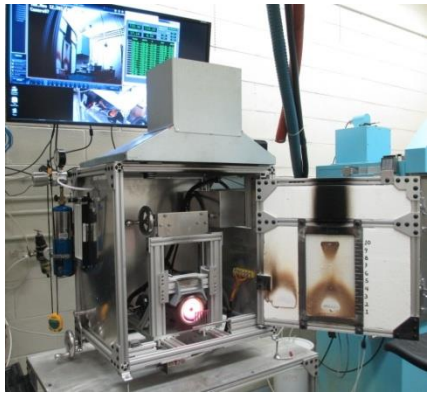
Summary of Post-Visit Studies

- Addition of windows was relatively easy, adds alternative visible access if cameras go down
- Backside chimneys do have a significant influence on test severity. A solution to backside smoke is presented, but other solutions are possible.
- The air velocity measurement location was integrated into the exhaust stack, as well as a damper system to regulate the air flow leaving the hood.
- A prototype re-ignition system was developed and proven successful. It was found to create a radiative shadow on the test sample for samples that have long test times. It should not always be used during testing, only when a material is tested that is known to blow out pilot flames.
- Furnace power was found to have an influence on test results. A range of 75 Watts was found to influence burn lengths on thicker (12-16 ply) samples, but thin samples (4 ply) saw little to no influence.

Wire Insulation Testing

Federal Aviation Administration





Presented to: IAMFTWG
By: Robert I. Ochs
Date: June 25-26, 2014, Solothurn, Switzerland

Reinhardt, J., "Development of an Improved Fire Test Method and Criteria for Aircraft Electrical Wiring," FAA report DOT/FAA/AR-10/2, April 2010.

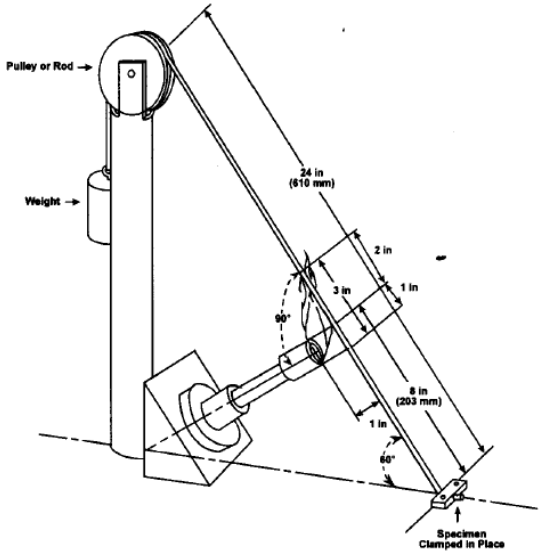


Figure 1. The 60-Degree Bunsen Burner Test Setup for Electric Wires

Figure 3. Microscale Combustion Calorimetry Test Equipment

Figure 22. Intermediate-Scale Fire Test Apparatus

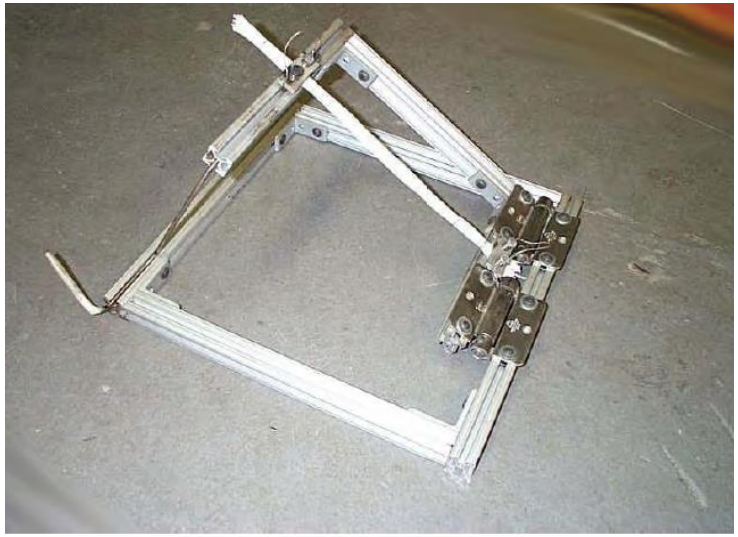
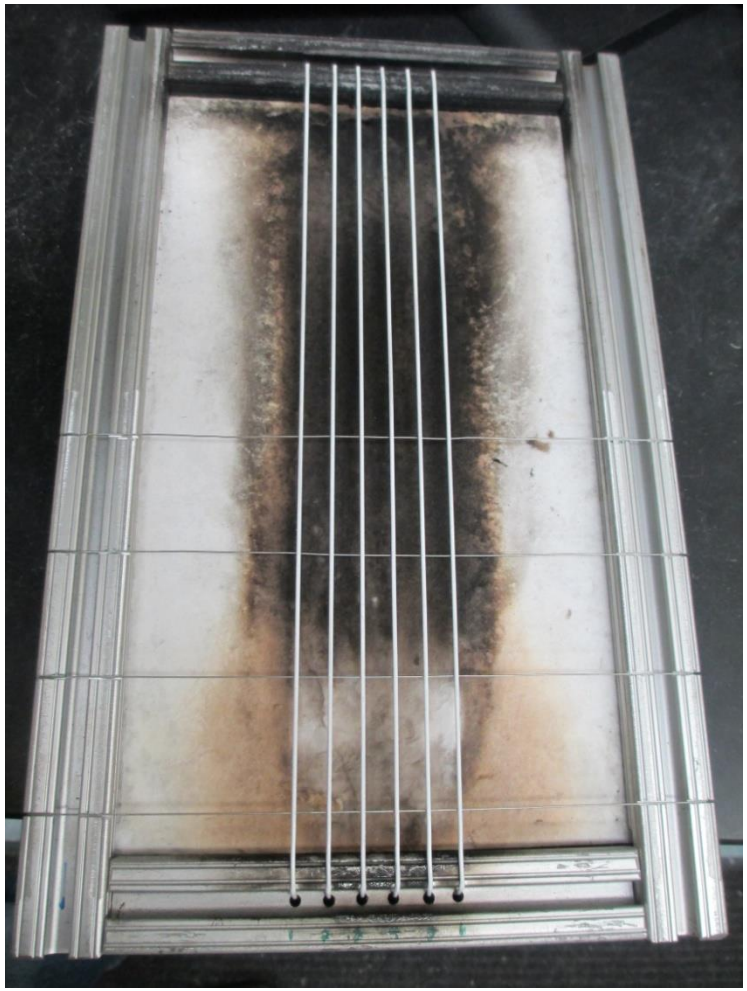


Figure 40. The 30-Degree RHP Test Bundled-Wire Holder, Procedure 10

Specification	Construction
MS81044/6	Cross-linked Polyalkene
MS5086/1	PVC/Nylon
BMS 13-60	Polyimide/PTFE
MS22759/16	ETFE
MS22759/33	XL-ETFE
MS22759/32	XL-ETFE
BMS 13-48	ETFE
MS22759/5	Extruded PTFE
MS22759/11	TFE
MS22759/14	Extruded FEP
MS22759/86	Composite: Fluoropolymer/PI tape
MS81381/21	Polyimide Tape

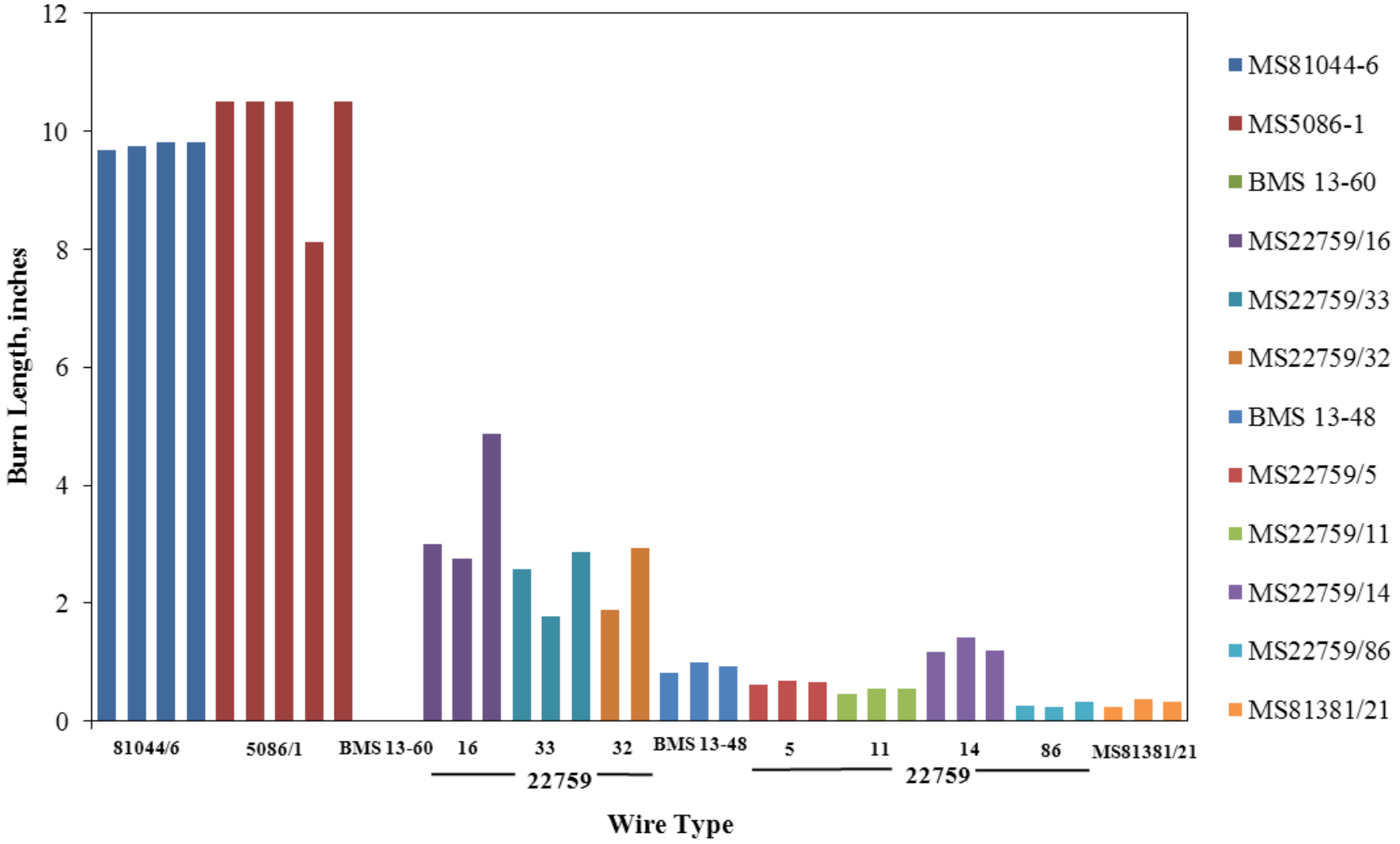



Wire Testing in VFP:
Setup

MS81044/6 – Cross-linked Polyalkene

BMS-13-48 – ETFE

Overall Results: Wire Testing on VFP



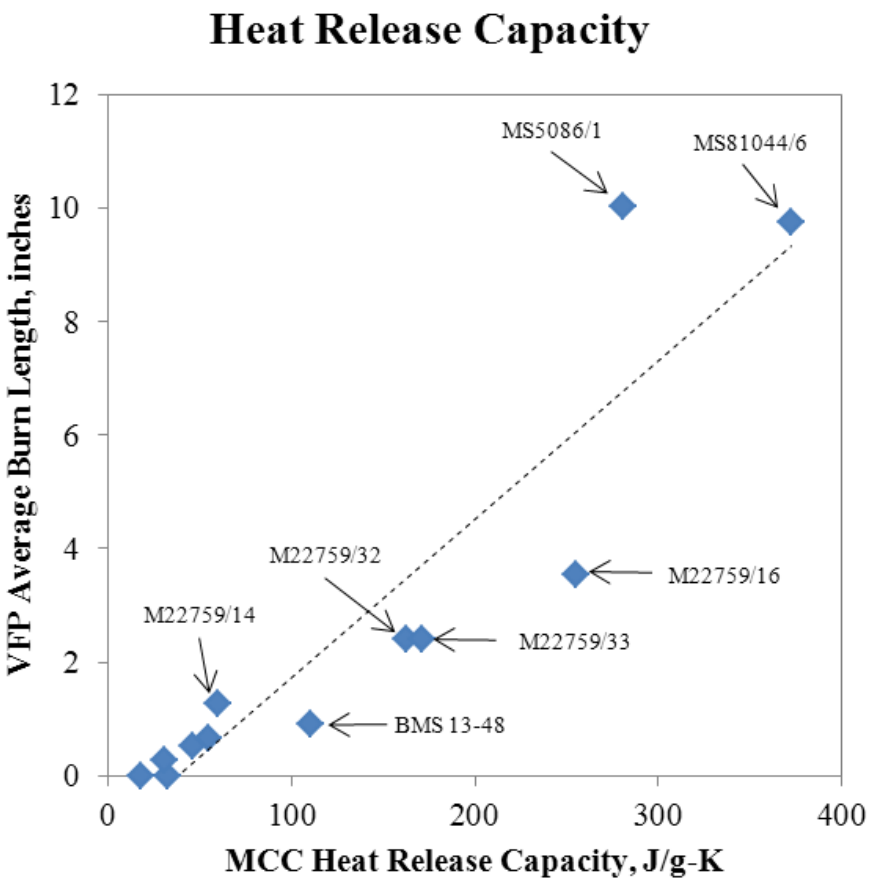
MS81044/6 – Cross-linked Polyalkene

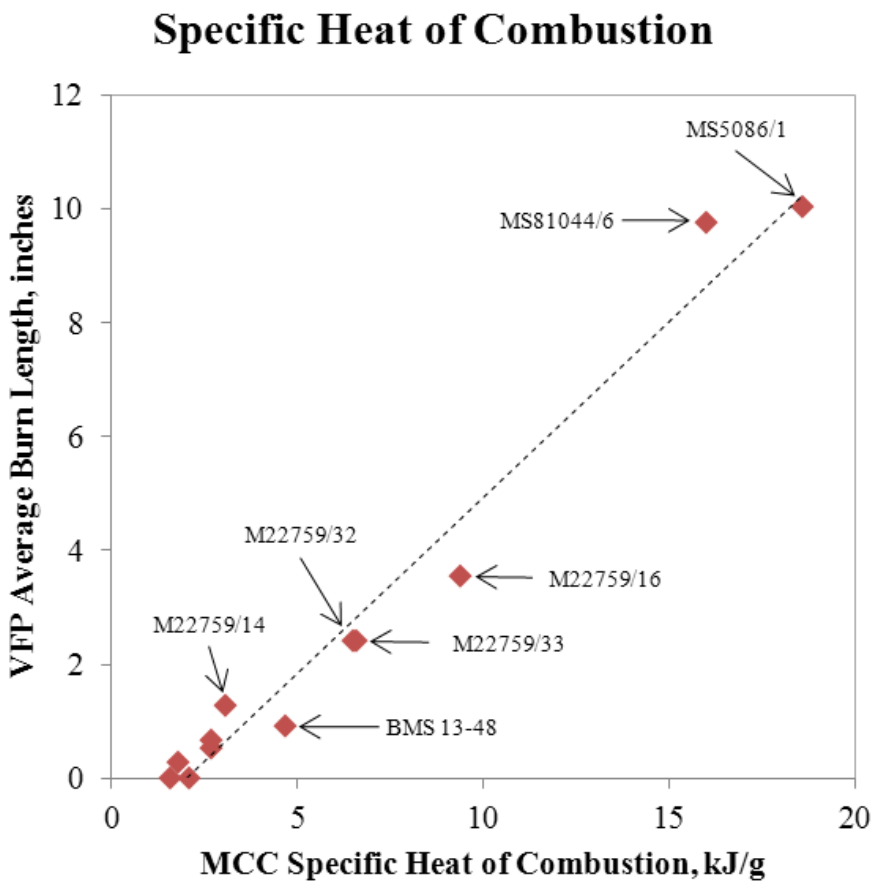
BMS-13-48 – ETFE

Microscale Data

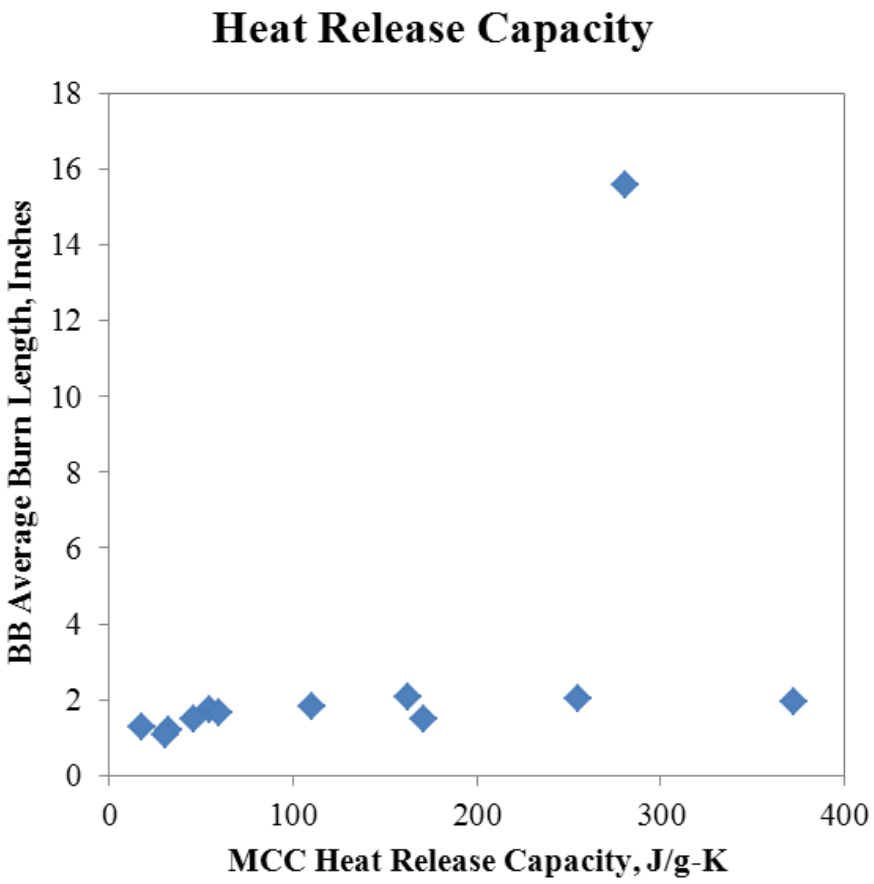
- Heat Release Capacity: maximum capability of a material to release combustion heat per degree of temperature rise during pyrolysis or burning. J/g-K.
- Heat of Combustion: Net heat of complete combustion of the volatiles liberated during controlled anaerobic thermal decomposition per unit initial sample mass. J/g.

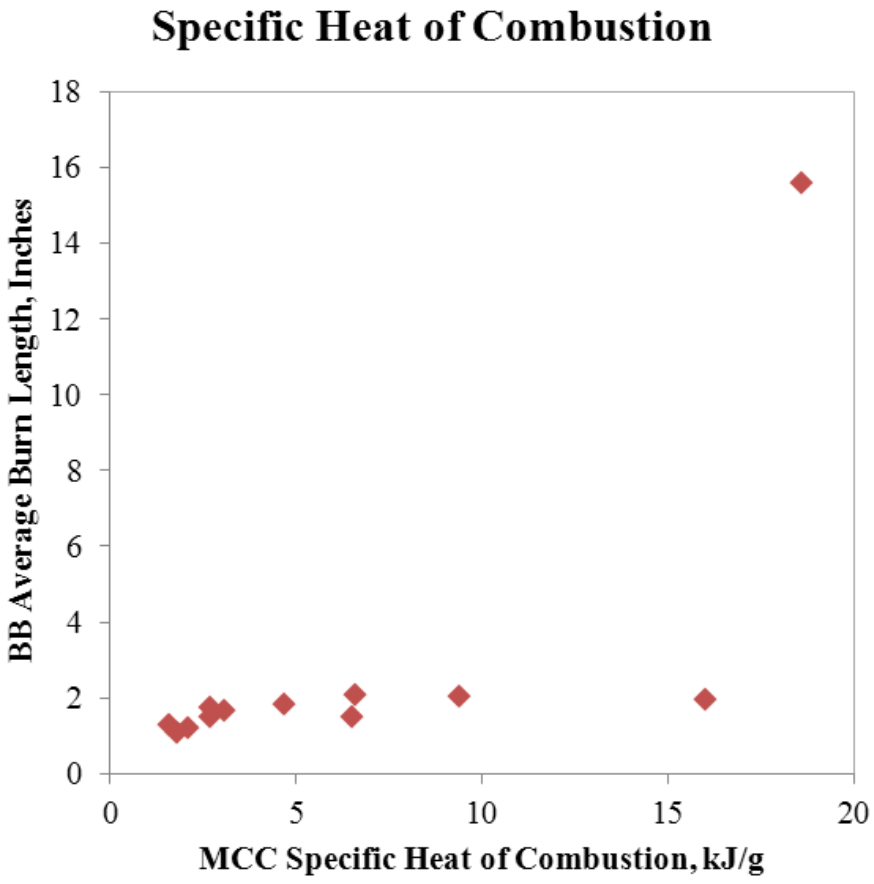
VFP vs. MCC


Heat Release Capacity
VFP Average Burn Length, inches
MCC Heat Release Capacity, J/g-K
0
2
4
6
8
10
12
0
100
200
300
400
MS5086/1
MS81044/6
M22759/32
M22759/16
M22759/14
M22759/33
BMS 13-48

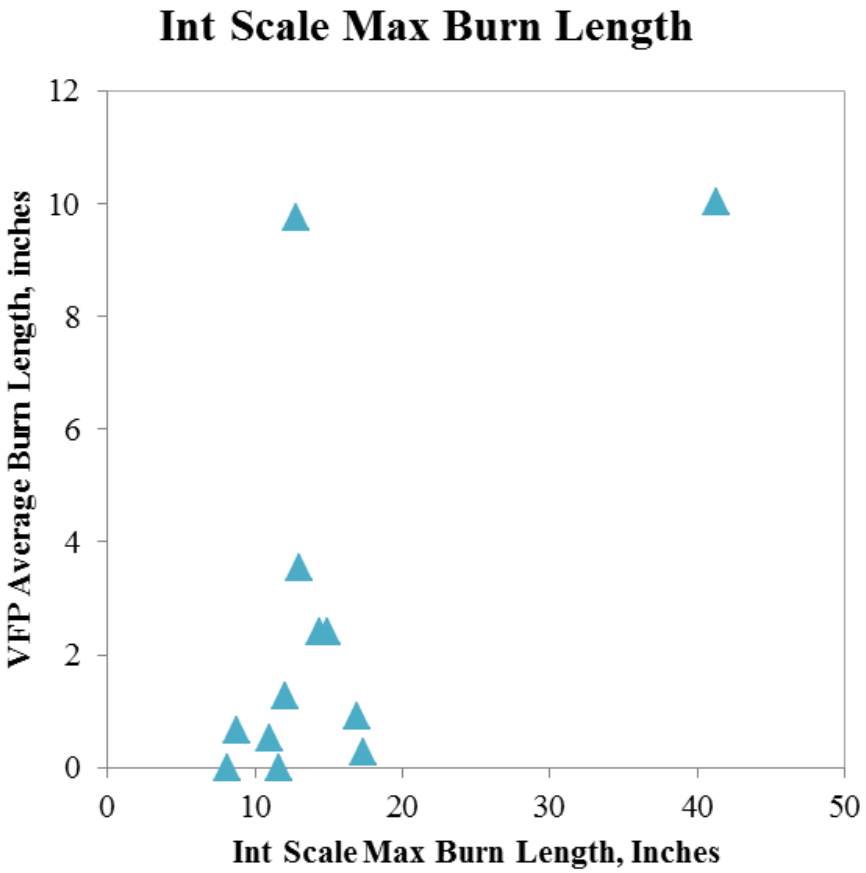

Specific Heat of Combustion
VFP Average Burn Length, inches
MCC Specific Heat of Combustion, kJ/g
0
2
4
6
8
10
12
0
5
10
15
20
MS5086/1
MS81044/6
M22759/32
M22759/16
M22759/14
M22759/33
BMS 13-48

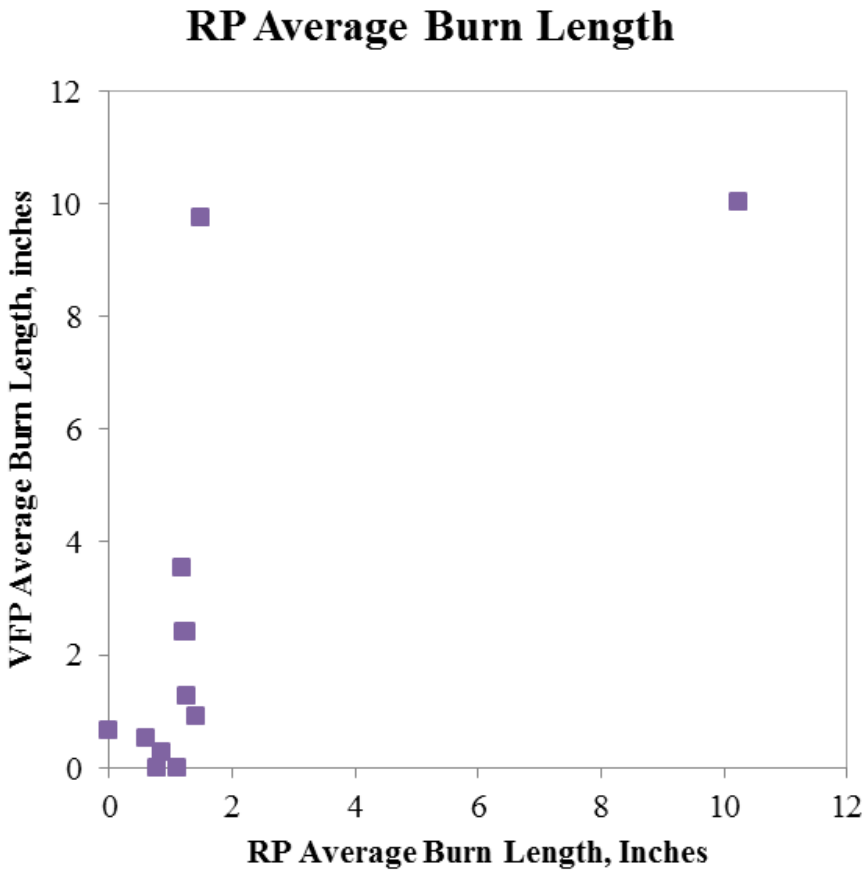
Bunsen Burner vs. MCC





VFP vs. Int. Scale & Radiant Panel

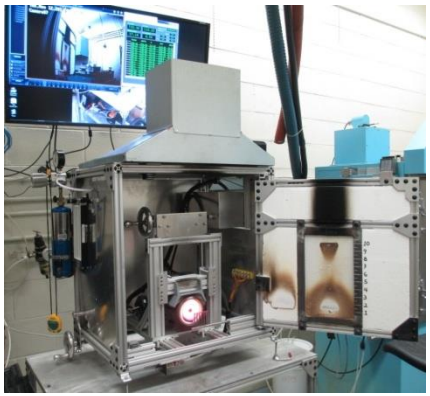




Wire Testing Summary

- Wire test method is feasible in VFP
- VFP test results correlate very well with MCC data
- Good repeatability is found on VFP
- Will conduct comparative testing with Boeing, Airbus in the coming months.





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Federal Aviation Administration