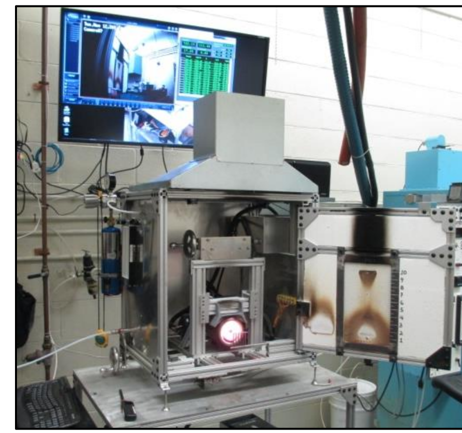
Development of a Flame Propagation Test Method for Inaccessible Area Materials

Federal Aviation Administration



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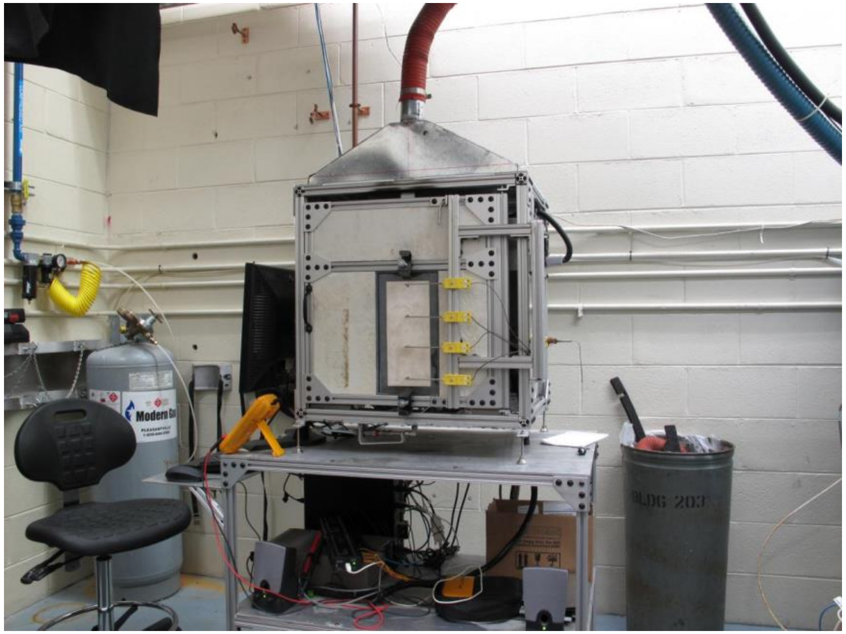
Introduction

- 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

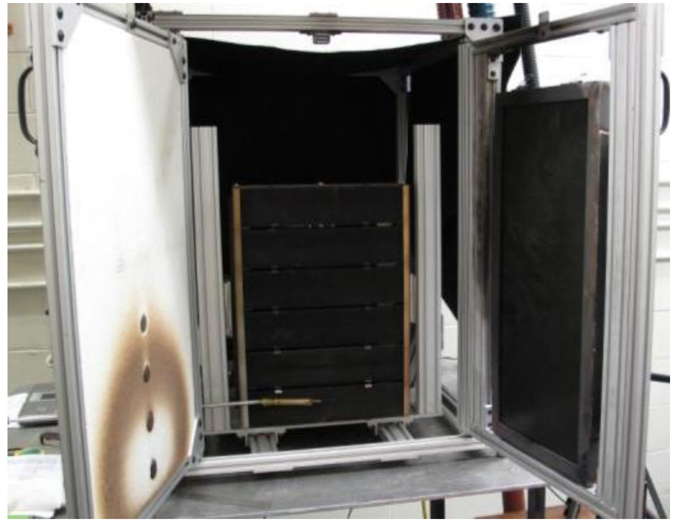


Iterative Test Method Development

Modified T/A Insulation RP

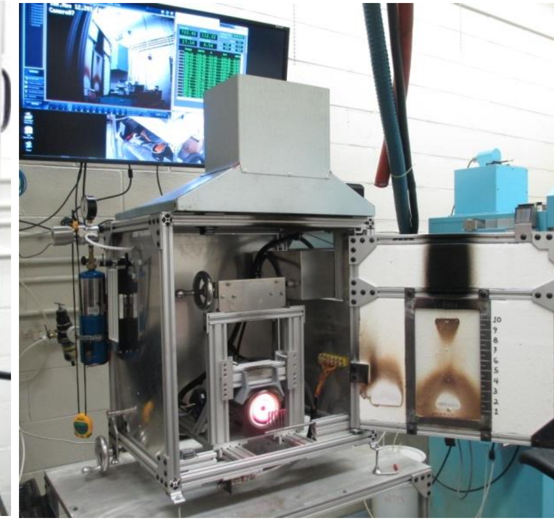
- Large sample size
- Sample parallel to RP in order to get more severe condition
- Pre-heat time required to correlate results to foam block

Vertical Radiant Panel



- Vertically mounted radiant panel heater identical to T/A panel
- Vertically mounted sample, 12" x 24"
- Same pilot torch from T/A test
- Pilot too severe, non-uniform in this orientation

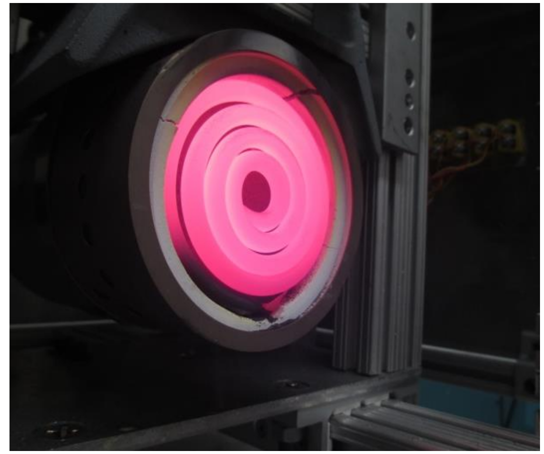
Vertical Radiant Furnace

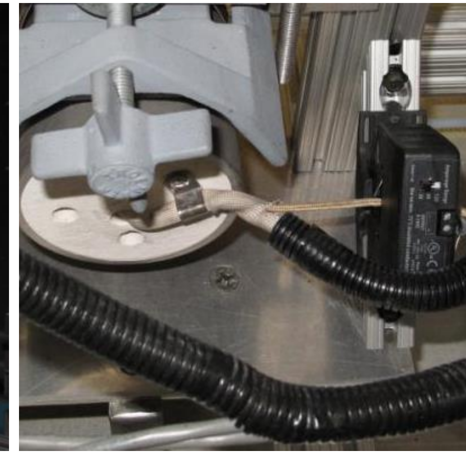


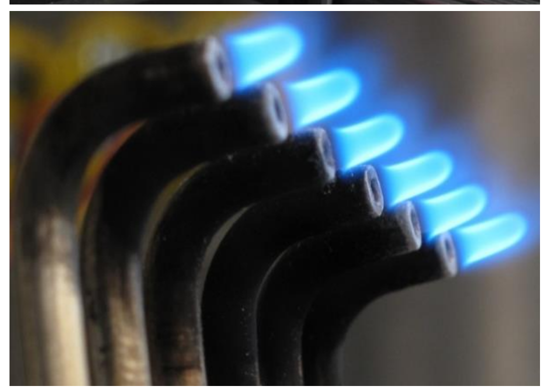
- Replaced radiant panel with modified NBS coil furnace
- Replaced pilot torch with uni-directional multi-flamelet pilot similar to NBS smoke chamber
- Replaced 4 HFG's with 4 K-type TC's
- Monitoring and control of furnace Voltage, Current
- Enclosed chamber, added hood
- Reduced sample size to 6" x 12"

Vertical Flame Propagation Test Apparatus

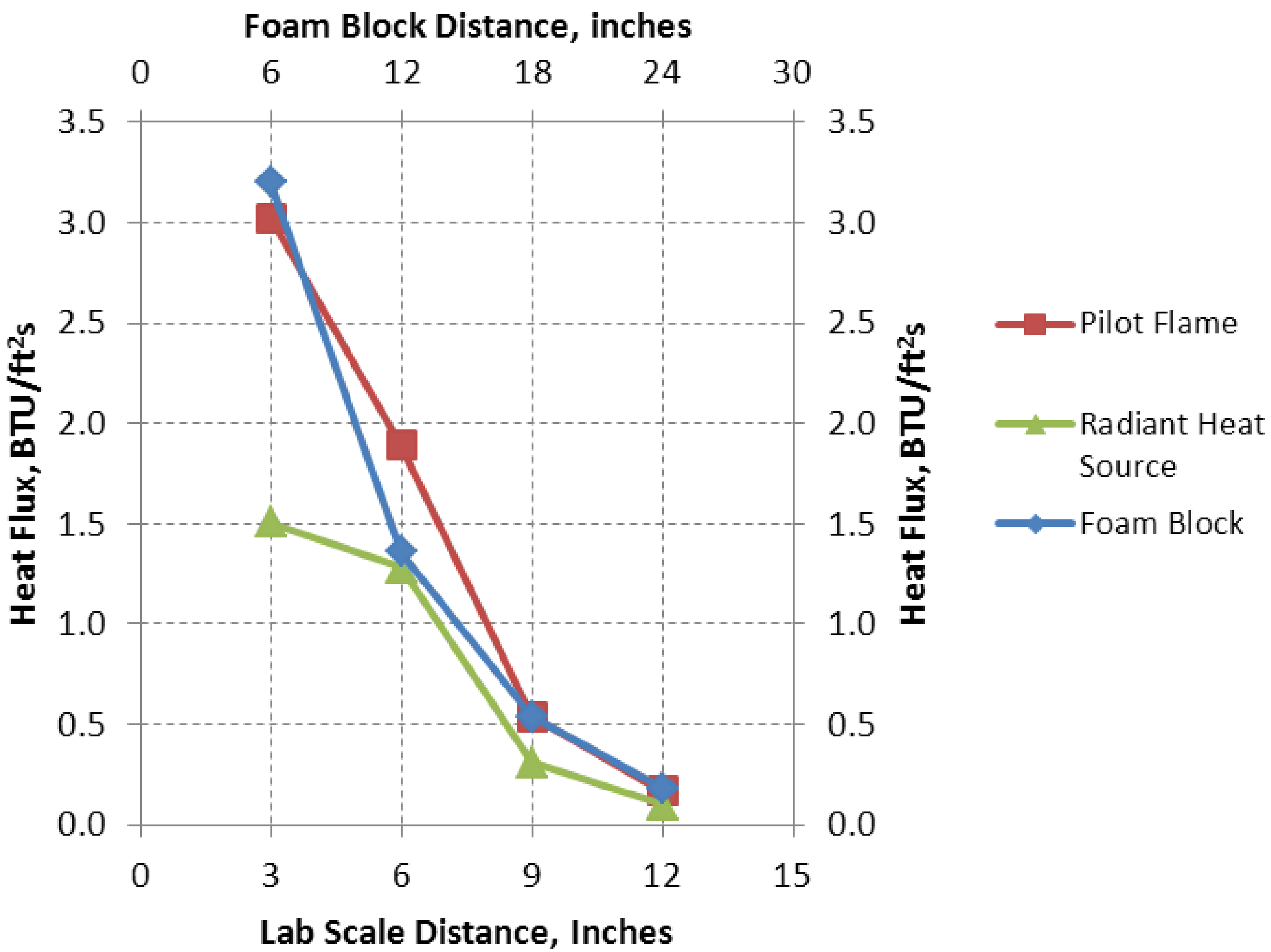
- Vertically-mounted coil furnace
  - 120V, 875W
  - Monitoring AC voltage and current, calculating input power, coil resistance
  - Adjust power with variable AC transformer
- Multi-flamelet pilot flame
  - Pre-mixed propane/air flame
  - Controlled with mixing type flowmeters

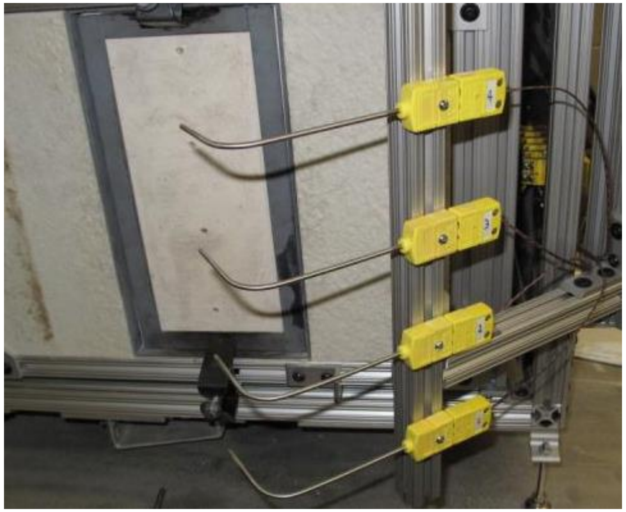


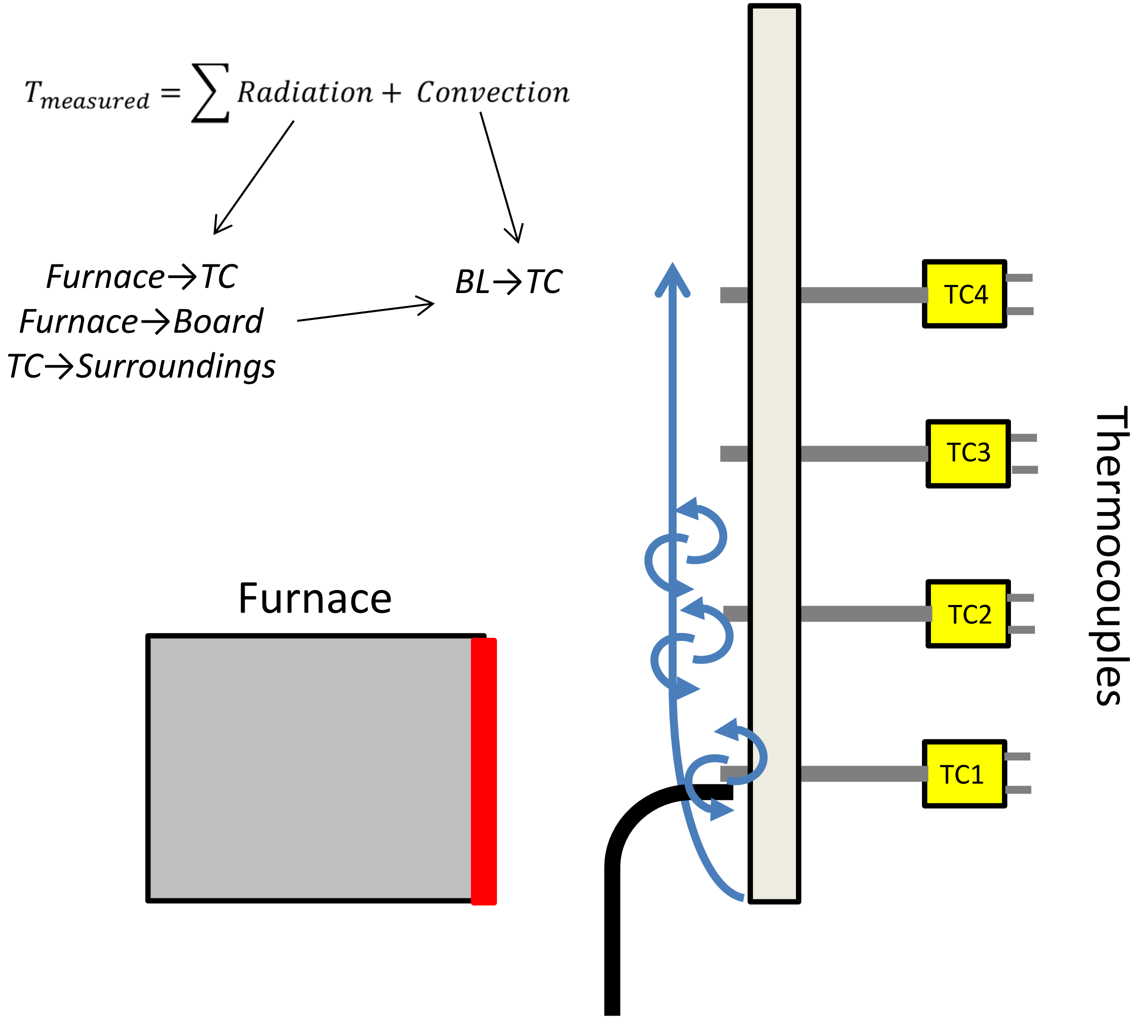




Measured Heat Flux: Foam Block vs. Lab Test



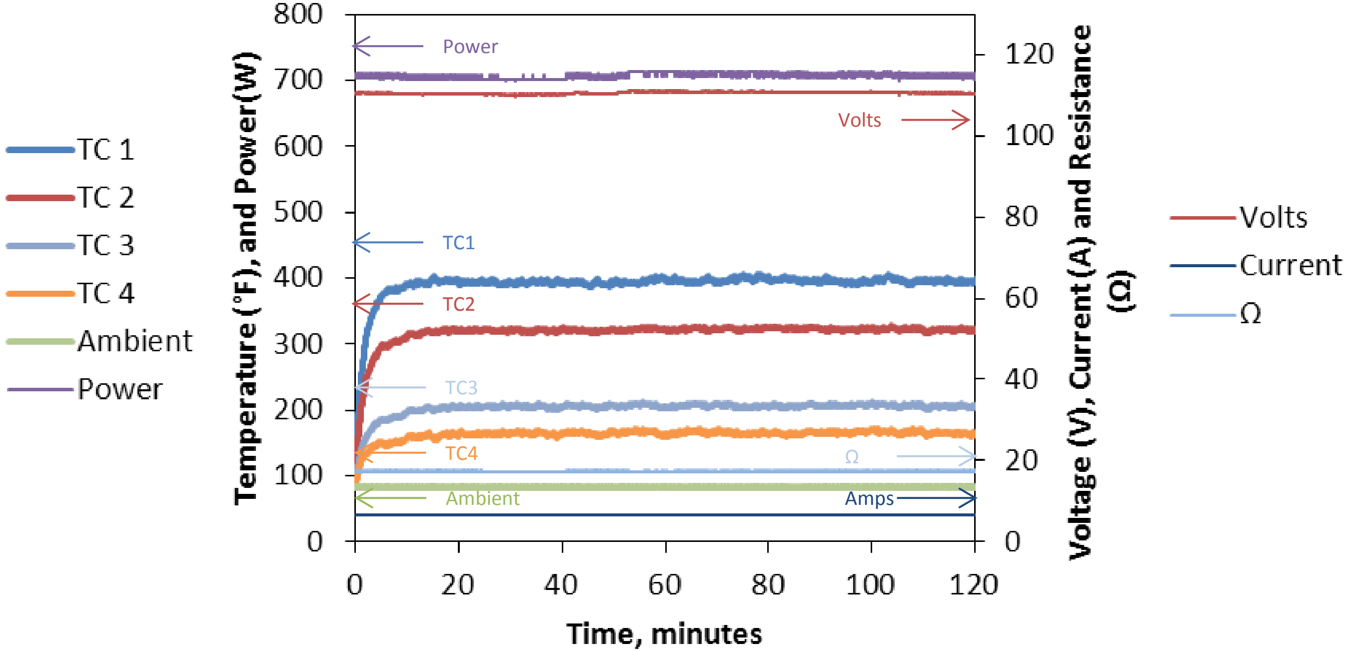




Ceramic Fiberboard
$T_{measured} = \sum Radiation + Convection$
Furnace→TC
Furnace→Board
TC→Surroundings
BL→TC
TC4
TC3
TC2
TC1
Thermocouples
Furnace
Pilot Burner

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



Ohm's Law

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

$$P = IV$$

*110 Volts * 6.42 Amps = 707 Watts*

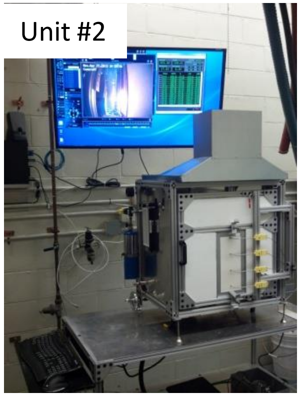
110 Volts / 6.42 Amps = 17.13 Ω

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

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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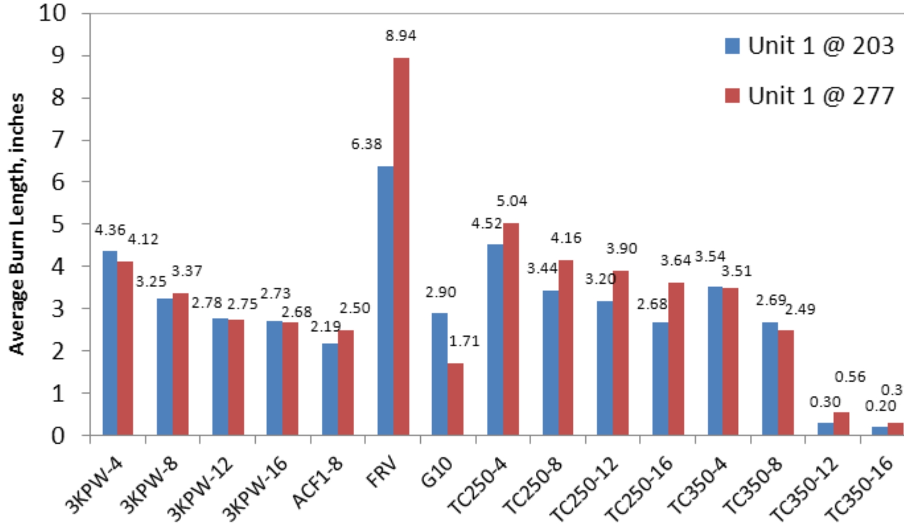
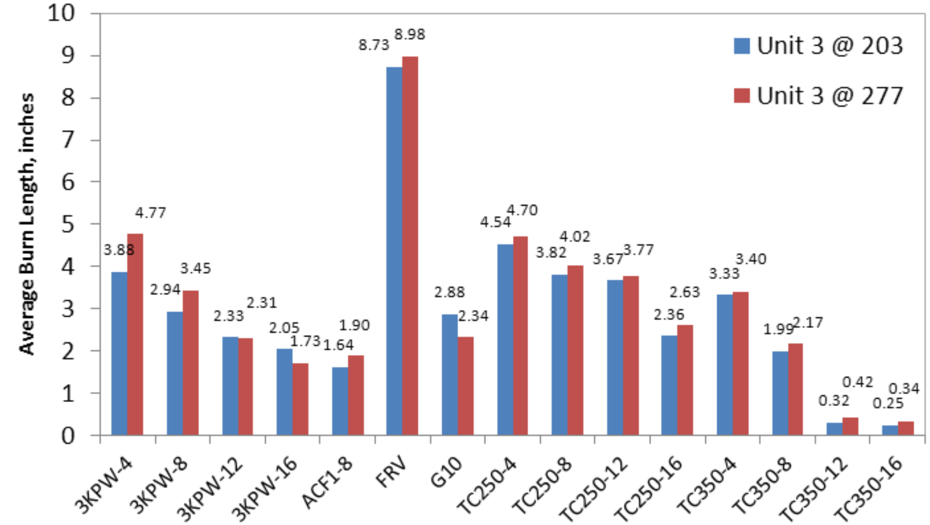
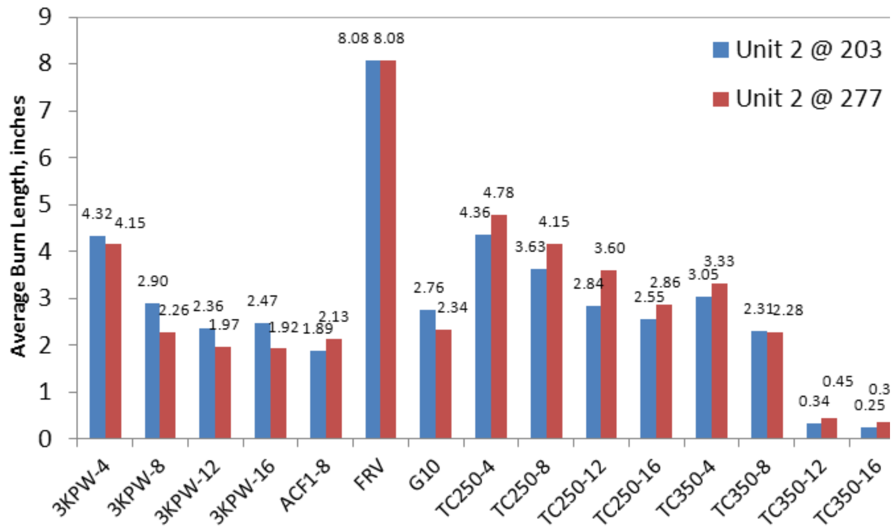
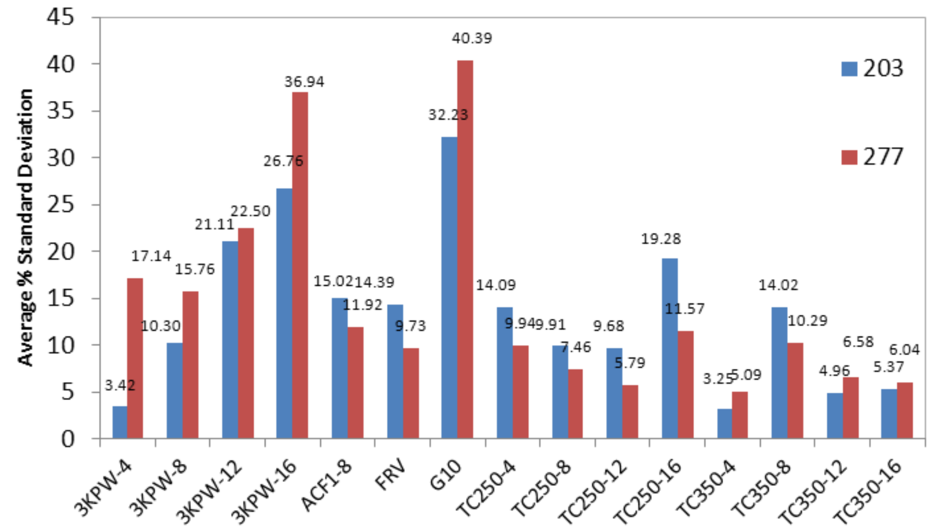
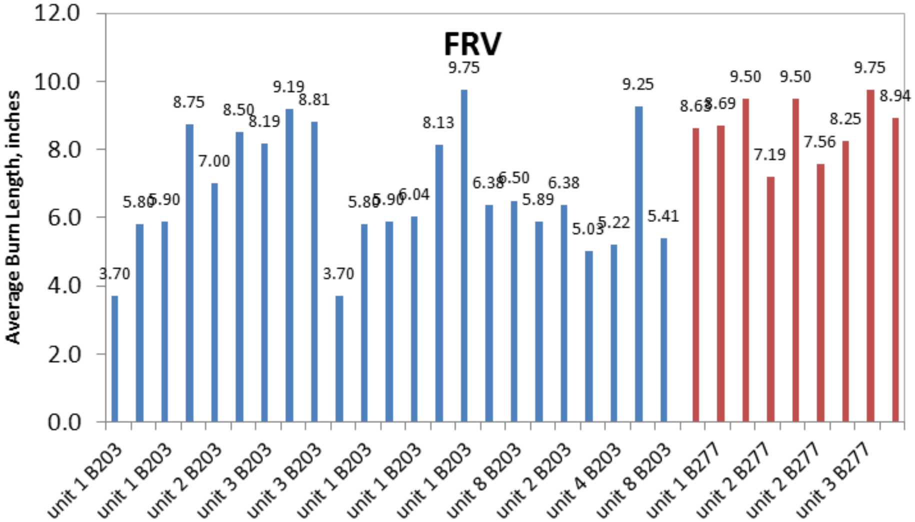
Overall Results

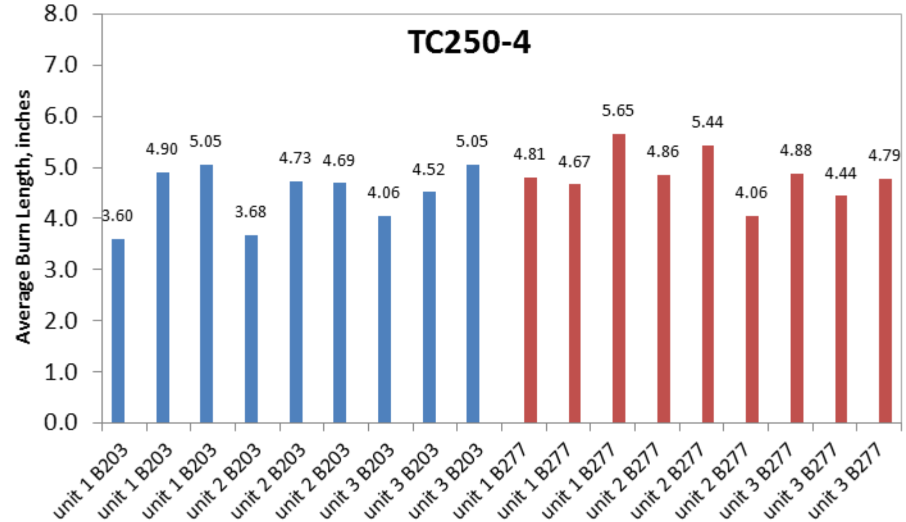


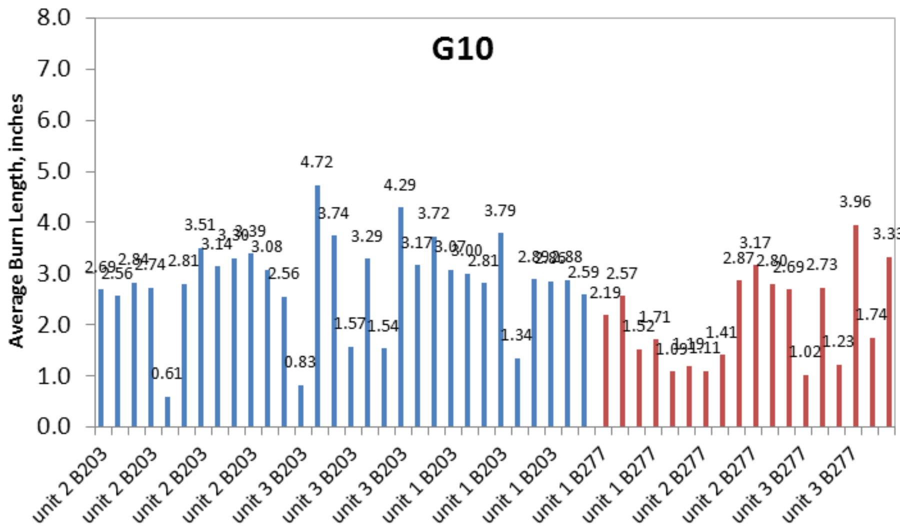







FRV
Average Burn Length, inches
0.0
2.0
4.0
6.0
8.0
10.0
12.0
3.70
5.80
5.90
8.75
7.00
8.50
8.19
9.19
8.81
3.70
5.80
5.90
6.04
8.13
9.75
6.38
6.50
5.89
6.38
5.03
5.22
9.25
5.41
8.63
8.69
9.50
7.19
9.50
7.56
8.25
9.75
8.94
unit 1 B203
unit 1 B203
unit 2 B203
unit 3 B203
unit 3 B203
unit 1 B203
unit 1 B203
unit 1 B203
unit 8 B203
unit 2 B203
unit 4 B203
unit 8 B203
unit 1 B277
unit 2 B277
unit 2 B277
unit 3 B277


TC250-4
Average Burn Length, inches
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
3.60
4.90
5.05
3.68
4.73
4.69
4.06
4.52
5.05
4.81
4.67
5.65
4.86
5.44
4.06
4.88
4.44
4.79
unit 1 B203
unit 1 B203
unit 1 B203
unit 2 B203
unit 2 B203
unit 2 B203
unit 3 B203
unit 3 B203
unit 3 B203
unit 1 B277
unit 1 B277
unit 1 B277
unit 2 B277
unit 2 B277
unit 2 B277
unit 3 B277
unit 3 B277
unit 3 B277


G10
Average Burn Length, inches
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
2.69
2.56
2.84
2.74
0.61
2.81
3.51
3.14
3.30
3.39
3.08
2.56
0.83
4.72
3.74
1.57
3.29
1.54
4.29
3.17
3.72
3.07
3.00
2.81
3.79
1.34
2.89
2.86
2.88
2.59
2.19
2.57
1.52
1.71
1.09
1.19
1.11
1.41
2.87
3.17
2.80
2.69
1.02
2.73
1.23
3.96
1.74
3.33
unit 2 B203
unit 2 B203
unit 2 B203
unit 2 B203
unit 3 B203
unit 3 B203
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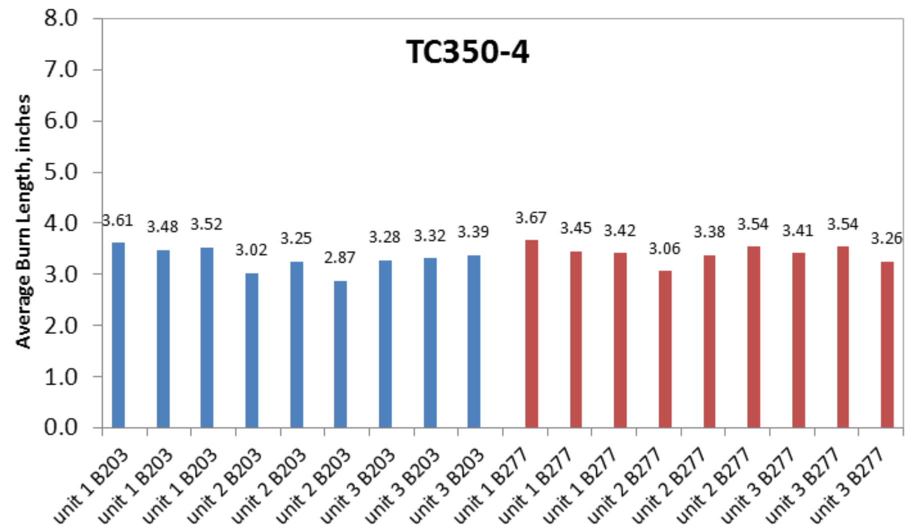
unit 3 B277
unit 3 B277


TC350-4
Average Burn Length, inches
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
3.61
3.48
3.52
3.02
3.25
2.87
3.28
3.32
3.39
3.67
3.45
3.42
3.06
3.38
3.54
3.41
3.54
3.26
unit 1 B203
unit 1 B203
unit 1 B203
unit 2 B203
unit 2 B203
unit 2 B203
unit 3 B203
unit 3 B203
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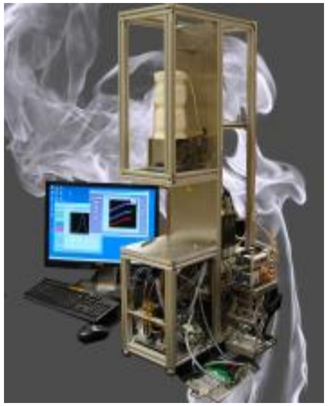
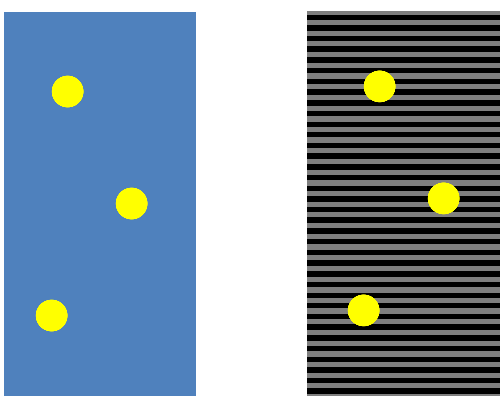


MCC and Cone Calorimeter Study: Evaluation of Repeatability of Material Properties

Property	% Standard Deviation		
	Glass Epoxy	ACF1	MCC
HRC (J/g-K)	6.99	7.58	3.2
PEAK HRR (W/g)	6.95	4.19	2.7
TOTAL HR (kJ/g)	3.91	3.98	1.4
T_P (°C)	0.46	0.92	<1

Property	% Standard Deviation		
	Glass Epoxy	ACF1	CC
PEAK HRR (kW/m²)	27.39	39.17	17
TOTAL HEAT RELEASE (MJ/m²)	14.07	19.00	8

Polymer Composite



- Good repeatability was found in the MCC (<10%)
  - Composite materials less repeatable than single component polymer materials used in repeatability study
- Cone calorimeter data shows more deviation
  - Conditions more representative of real material combustion

Test Method Summary

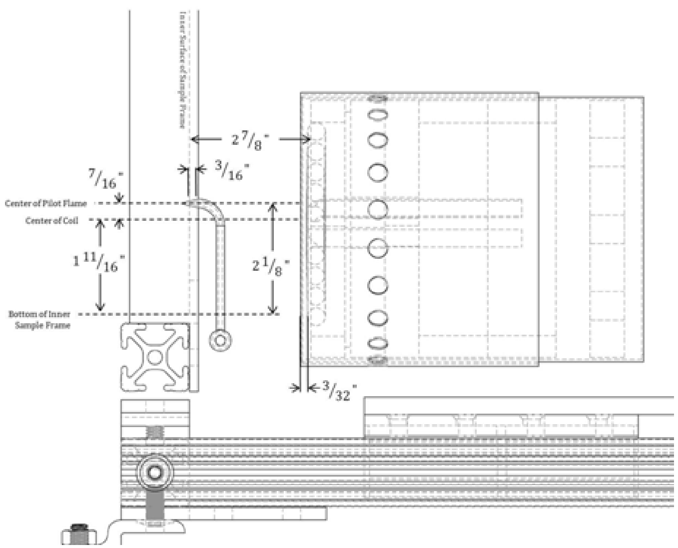
- A test method has been developed to assess the flame propagation potential of composite materials
- Three identical apparatuses have been constructed and tested in two different laboratories
- An overall reproducibility of about 20% was achieved in this study
- Two apparatuses will be shipped out to other labs to verify performance

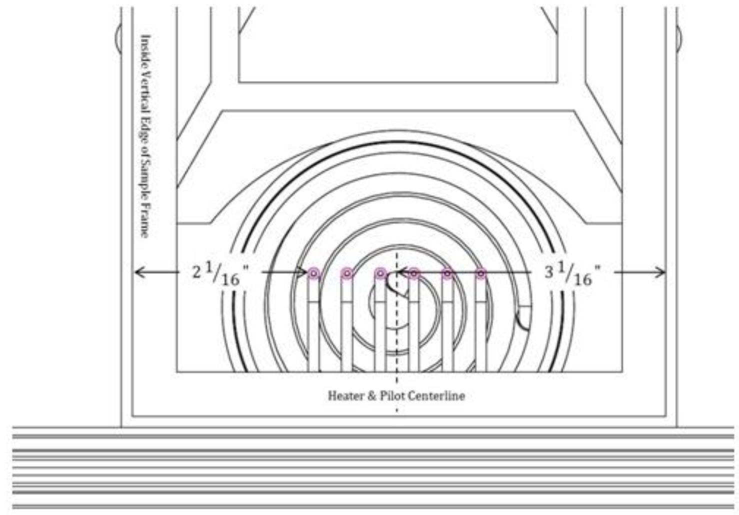
Draft Test Method Procedure

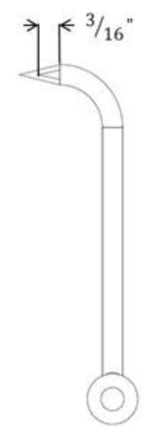
Draft Test Method Procedure: Composite Flame Propagation Test Method

Apparatus Dimension Check

1. Measure distance from heater to inner surface of sample holder
   a. Distance is 2 7/8" (73.025 mm)
2. Measure height from center of coil heater
   a. 1 11/16" (42.8625 mm)
3. Push pilot flame into test position
4. Ensure pilot flame is centered laterally on sample frame
   a. Distance from outer surface of end flamelet tube to inner surface of sample frame is 2 1/16" (52.3875 mm)
5. Measure height of center of pilot flame opening
   a. Height is 2 1/8" from center of flamelet tube to bottom inner surface of sample frame
6. Ignite pilot flame
7. Set air pressure to 40 psig and propane gas pressure to 15 psig
8. Set gas to approx. 25/50 ccm gas/air mixture
9. Measure flamelet length
   a. Use ruler or calipers to measure length of inner blue cone of flamelet
   b. Flamelet length should be 3/16" long
   c. Adjust gas/air flow rates to achieve proper flamelet length







Draft Test Method Procedure

Pre-Heat Procedure

1. Switch on AC voltage
2. Begin data collection
3. Adjust AC voltage to achieve 706 Watts over 5 minute average
4. Ensure exhaust fan that will run during testing is on
5. Allow chamber to stabilize for 20 minutes, or when the rate of change of measured temperature of the 4 thermocouples to within <5%
6. Once the chamber has stabilized, place the vane anemometer holder over the exhaust stack
7. Record the average flow velocity through the anemometer
    a. Typical flow rates achieved are around 125 ± 5 fpm with a stable chamber and exhaust fan on

Test Procedure

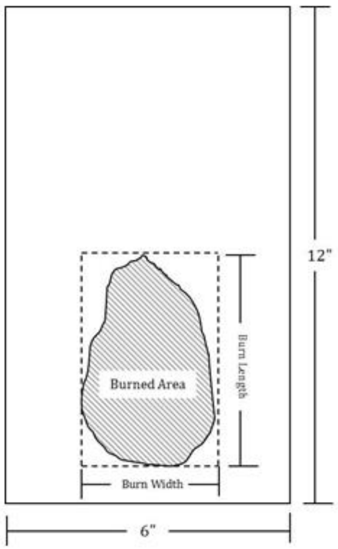
1. Condition test samples at 70°F, 50% humidity for at least 24 hours before testing
2. Swing away thermocouple arm, lock in place in standby position
3. Open sample door
4. Initiate flow of premixed propane/air mixture to pilot burner
5. Ignite pilot burner with handheld lighter
6. Push out ceramic TC board in sample rig
7. Place test sample in sample frame with tested face facing the radiant heater
8. Secure test sample with outer retainer ring and spring clamps
9. Push pilot burner in to test position
10. Reset stopwatch to zero and prepare to start timing upon door closing
11. Close door, begin stopwatch count
12. At 50 seconds, pull pilot flame away from sample to standby position
13. Monitor sample flame propagation via monitor
14. Stop timer when all flaming on sample surface ceases
15. Record after-flame time as time at extinguishment minus flame impingement time
16. Open door, remove sample and place under fume hood until off gassing ceases
17. If continuing to test, place next sample in sample frame and repeat, OR
18. If testing is complete, place ceramic TC board back in sample frame, replace outer retainer ring and clamp in to place
19. Close door, swing TC arm back into calibration position

Burn Length Measurement Procedure

1. Wait until sample has cooled to the touch and is no longer off gassing
2. Use mild detergent cleaner and a cloth to wipe away sooted areas of the sample face
3. Burn length measurement:
    a. Determine the boundaries of the burned area
        i. For the purposes of this test method, burn areas are considered to be areas where the outermost layer of the material has been burned away, breached, or opened, indicating that volatiles have escaped the material at that location and could have been ignited
        ii. Sooted or discolored areas are not considered part of the burned area
        iii. Draw lines parallel to the horizontal (6" dimension) edges of the sample that include the extent of the burned length
        iv. Draw lines parallel to the vertical (12" dimension) edges of the sample that include the extent of the burned width
        v. Measure the length and width of this rectangle
        vi. The burned length is the vertical dimension of the rectangle
        vii. The burned width is the horizontal dimension of the rectangle

Test Reporting

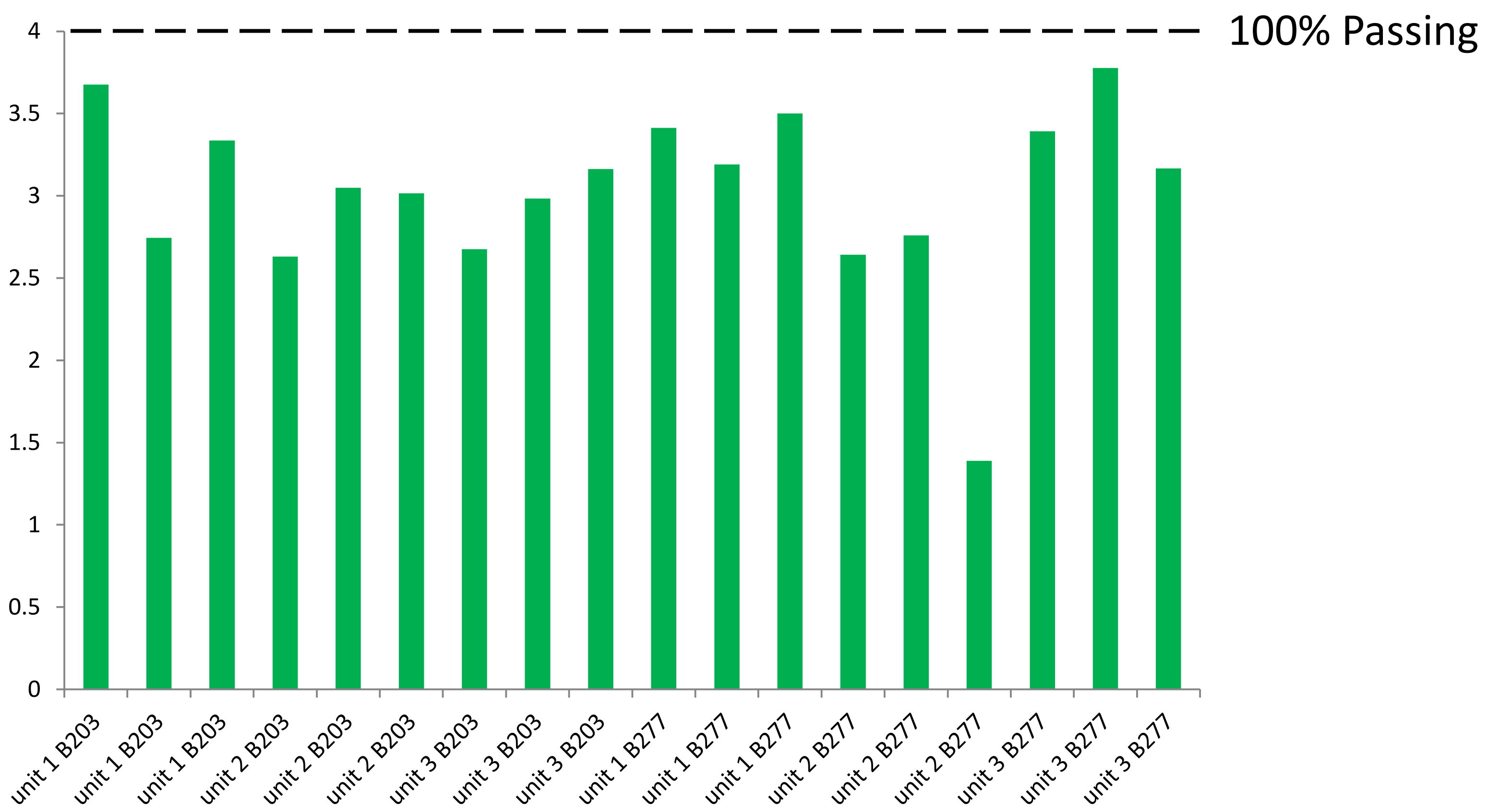
1. Record the burn length, burn width, and after flame time



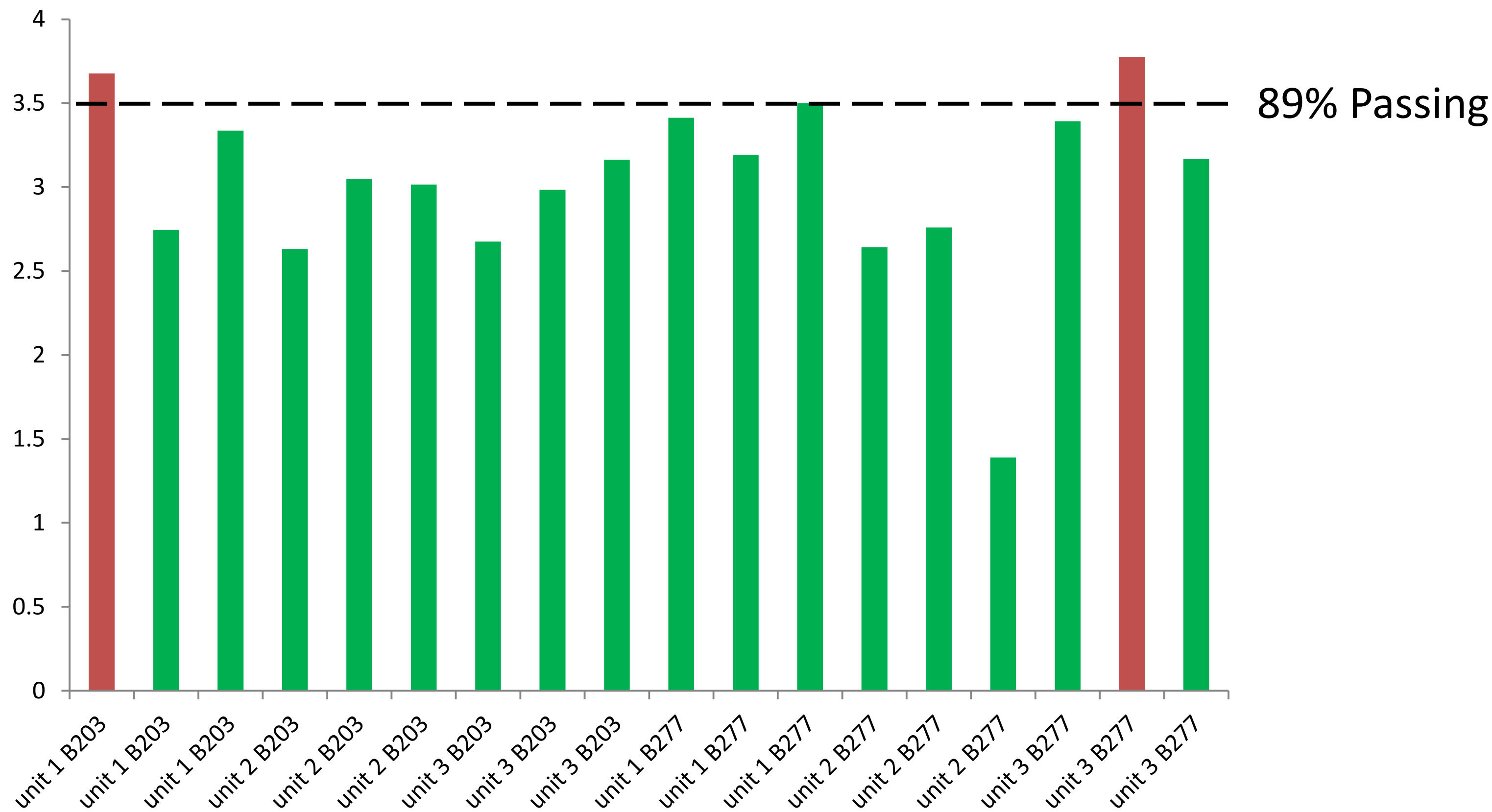
Minimum 80% Passing Samples

Samples Tested	3	5	10	15	20	25	30	35	40	45	50
# Must Pass	3	4	8	12	16	20	24	28	32	36	40
Max Failures Allowable	0	1	2	3	4	5	6	7	8	9	10
% Pass	100%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%
% Fail	0%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
Total %	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

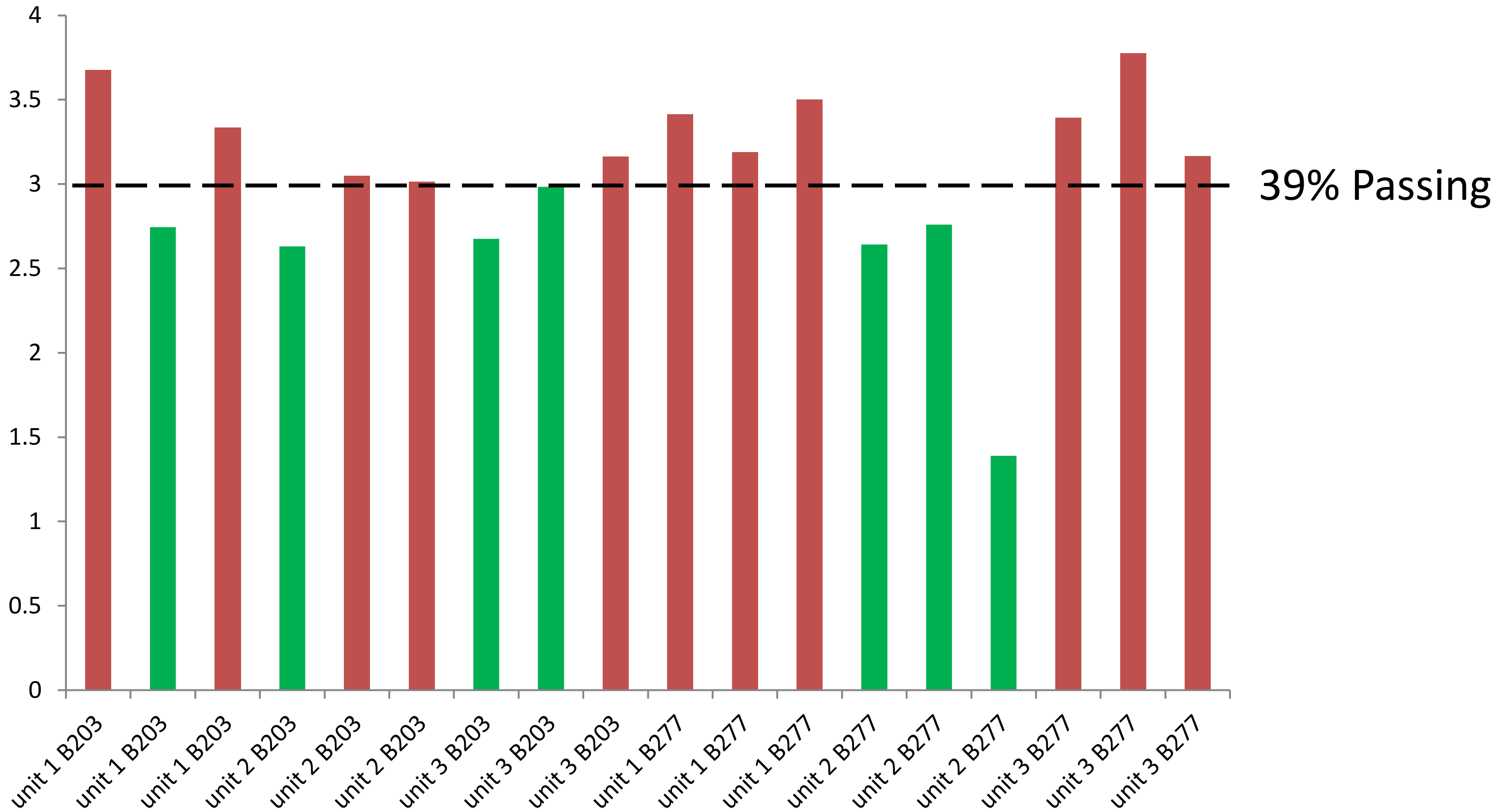
3KPW-8 PLY
4-inch Pass/Fail



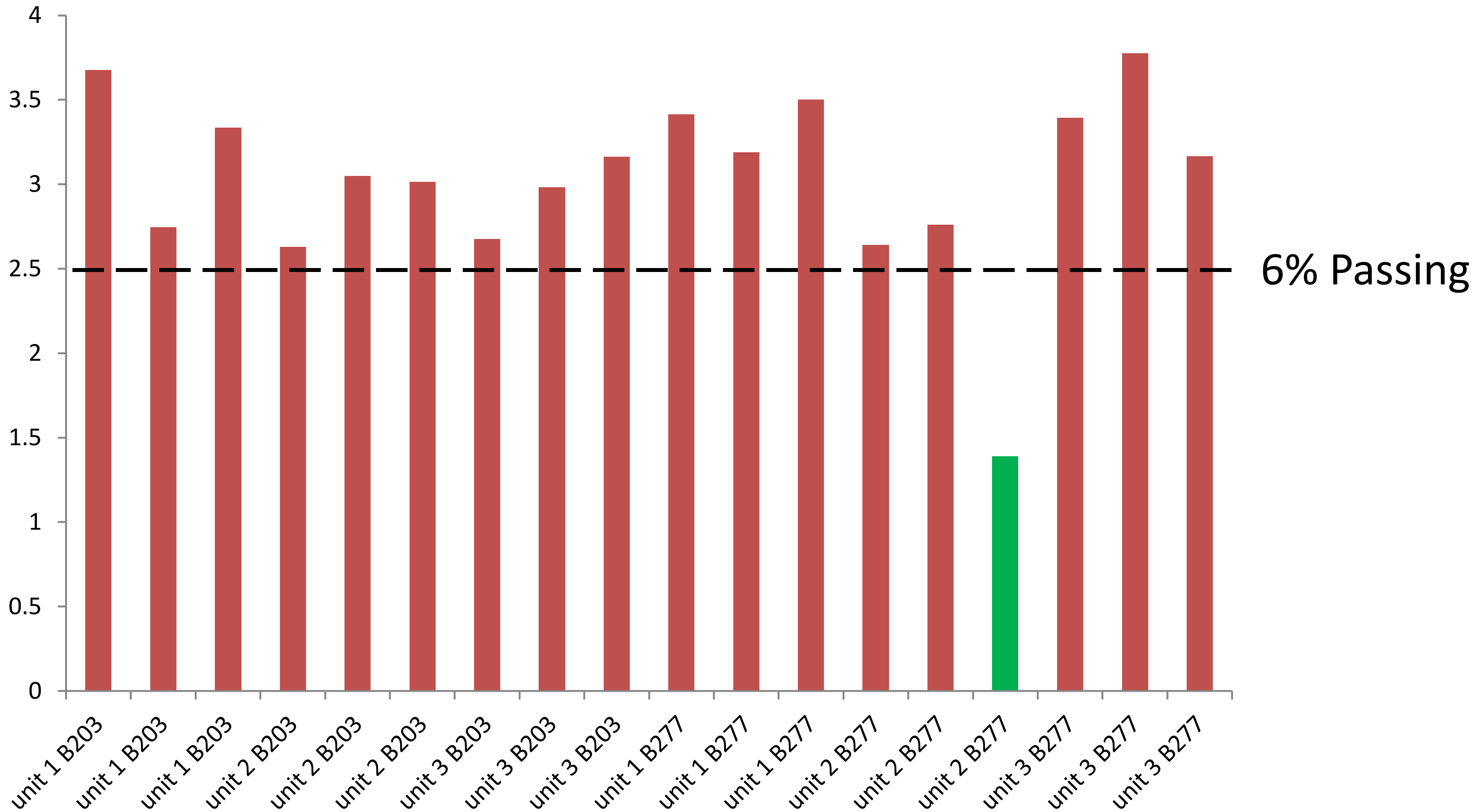
3KPW-8 PLY
3.5-inch Pass/Fail



3KPW-8 PLY
3-inch Pass/Fail



3KPW-8 PLY
2.5-inch Pass/Fail



Varying Pass/Fail Criteria
Overall Pass/Fail for Entire Data Set

		Pass Fail Line, inches (Greater than PFL is a failure)						
	Material	2	2.5	3	3.5	4	4.5	5
Woven CF	3KPW-4	Fail	Fail	Fail	Fail	Fail	Pass	Pass
	3KPW-8	Fail	Fail	Fail	Pass	Pass	Pass	Pass
	3KPW-12	Fail	Fail	Fail	Pass	Pass	Pass	Pass
	3KPW-16	Fail	Fail	Fail	Pass	Pass	Pass	Pass
	ACF1-8	Fail	Pass	Pass	Pass	Pass	Pass	Pass
	FRV	Fail	Fail	Fail	Fail	Fail	Fail	Fail
	G10	Fail	Fail	Fail	Pass	Pass	Pass	Pass
Uni-Directional 250-cure epoxy	TC250-4	Fail	Fail	Fail	Fail	Fail	Fail	Fail
	TC250-8	Fail	Fail	Fail	Fail	Fail	Pass	Pass
	TC250-12	Fail	Fail	Fail	Fail	Pass	Pass	Pass
	TC250-16	Fail	Fail	Fail	Pass	Pass	Pass	Pass
Uni-Directional 350-cure epoxy	TC350-4	Fail	Fail	Fail	Fail	Pass	Pass	Pass
	TC350-8	Fail	Fail	Pass	Pass	Pass	Pass	Pass
	TC350-12	Pass	Pass	Pass	Pass	Pass	Pass	Pass
	TC350-16	Pass	Pass	Pass	Pass	Pass	Pass	Pass

Varying Pass/Fail Criteria
Overall Pass/Fail for Entire Data Set

		Pass Fail Line, inches (Greater than PFL is a failure)						
Foam Block Burn Lengths	Material	2	2.5	3	3.5	4	4.5	5
	3KPW-4	Fail	Fail	Fail	Fail	Fail	Pass	Pass
	3KPW-8	Fail	Fail	Fail	Pass	Pass	Pass	Pass
	3KPW-12	Fail	Fail	Fail	Pass	Pass	Pass	Pass
	3KPW-16	Fail	Fail	Fail	Pass	Pass	Pass	Pass
21.25"	ACF1-8	Fail	Pass	Pass	Pass	Pass	Pass	Pass
44"	FRV	Fail	Fail	Fail	Fail	Fail	Fail	Fail
16.5"	G10	Fail	Fail	Fail	Pass	Pass	Pass	Pass
	TC250-4	Fail	Fail	Fail	Fail	Fail	Fail	Fail
	TC250-8	Fail	Fail	Fail	Fail	Fail	Pass	Pass
	TC250-12	Fail	Fail	Fail	Fail	Pass	Pass	Pass
	TC250-16	Fail	Fail	Fail	Pass	Pass	Pass	Pass
	TC350-4	Fail	Fail	Fail	Fail	Pass	Pass	Pass
	TC350-8	Fail	Fail	Pass	Pass	Pass	Pass	Pass
	TC350-12	Pass	Pass	Pass	Pass	Pass	Pass	Pass
	TC350-16	Pass	Pass	Pass	Pass	Pass	Pass	Pass

Pass / Fail on each apparatus at 2 labs

	Overall Average			Unit 1 203			Unit 1 277			Unit 2 203			Unit 2 277			Unit 3 203			Unit 3 277		
Material	Avg B.L.	% Pass	P/F	Avg B.L.	% Pass	P/F	Avg B.L.	% Pass	P/F	Avg B.L.	% Pass	P/F	Avg B.L.	% Pass	P/F	Avg B.L.	% Pass	P/F	Avg B.L.	% Pass	P/F
3KPW-4	4.27	6%	Fail	4.36	0%	Fail	4.12	33%	Fail	4.32	0%	Fail	4.15	0%	Fail	3.88	0%	Fail	4.77	0%	Fail
3KPW-8	3.03	89%	Pass	3.25	67%	Fail	3.37	100%	Pass	2.90	100%	Pass	2.26	100%	Pass	2.94	100%	Pass	3.45	67%	Fail
3KPW-12	2.42	100%	Pass	2.78	100%	Pass	2.75	100%	Pass	2.36	100%	Pass	1.97	100%	Pass	2.33	100%	Pass	2.31	100%	Pass
3KPW-16	2.26	96%	Pass	2.73	90%	Pass	2.68	100%	Pass	2.47	100%	Pass	1.92	100%	Pass	2.05	100%	Pass	1.73	100%	Pass
ACF1-8	2.04	100%	Pass	2.19	86%	Pass	2.50	100%	Pass	1.89	100%	Pass	2.13	100%	Pass	1.64	100%	Pass	1.90	100%	Pass
FRV	8.20	0%	Fail	6.38	0%	Fail	8.94	0%	Fail	8.08	0%	Fail	8.08	0%	Fail	8.73	0%	Fail	8.98	0%	Fail
G10	2.49	85%	Pass	2.90	80%	Pass	1.71	100%	Pass	2.76	90%	Pass	2.34	100%	Pass	2.88	70%	Fail	2.34	83%	Pass
TC250-4	4.66	0%	Fail	4.52	0%	Fail	5.04	0%	Fail	4.36	0%	Fail	4.78	0%	Fail	4.54	0%	Fail	4.70	0%	Fail
TC250-8	3.87	22%	Fail	3.44	67%	Fail	4.16	0%	Fail	3.63	33%	Fail	4.15	0%	Fail	3.82	33%	Fail	4.02	0%	Fail
TC250-12	3.50	33%	Fail	3.20	100%	Pass	3.90	0%	Fail	2.84	67%	Fail	3.60	33%	Fail	3.67	0%	Fail	3.77	0%	Fail
TC250-16	2.79	94%	Pass	2.68	100%	Pass	3.64	67%	Fail	2.55	100%	Pass	2.86	100%	Pass	2.36	100%	Pass	2.63	100%	Pass
TC350-4	3.36	72%	Fail	3.54	33%	Fail	3.51	67%	Fail	3.05	100%	Pass	3.33	67%	Fail	3.33	100%	Pass	3.40	67%	Fail
TC350-8	2.32	100%	Pass	2.69	100%	Pass	2.49	100%	Pass	2.31	100%	Pass	2.28	100%	Pass	1.99	100%	Pass	2.17	100%	Pass
TC350-12	0.40	100%	Pass	0.30	100%	Pass	0.56	100%	Pass	0.34	100%	Pass	0.45	100%	Pass	0.32	100%	Pass	0.42	100%	Pass
TC350-16	0.28	100%	Pass	0.20	100%	Pass	0.31	100%	Pass	0.25	100%	Pass	0.36	100%	Pass	0.25	100%	Pass	0.34	100%	Pass

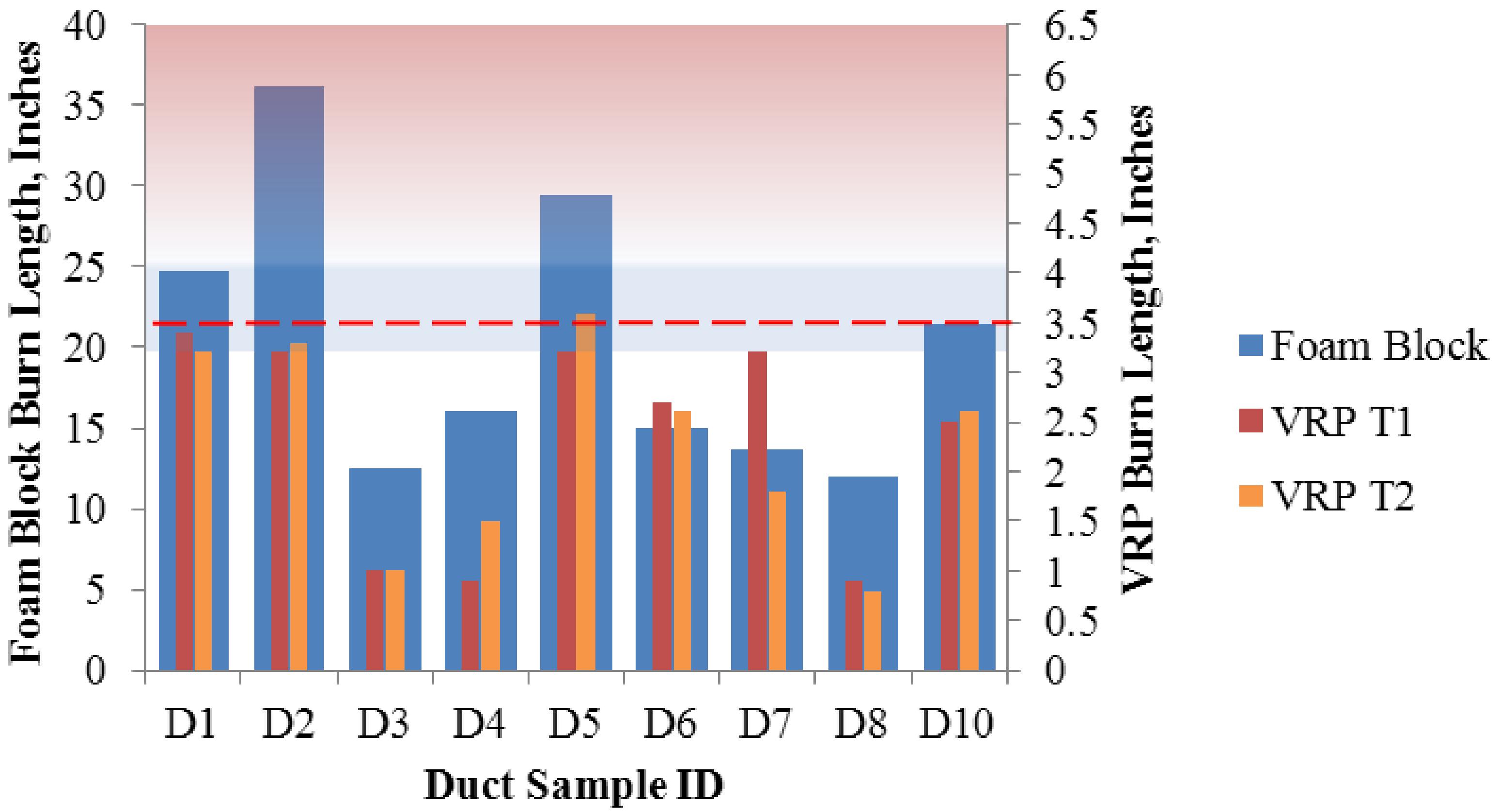
Ducts

Cut from duct, flattened

Cut from duct, not flattened

Intact Hoses

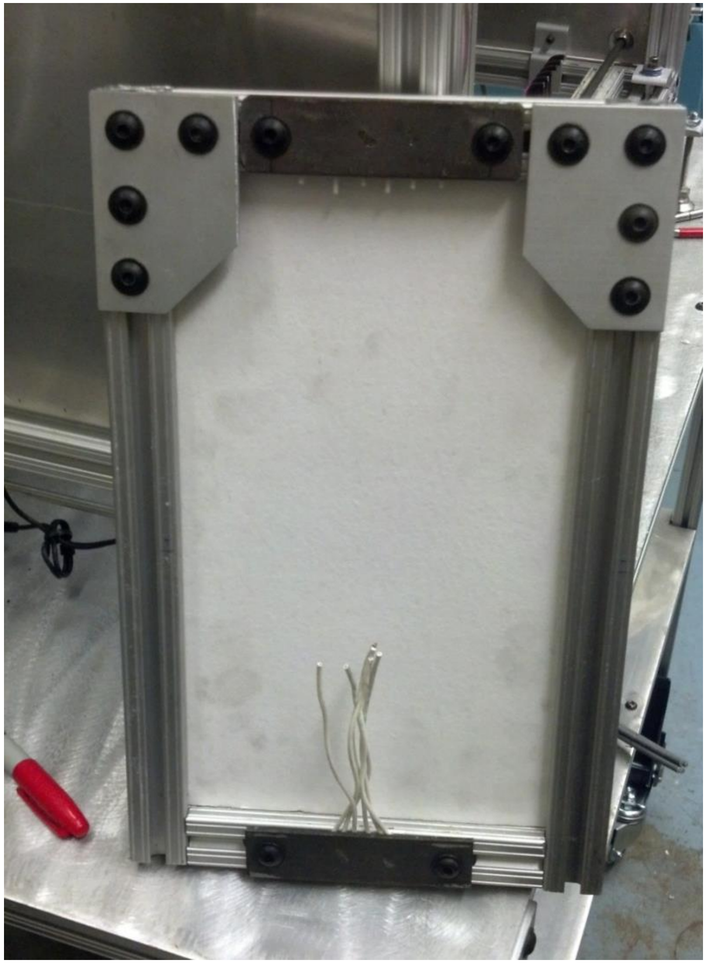
Duct Materials – Flat Sheets



Wire Insulation Study on Composite Rig

Front

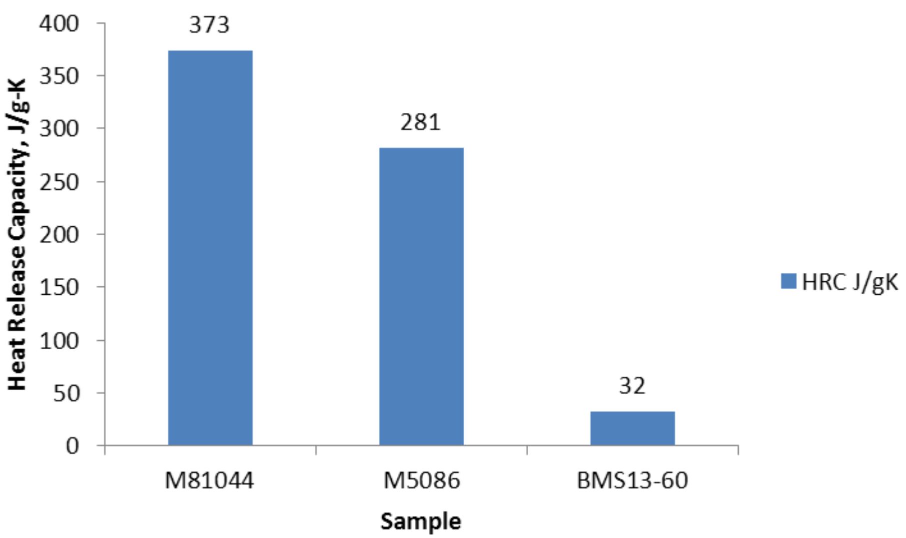
Back



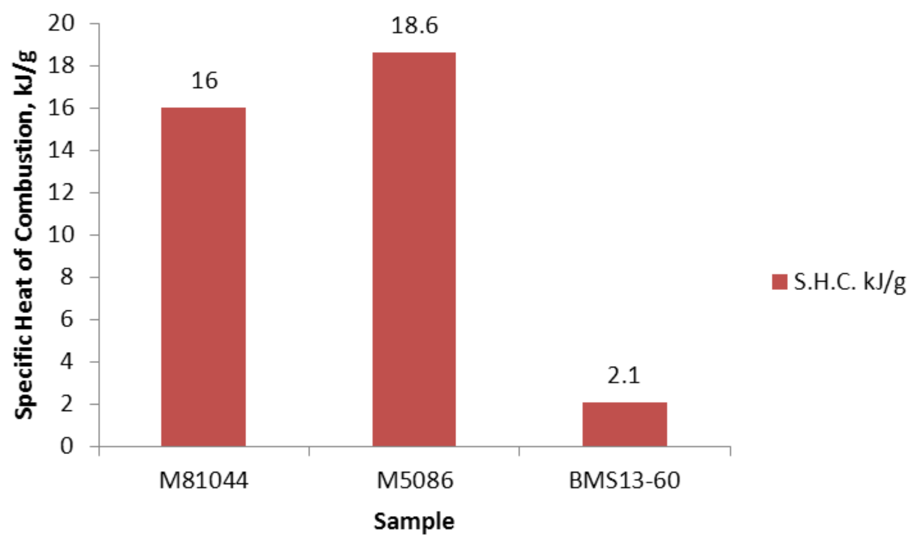
MCC Data – from DOT/FAA/AR-10/2

"Development of an Improved Fire Test Method and Criteria for Aircraft Electrical Wiring"

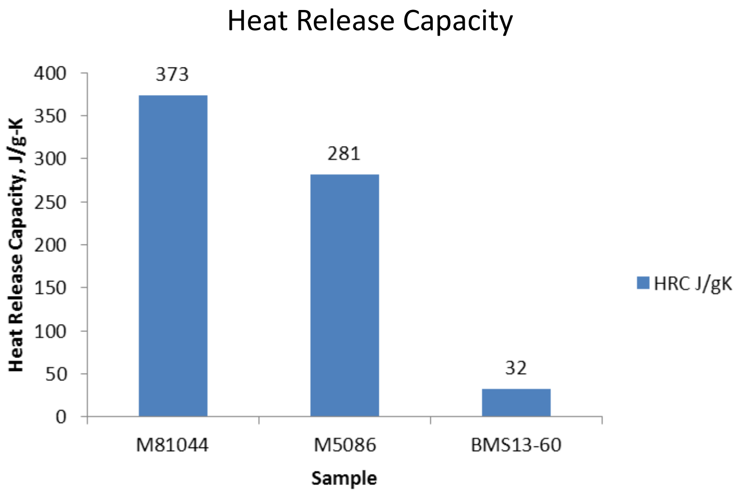
Heat Release Capacity

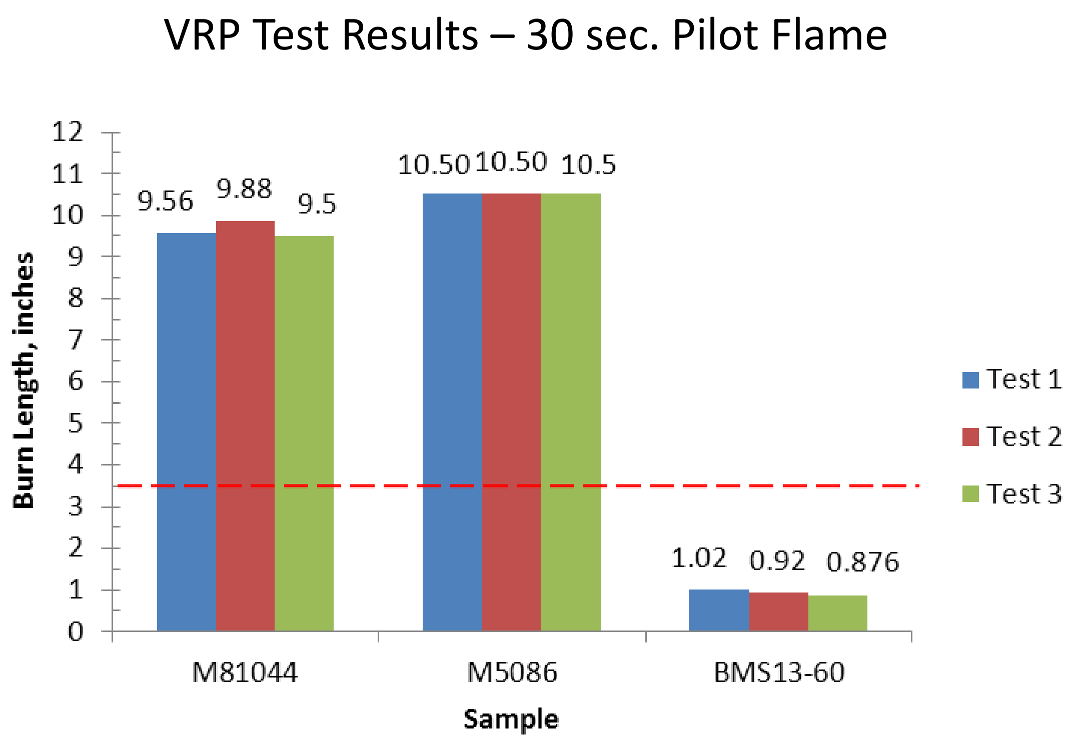


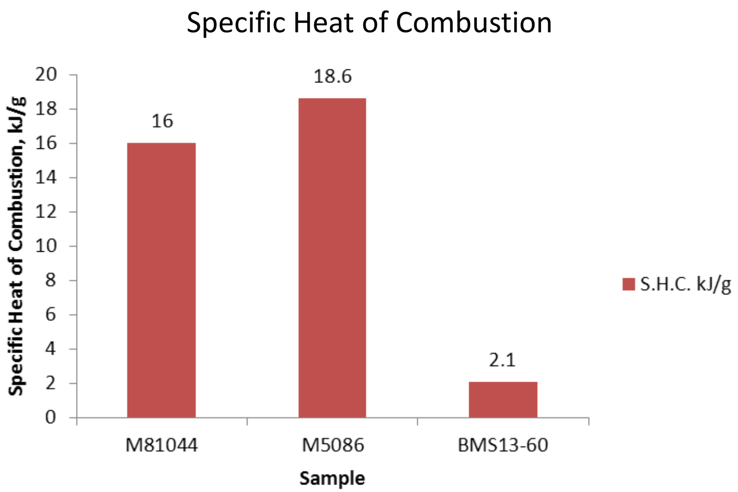
Specific Heat of Combustion



Identifier	Composition
M81044	X-linked Polyalkene
M5086	PVC/Nylon
BMS13-60	PTFE/Polyimide


Heat Release Capacity
Heat Release Capacity, J/g-K
400
350
300
250
200
150
100
50
0
373
281
32
M81044
M5086
BMS13-60
Sample
HRC J/gK


VRP Test Results – 30 sec. Pilot Flame
Burn Length, inches
12
11
10
9
8
7
6
5
4
3
2
1
0
9.56
9.88
9.5
10.50
10.50
10.5
1.02
0.92
0.876
M81044
M5086
BMS13-60
Sample
Test 1
Test 2
Test 3


Specific Heat of Combustion
Specific Heat of Combustion, kJ/g
20
18
16
14
12
10
8
6
4
2
0
16
18.6
2.1
M81044
M5086
BMS13-60
Sample
S.H.C. kJ/g

Current Status

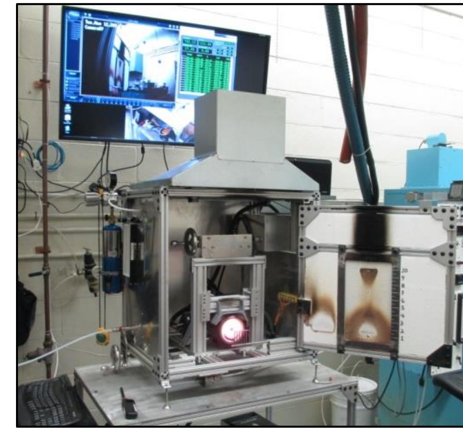
- Ducts
  - Have:
    - Method for testing flat sheets of duct material
    - Method for installing actual hoses or ducts in test rig
  - Need:
    - Suggestions for other hoses/ducts that could not be tested in the above manner
    - More duct materials

- Wires
  - Have:
    - Method for testing individual wires of gauge less than X gauge
    - Bundles will not be tested. Individual wires will be tested and can be used in bundles
  - Need:
    - Suggestions for other wire configurations that can not be tested in this manner
    - More wire samples

Flame Propagation Test Method Development: Summary

- Testing of ducting and wire insulation seems feasible in this apparatus
- Testing of various configurations will need to be discussed in IAMFTWG task groups
- Task group members can help with correlating performance in this apparatus to other test methods
  - VBB
  - Radiant Panel
  - Intermediate scale crown section tests
- Harmonization of test method / apparatus for all inaccessible area materials (besides T/A insulation) could greatly simplify certification testing
- Application of test method to actual installations will depend on wording of future rule
  - Small parts definition
  - Approved materials database
  - Test method hierarchy



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Federal Aviation Administration