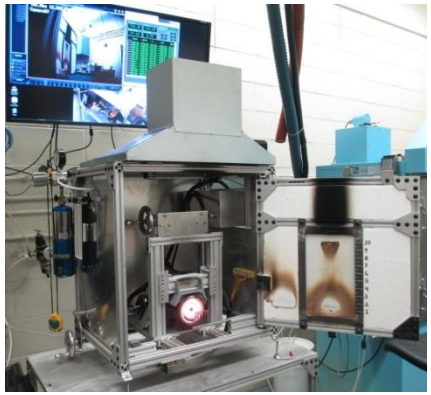
Development of a Flame Propagation Test Apparatus for Inaccessible Area Materials

Federal Aviation Administration





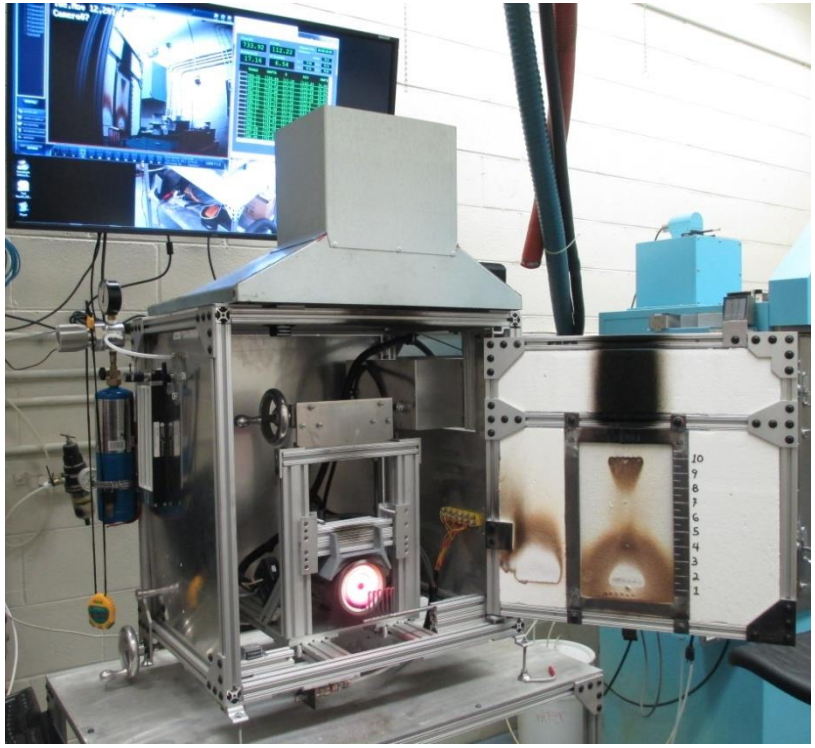
Presented to: IAMFTWG
By: Robert I. Ochs
Date: October 27-28, 2014, Atlantic City, NJ

Introduction

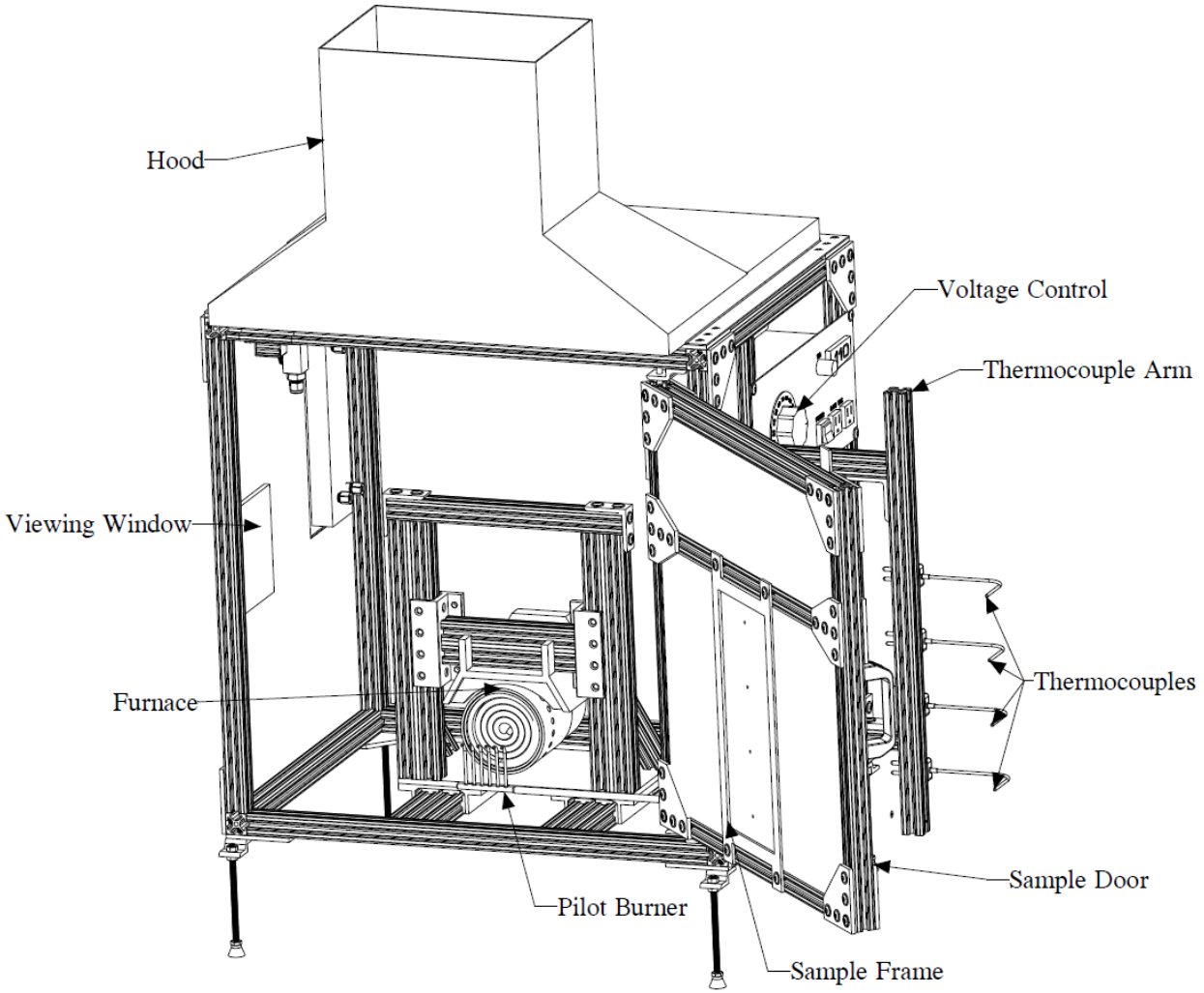
- Carbon fiber composites are being used more frequently in aerospace applications
  - Increased strength
  - Lower density
  - Better corrosion resistance
- New designs of commercial transport airplanes include primary and secondary structure constructed from carbon fiber composites
- Current FAR's 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

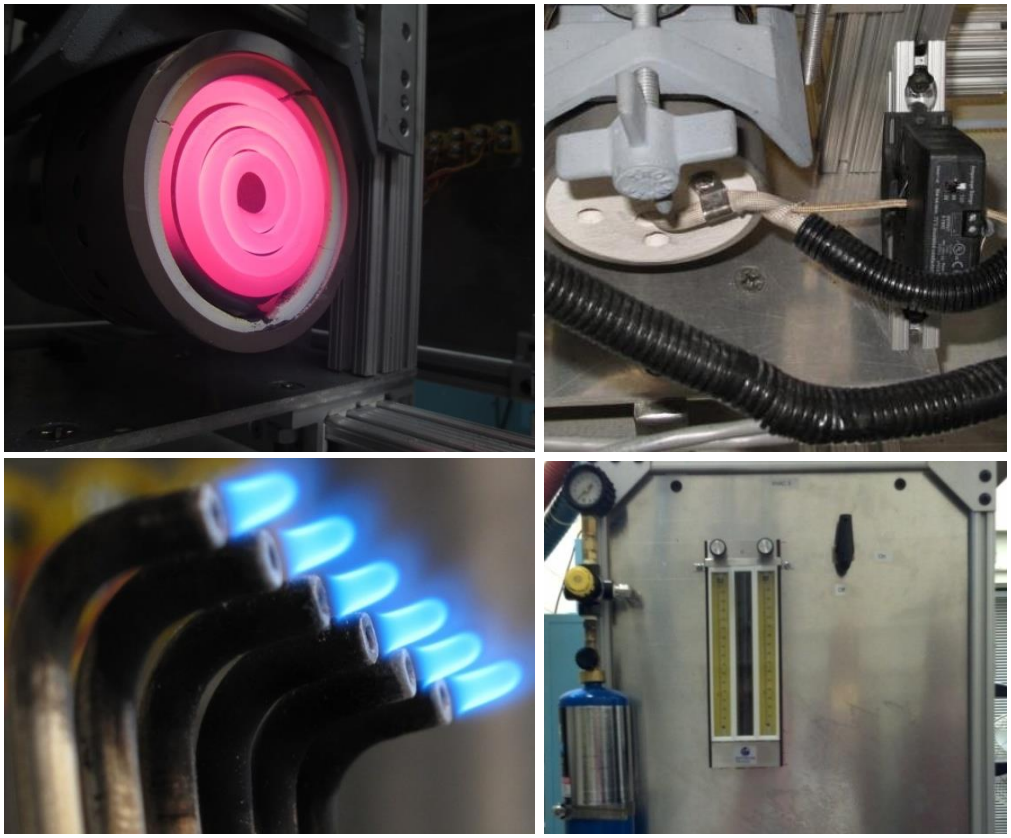


Vertical Flame Propagation Test Apparatus



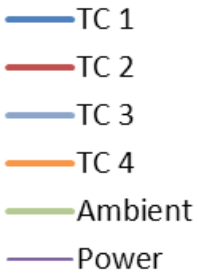
Vertical Flame Propagation Test Apparatus

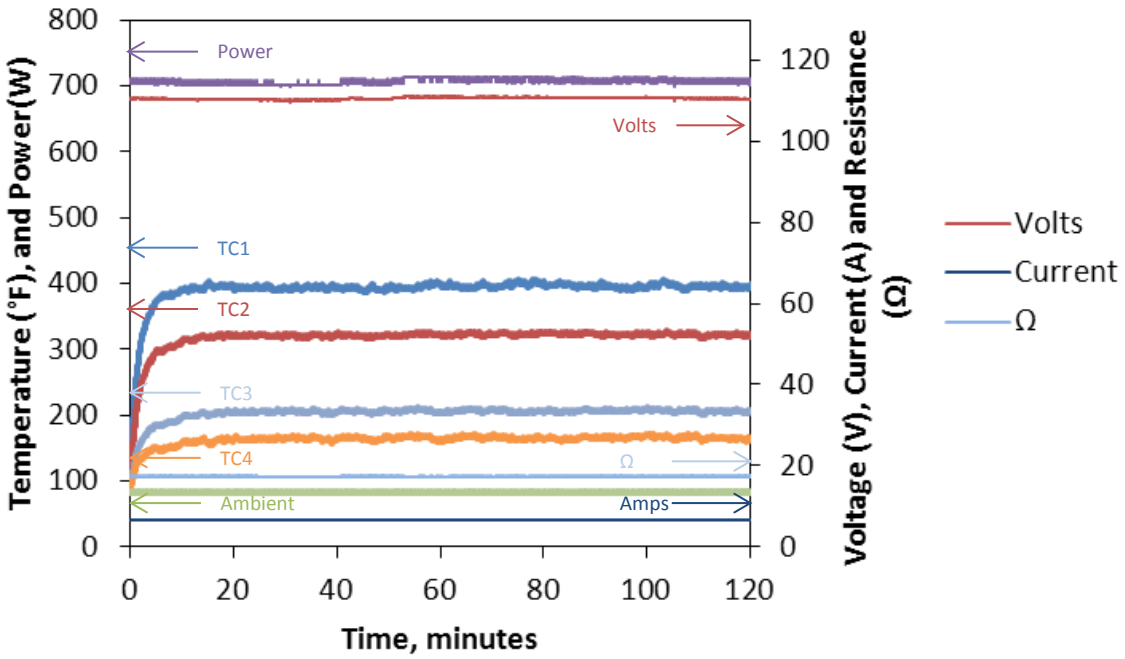
- Vertically-mounted coil furnace
  - 120V, 875W
  - Monitoring AC voltage and current, calculating input power, coil resistance
  - Adjust power with variable AC transformer
- Multi-flamelet pilot flame
  - Pre-mixed propane/air flame
  - Controlled with mixing type flowmeters



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





Ohm's Law

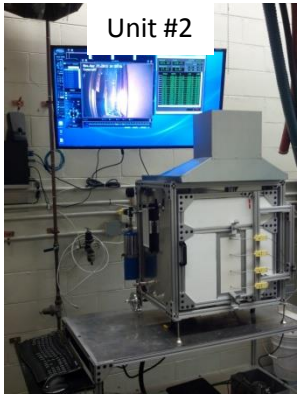
$$R = \frac{V}{I}$$

$$P = IV$$

*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



Description of Analysis

Measured Burn Length

Repeatability for Each Lab/Unit

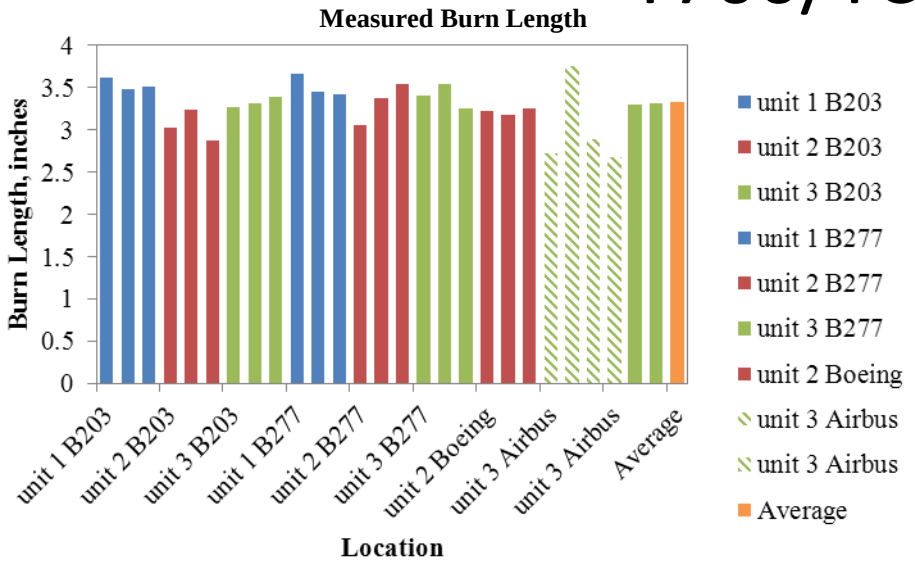
Date	Unit	Location	Test	Material	Plies / Thickness	Identifier	After Flame	Burn Length	Burn Width	Average BL @ LOC	STDEV @ LOC	%SD @ LOC
6/11/2013	1	203	T2	3KPW	4 PLY	unit 1 B203	39	4.397	2.555			
6/11/2013	1	203	T3	3KPW	4 PLY	unit 1 B203	45	4.447	2.641			
6/11/2013	1	203	T4	3KPW	4 PLY	unit 1 B203	40	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%

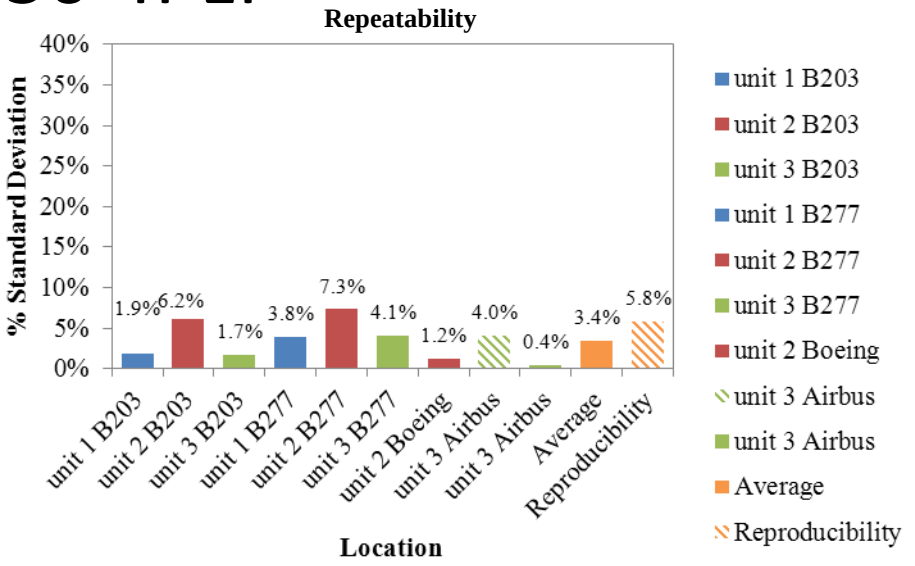
Average Burn Length

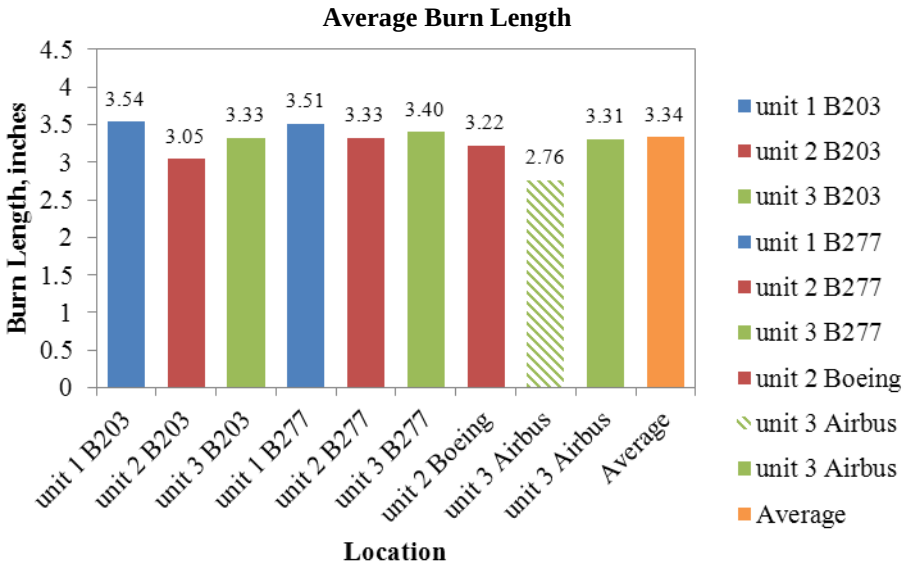
Reproducibility

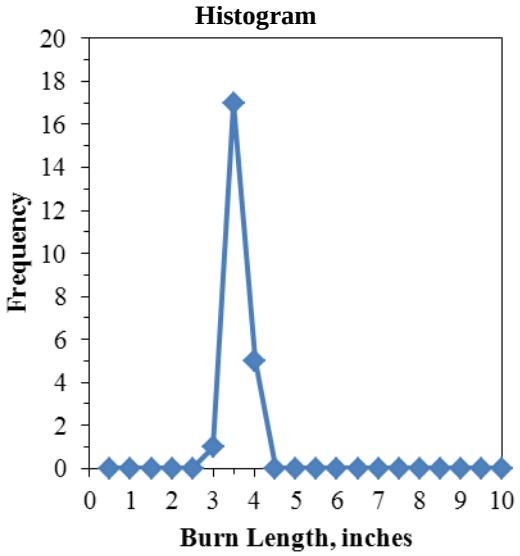
Average Repeatability

Comparative Test Series Results
T700/TC350 4PLY

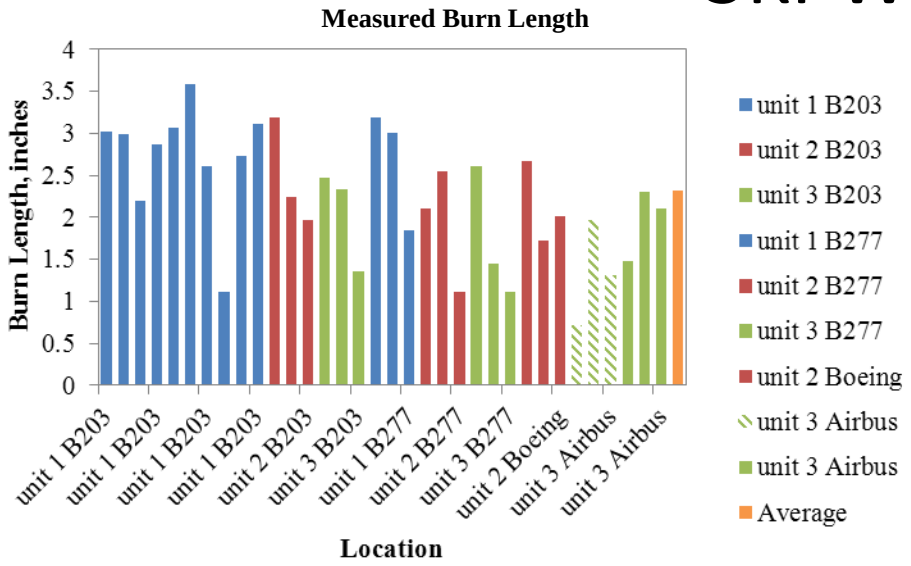


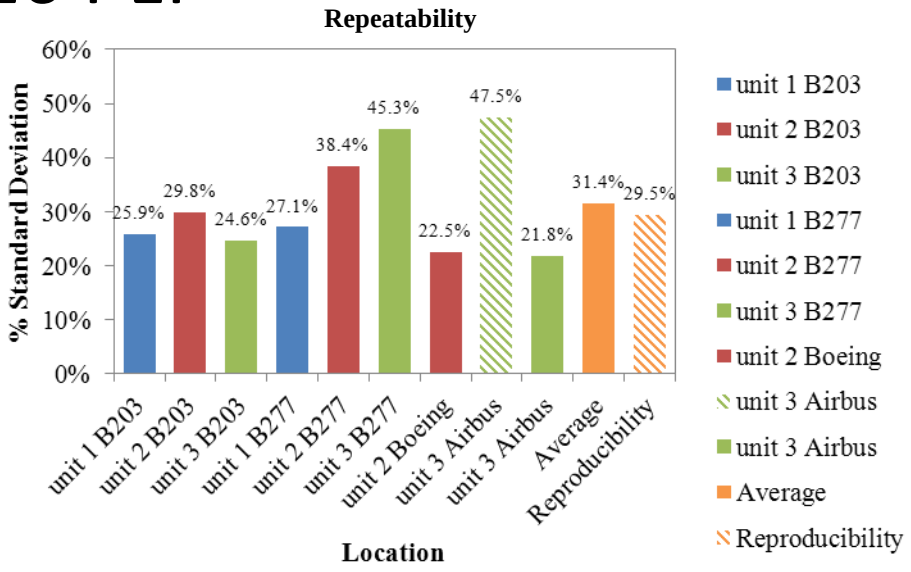


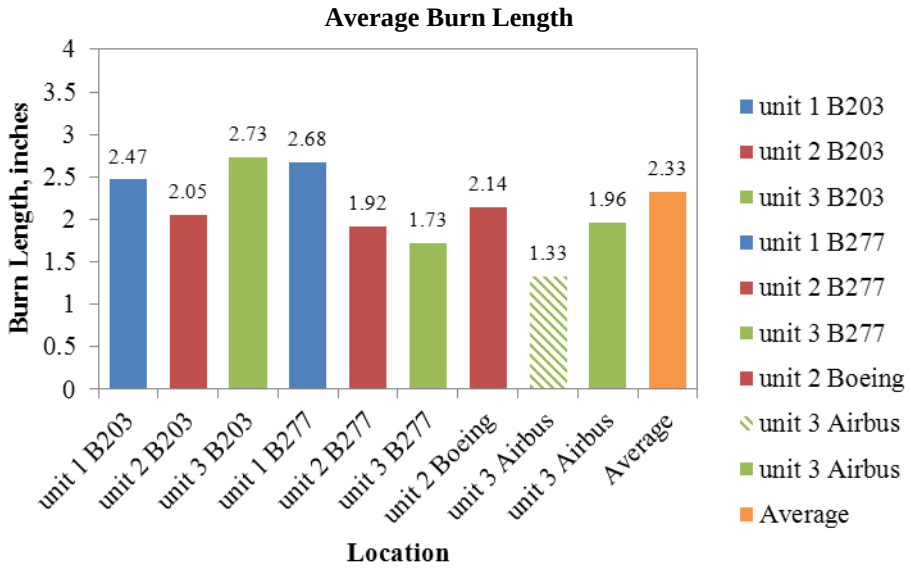


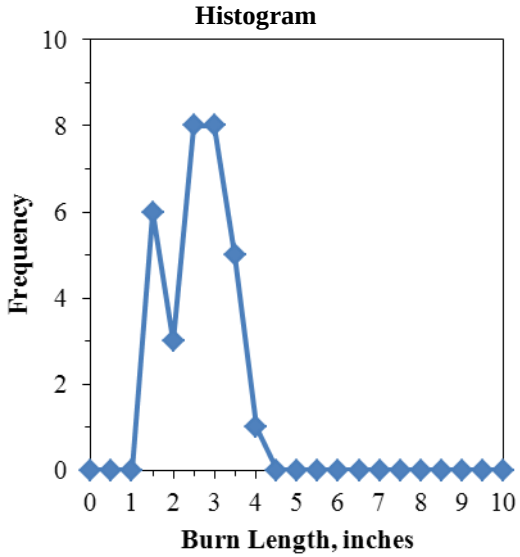


Comparative Test Series Results
3KPW-16 PLY



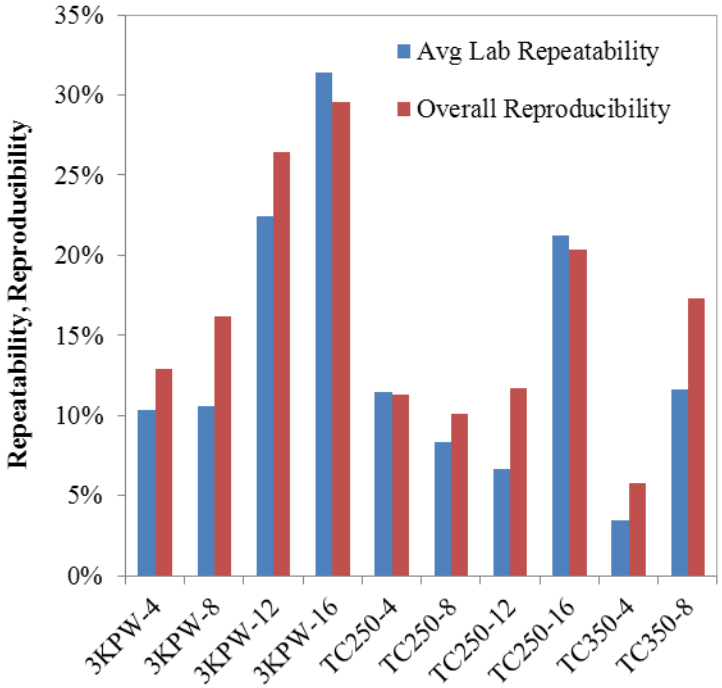






Overall Results

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

Wire Insulation Testing

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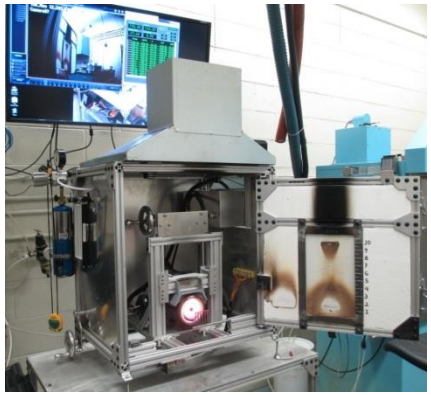

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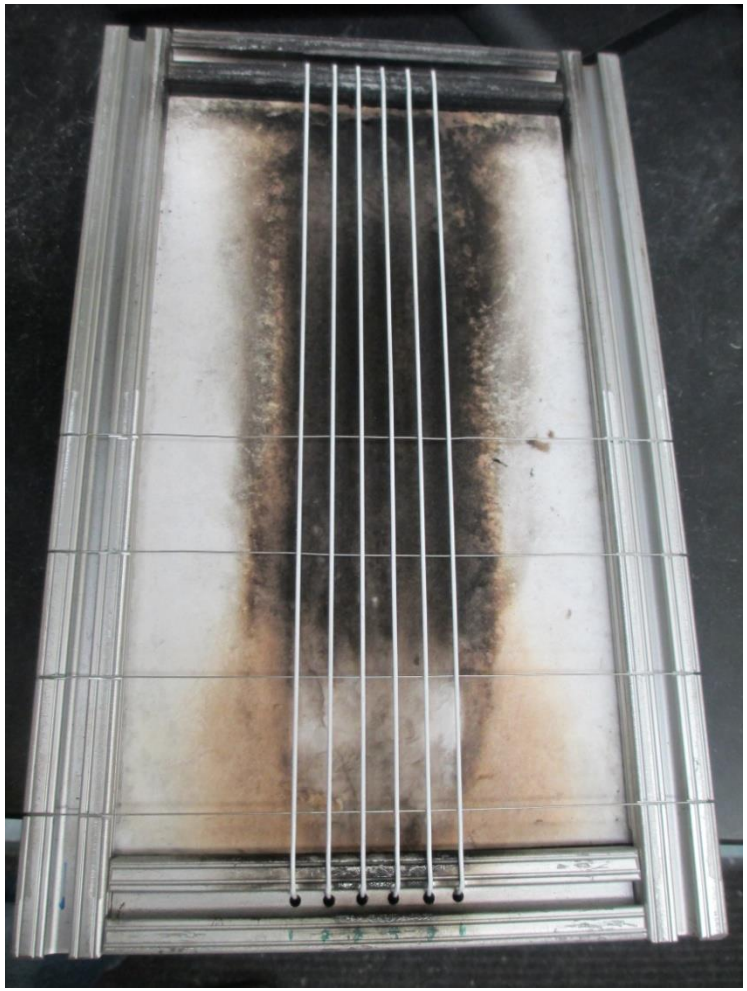
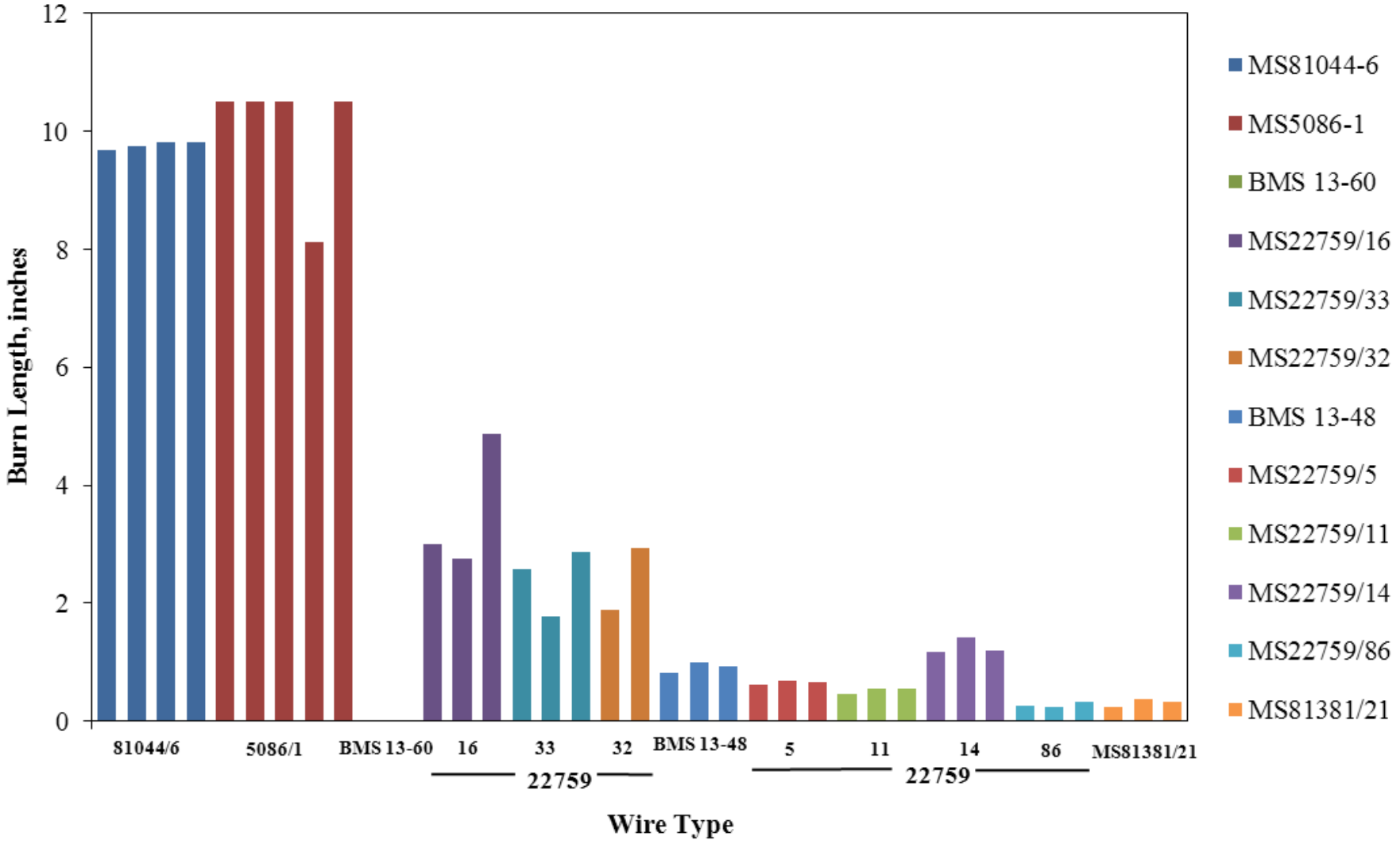
Specification	Construction
MS81044/6	Cross-linked Polyalkene
MS5086/1	PVC/Nylon
BMS 13-60	Polyimide/PTFE
MS22759/16	ETFE
MS22759/33	XL-ETFE
MS22759/32	XL-ETFE
BMS 13-48	ETFE
MS22759/5	Extruded PTFE
MS22759/11	TFE
MS22759/14	Extruded FEP
MS22759/86	Composite: Fluoropolymer/PI tape
MS81381/21	Polyimide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



Overall Results: Wire Testing on VFP



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.

What's New?

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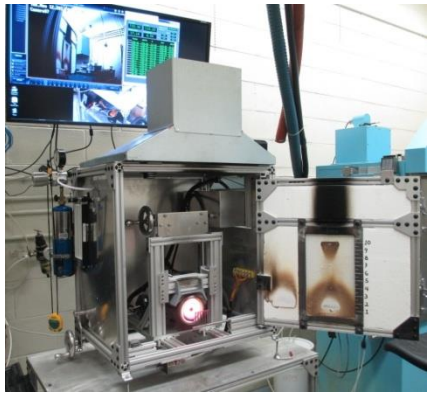

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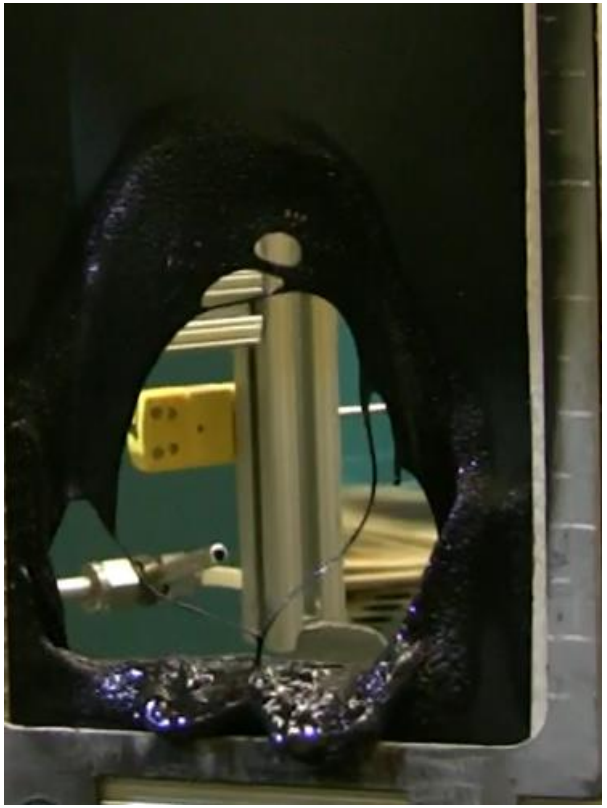
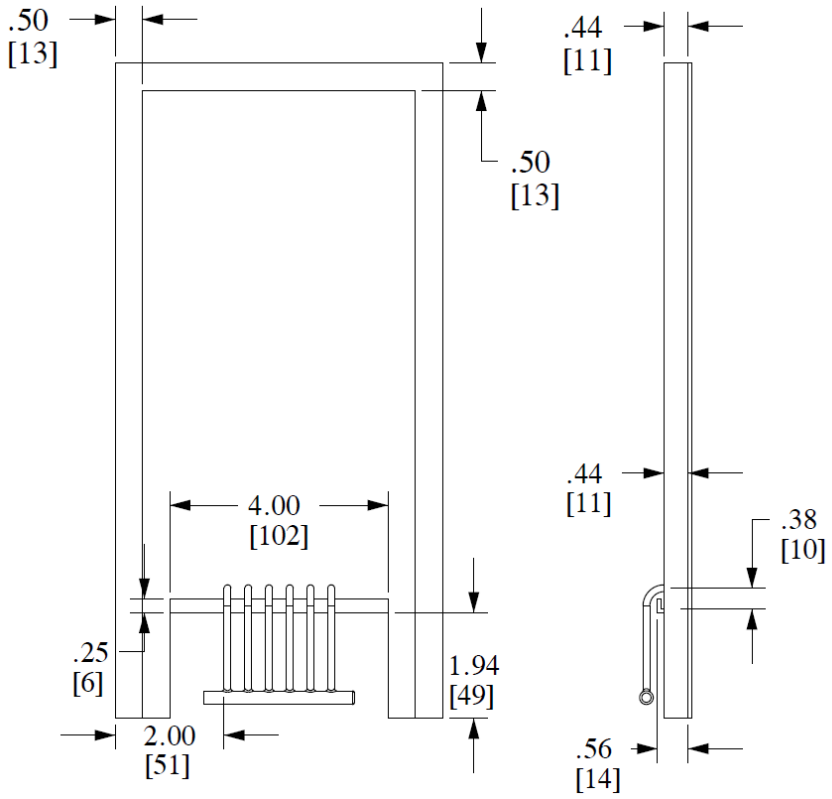
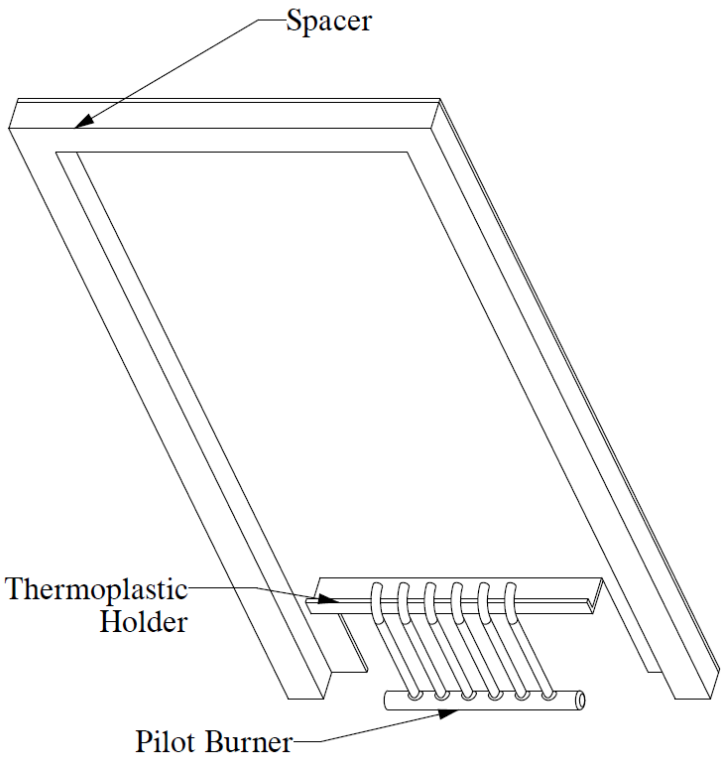
Thermoplastic Issues

- Unreinforced thermoplastics present testing issues
  - Typically melt under heating and flame impingement
  - Melted material flows into pilot flame tubes, extinguishing flames
  - Clogged tubes are very difficult to clean out
- A new sample holder was developed for these types of materials
  - Recesses sample from pilot flame, eliminating clogging
  - Drip tray collects flaming drips, which can still impinge on sample, representing worst-case
    - Drip tray flaming measured as after flame time
    - As of now, after flame time not a test criteria
  - Pilot flame length increased to impinge on sample

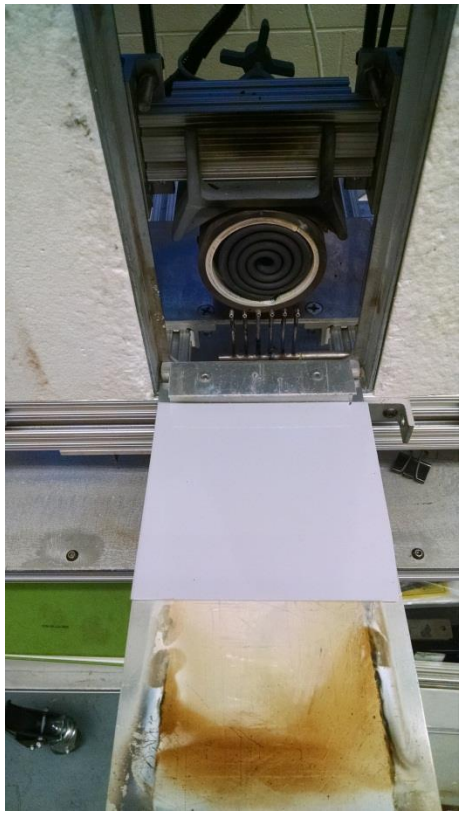


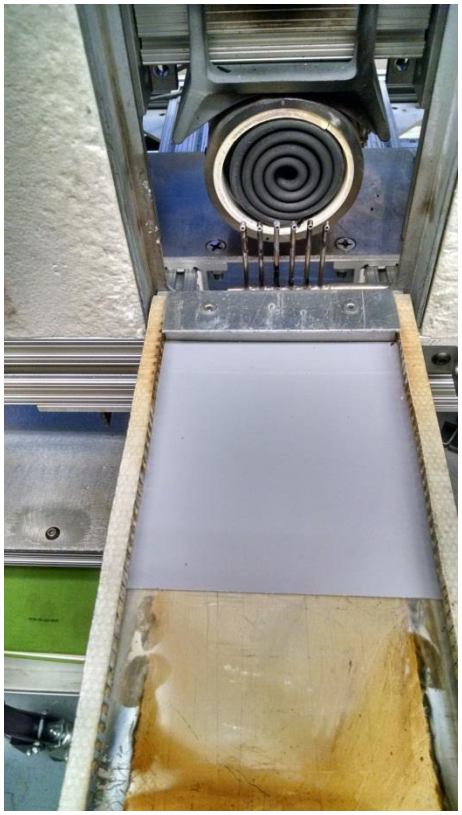
Thermoplastic Sample Holder





Thermoplastic Sample Holder

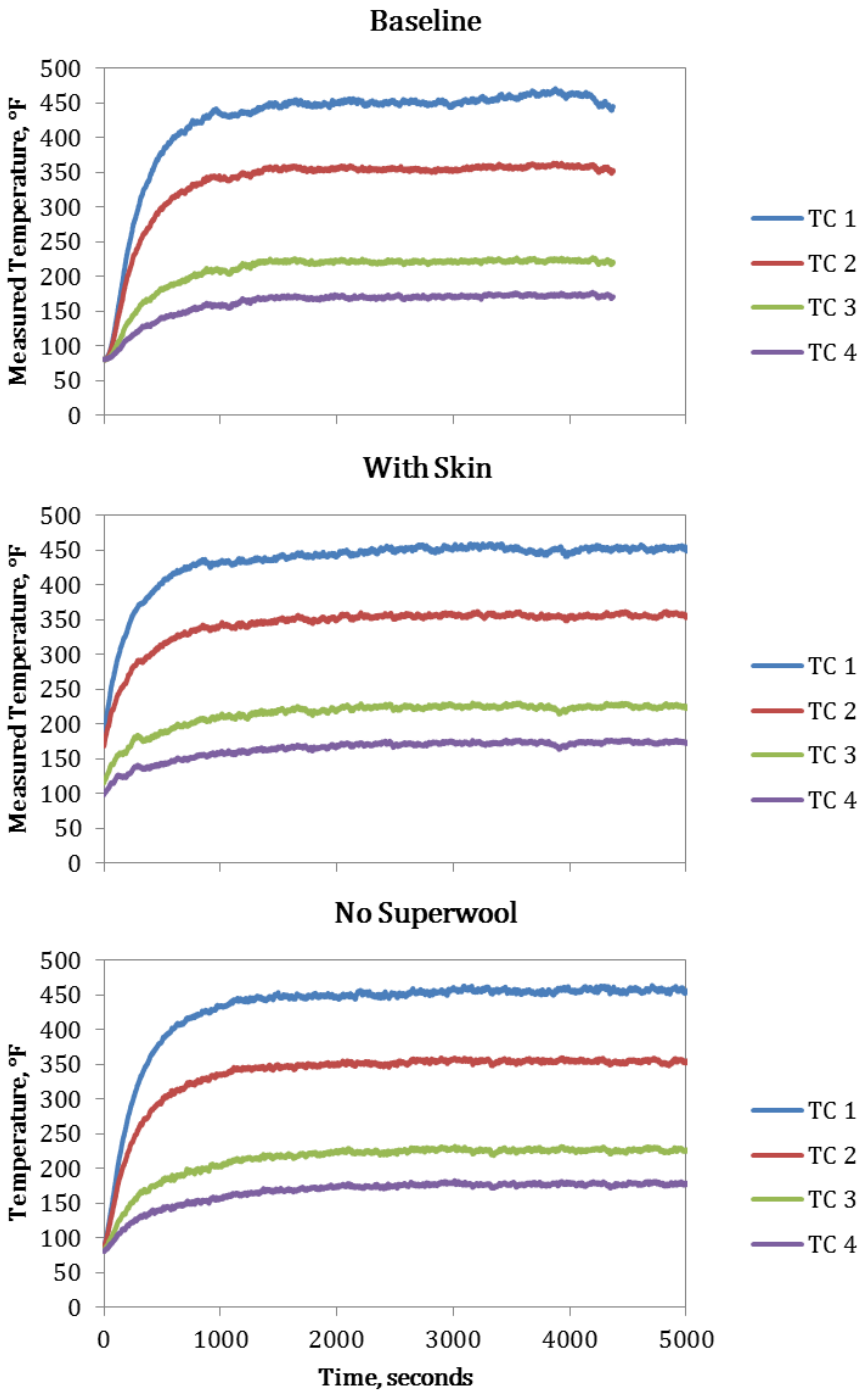


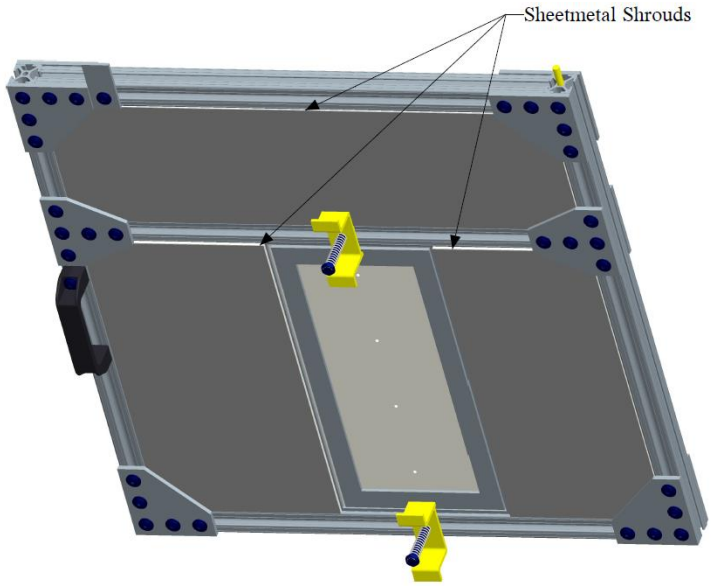


Thermoplastic Sample Holder Settings

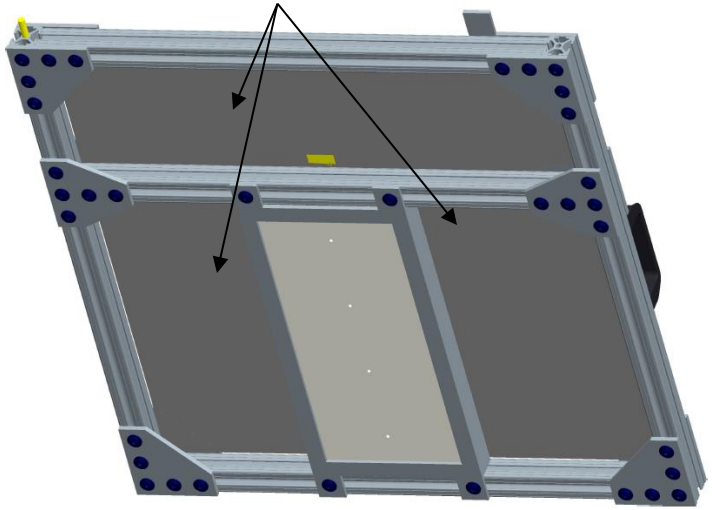
- Spacer recesses sample by about ½”
- Flamelet length is increased by proportionally increasing the fuel and air flow rates
  - 1:2 fuel-air ratio
  - 35 ccm propane
  - 70 ccm air
- Furnace distance to sample is not adjusted
  - Increase in flame severity offsets reduction in radiant intensity

Enclosed Door with Sheet Metal Skin





Removed Superwool Boards



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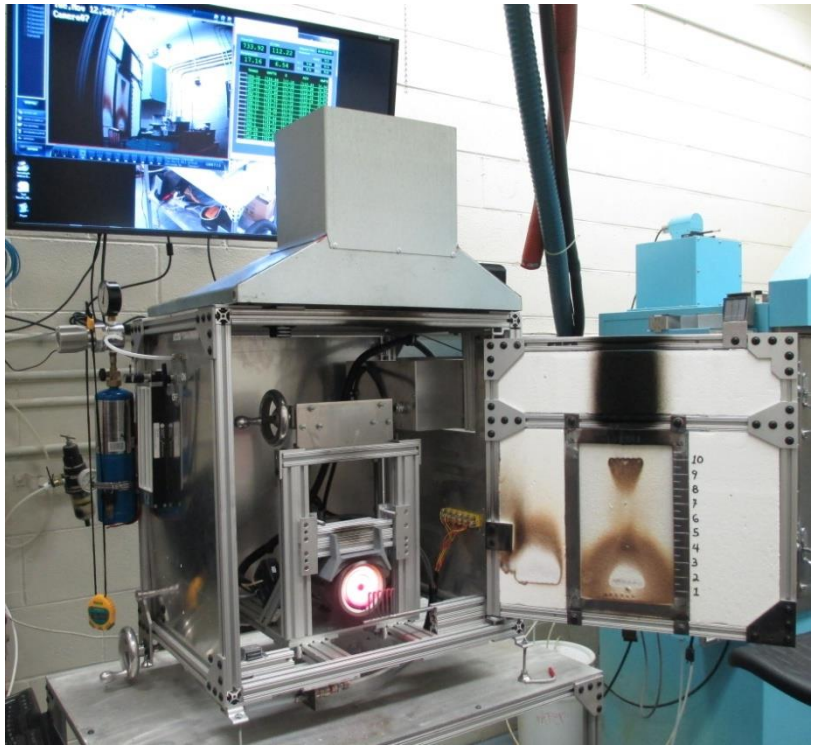
Apparatus Summary

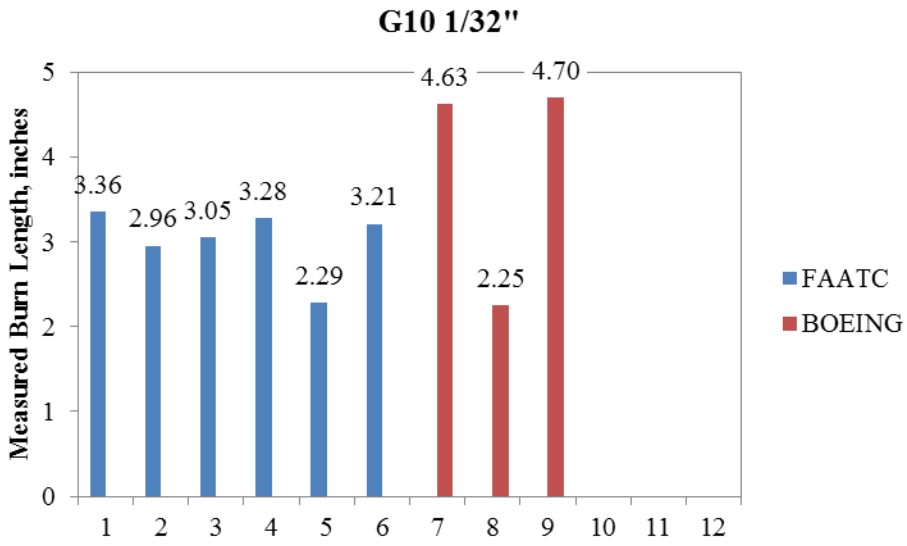
- A method was developed for evaluating flammability of thermoplastics in the VFP
  - Need materials or suggestions for materials from task group to begin evaluating thermoplastics
  - Need to define method for measuring burn length accurately for these types of materials
- Sheetmetal skin on sample door
  - no effect on chamber temperature
  - Removing the superwool on the sample door had no effect on chamber temperature
  - Testing needs to confirm this has no effect on burn length

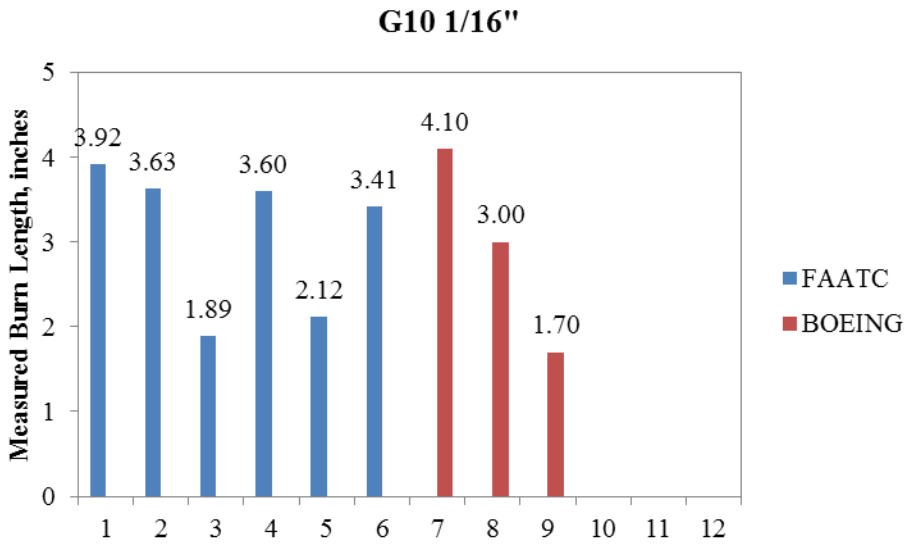


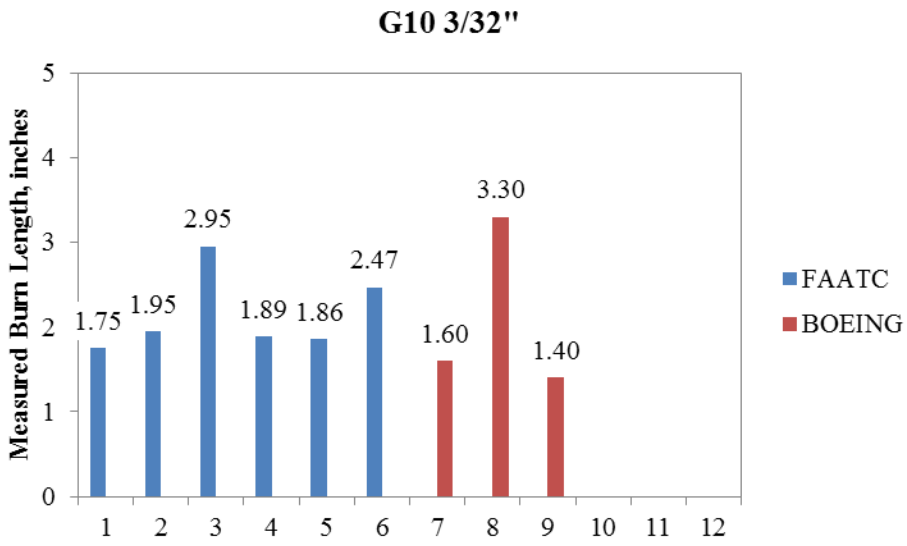
Comparative Testing with Boeing VFP

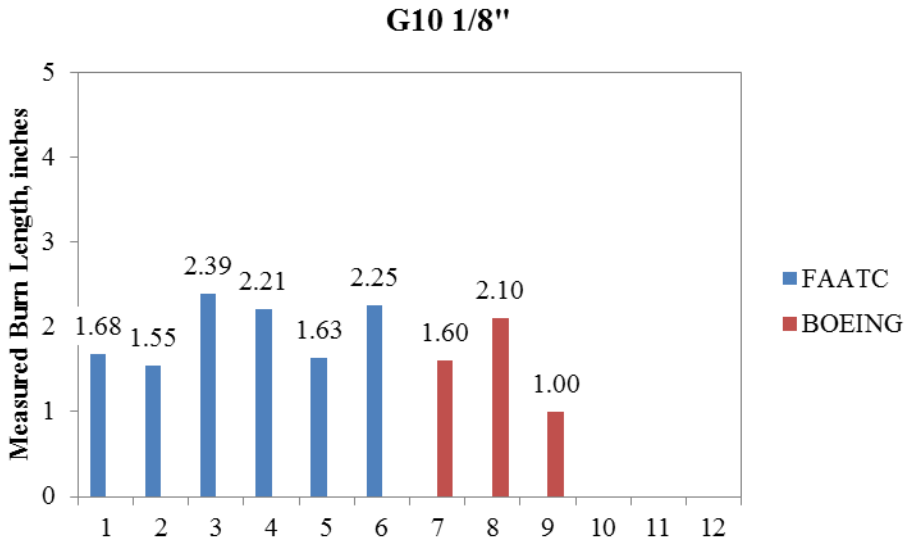
- Samples sent to Boeing, FAATC personnel traveled to Boeing lab
  - Glass Epoxy
    - 1/32”
    - 1/16”
    - 3/32”
    - 1/8”
  - Carbon Fiber
    - 1/32”
    - 1/16”
    - 1/8”
  - Wires
    - 81044
    - 13-60
    - 22759/16
    - 22759/32
    - 5086
    - 22759/33

Glass Epoxy G10

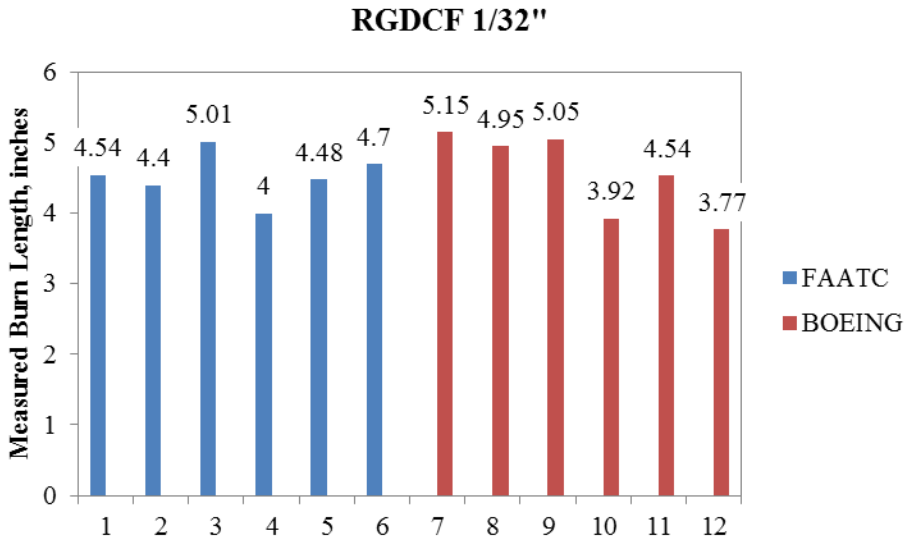


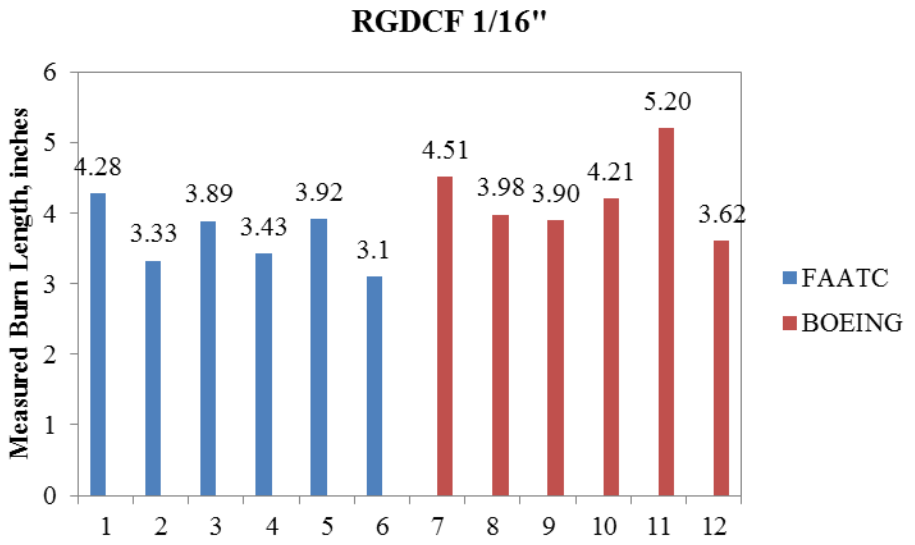


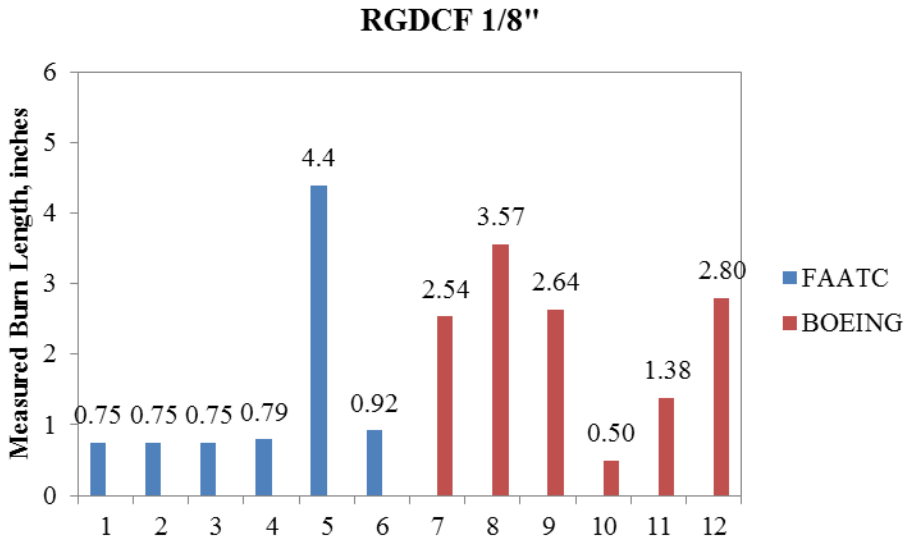


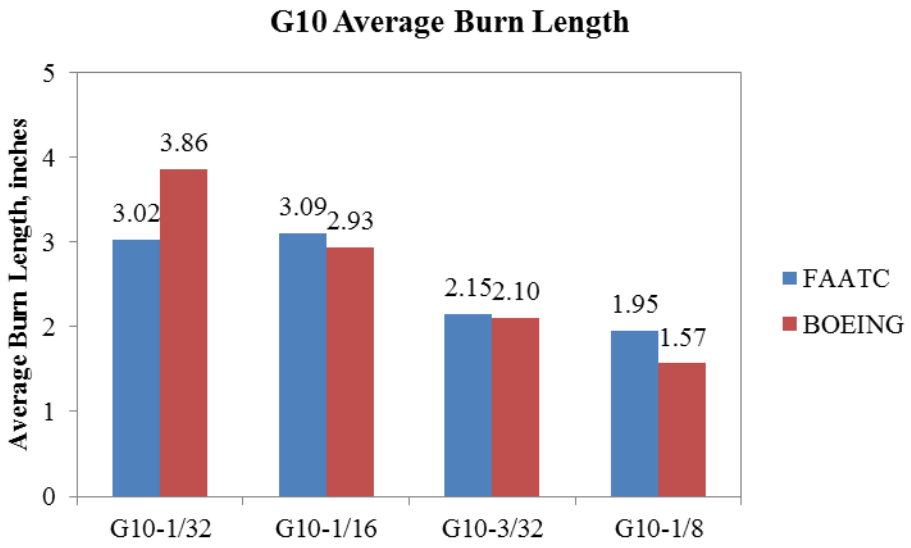


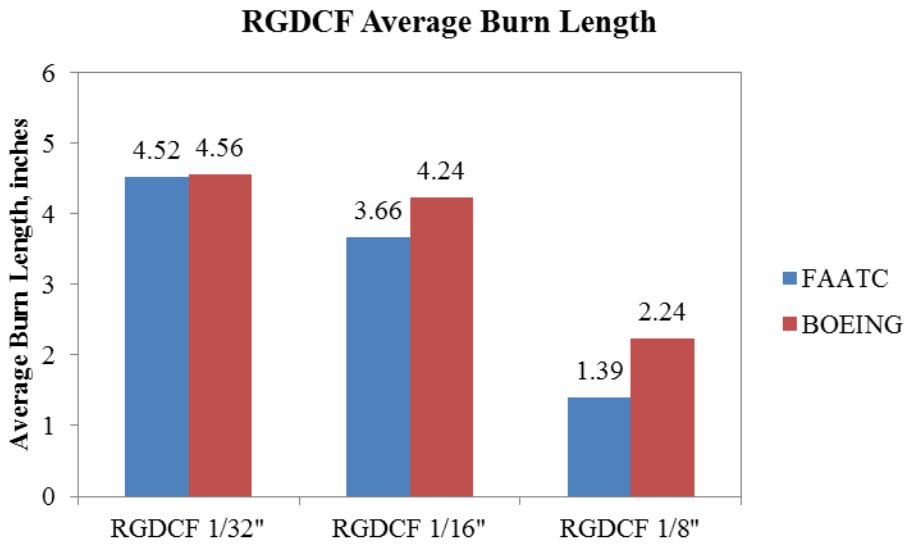
Carbon Fiber RGDCF

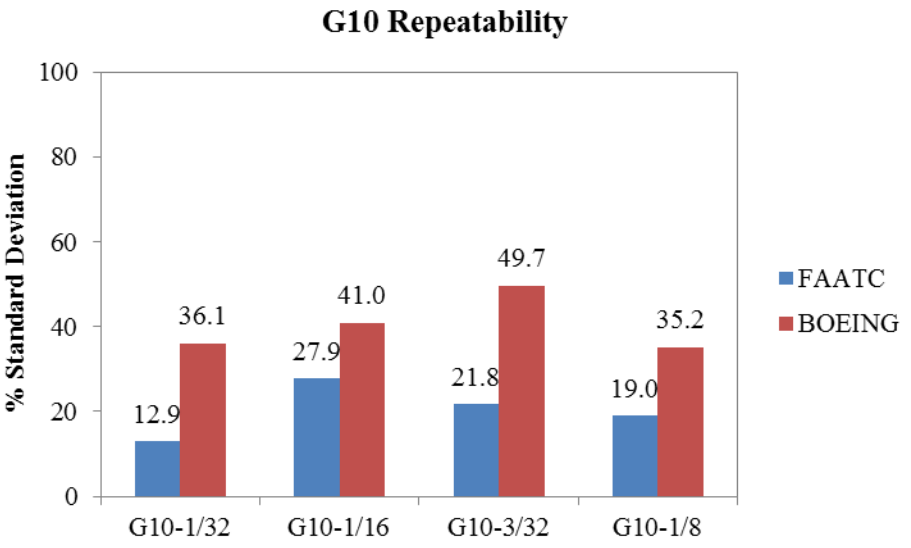


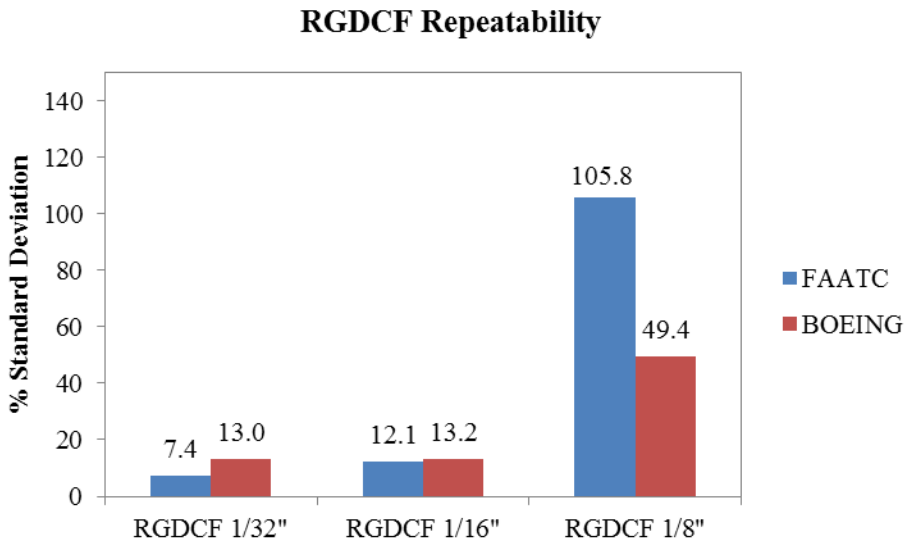




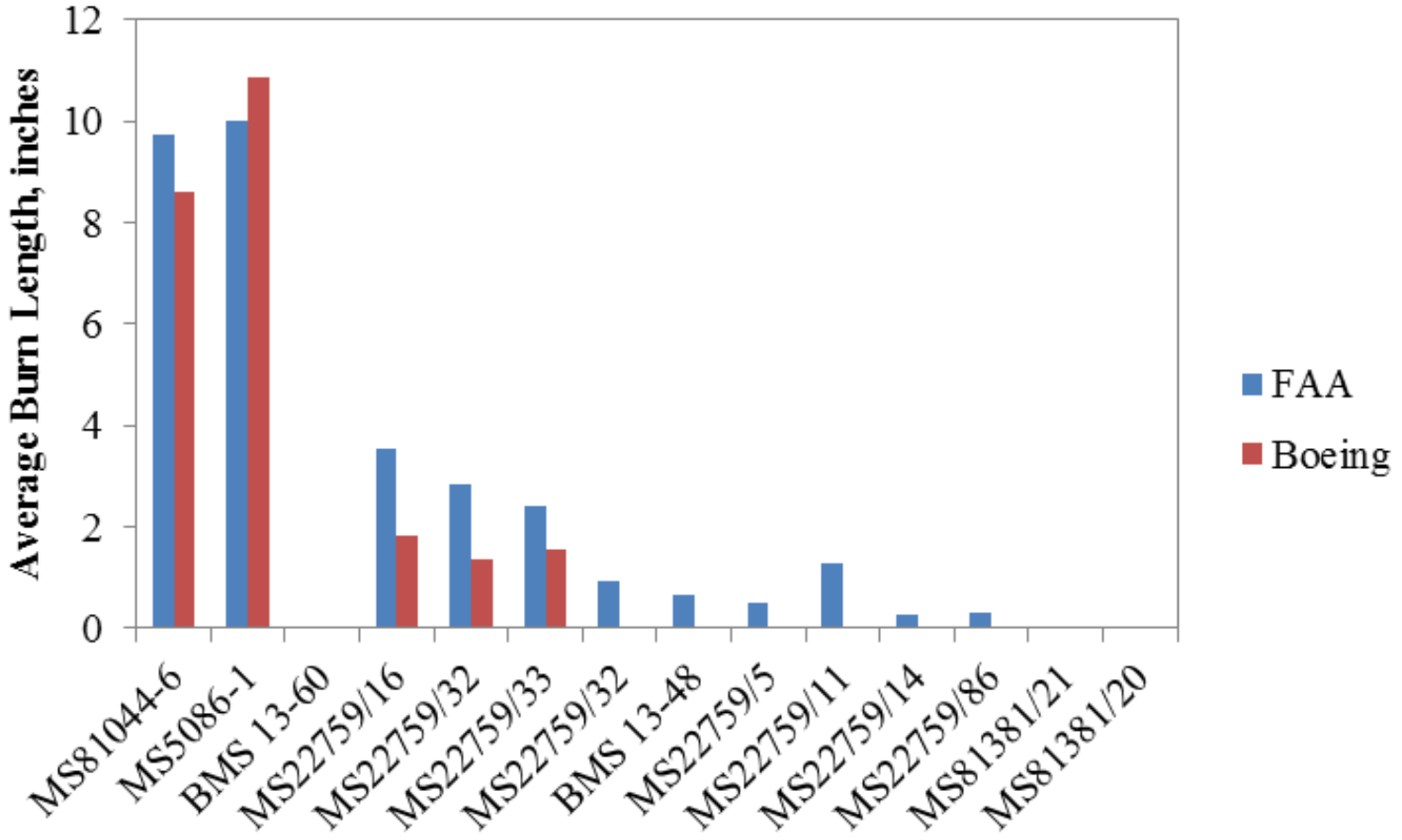

G10 Average Burn Length
Average Burn Length, inches
0
1
2
3
4
5
3.02
3.86
3.09
2.93
2.15
2.10
1.95
1.57
G10-1/32
G10-1/16
G10-3/32
G10-1/8
FAATC
BOEING


RGDCF Average Burn Length
Average Burn Length, inches
0
1
2
3
4
5
6
4.52
4.56
3.66
4.24
1.39
2.24
RGDCF 1/32"
RGDCF 1/16"
RGDCF 1/8"
FAATC
BOEING

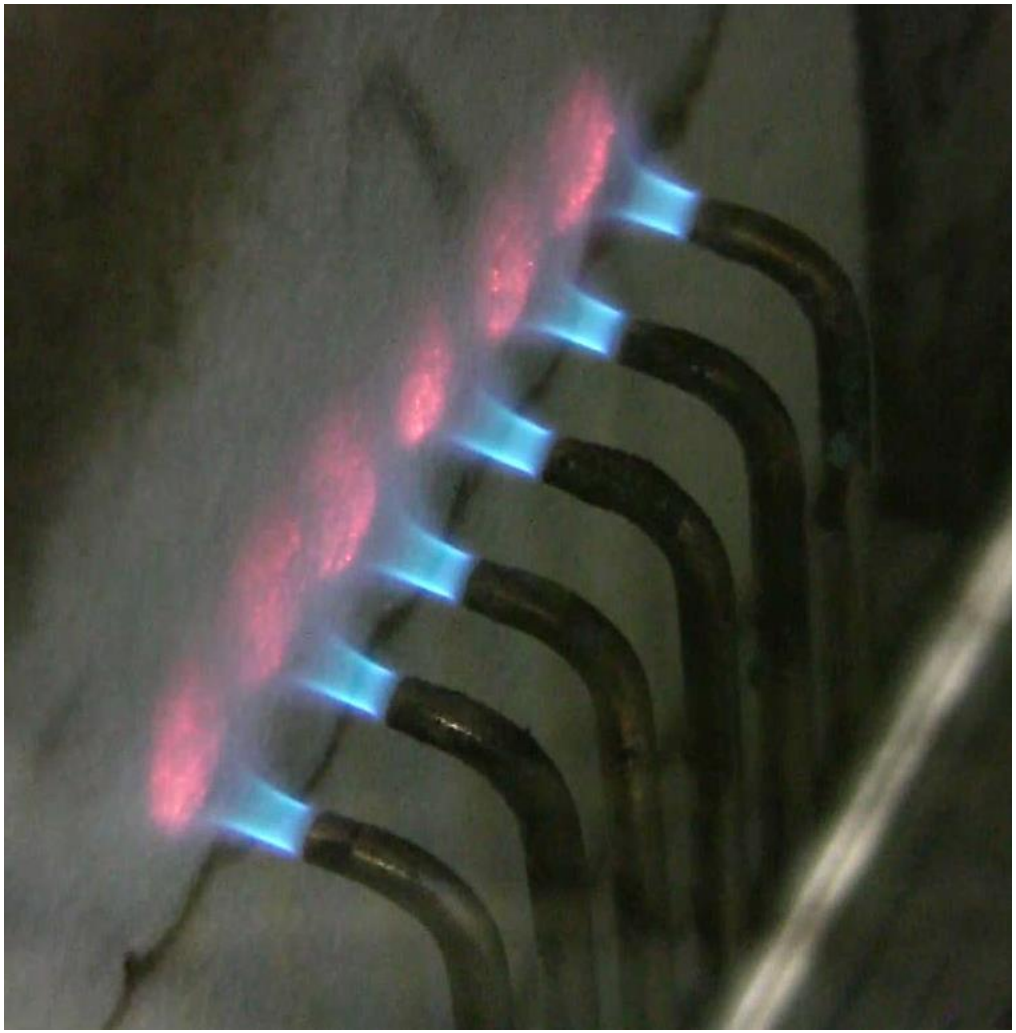

G10 Repeatability
% Standard Deviation
0
20
40
60
80
100
12.9
36.1
27.9
41.0
21.8
49.7
19.0
35.2
G10-1/32
G10-1/16
G10-3/32
G10-1/8
FAATC
BOEING


RGDCF Repeatability
% Standard Deviation
0
20
40
60
80
100
120
140
7.4
13.0
12.1
13.2
105.8
49.4
RGDCF 1/32"
RGDCF 1/16"
RGDCF 1/8"
FAATC
BOEING

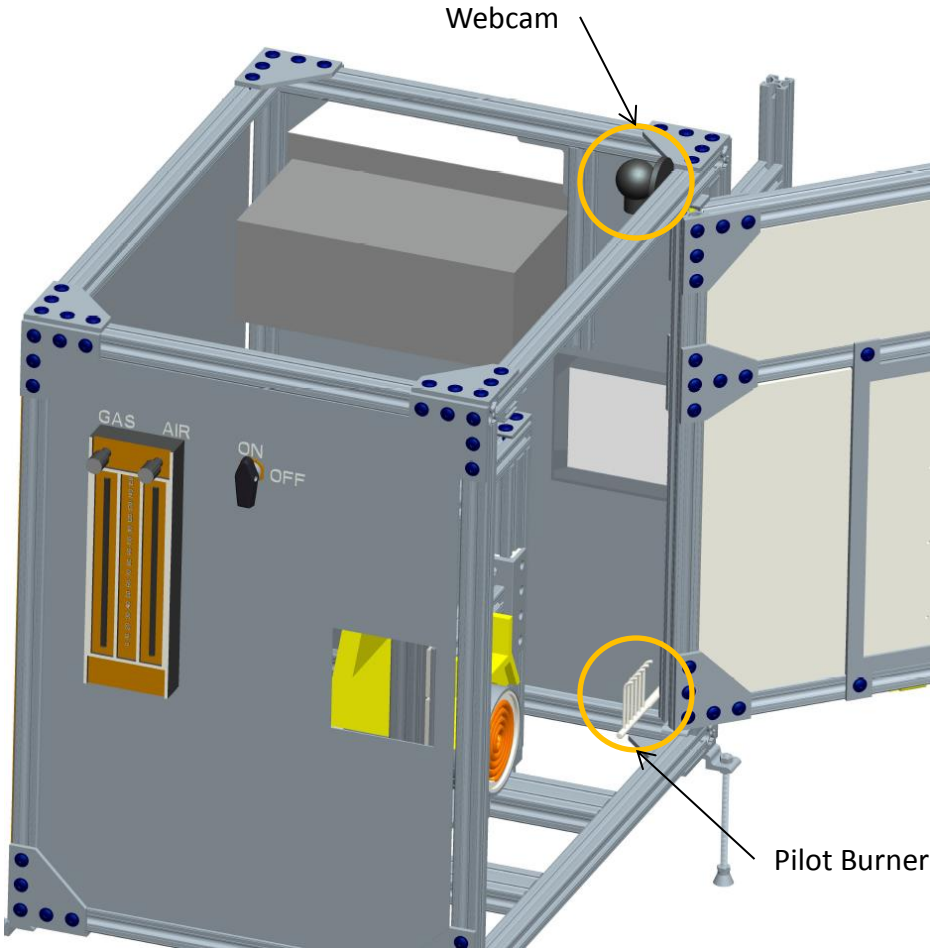
Wire Test Comparison



Flame Length / Distance

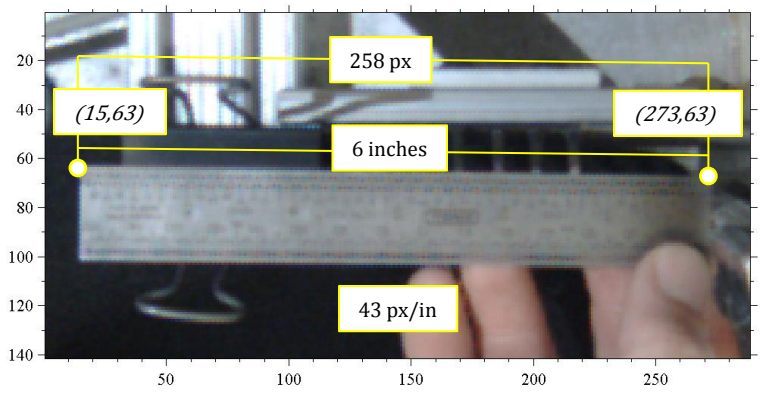


Flame Length Measurement



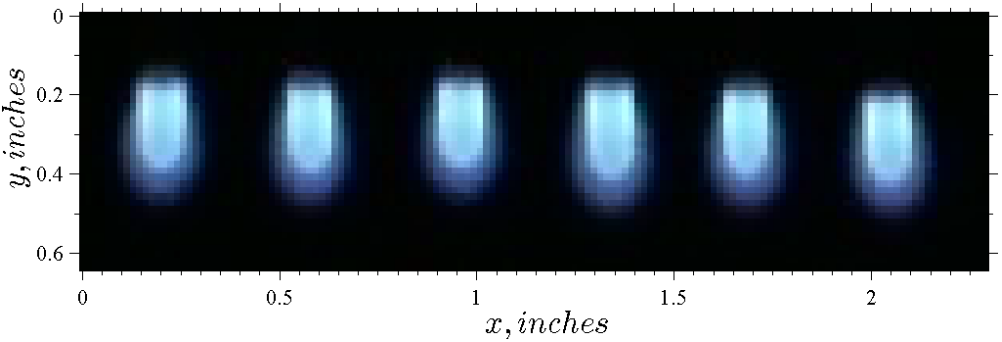
- Borrowed idea from Boeing Flammability Lab
  - Thanks Yusuf!
- USB webcam mounted above pilot burner in standby position
- Images taken of flames when steady
  - Images are RGB
  - $x \times y \times 3$ array

Take image of ruler in same plane as flamelets determine pixels/inch conversion

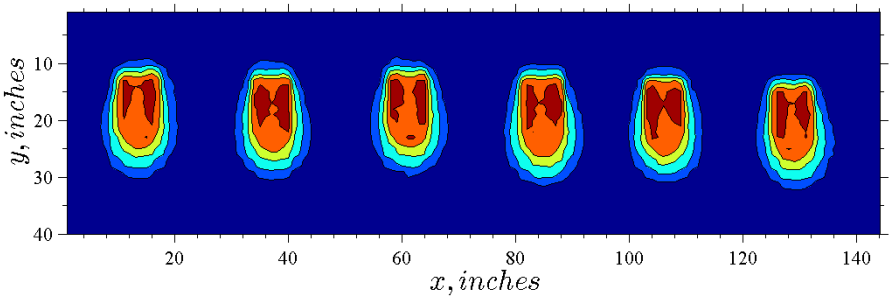


Flamelet Length Measurement

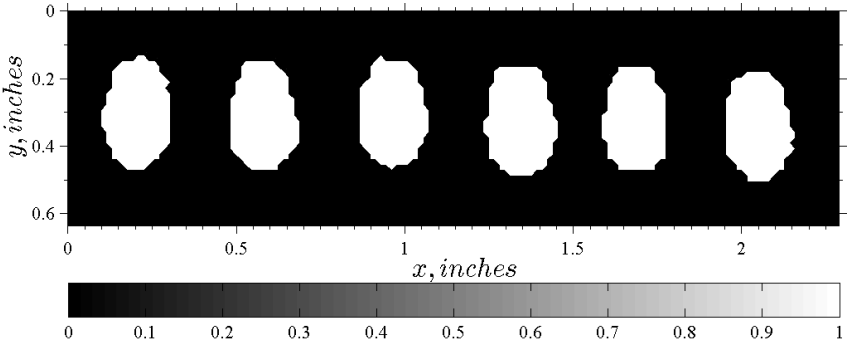
Blue pixel intensity 0-255



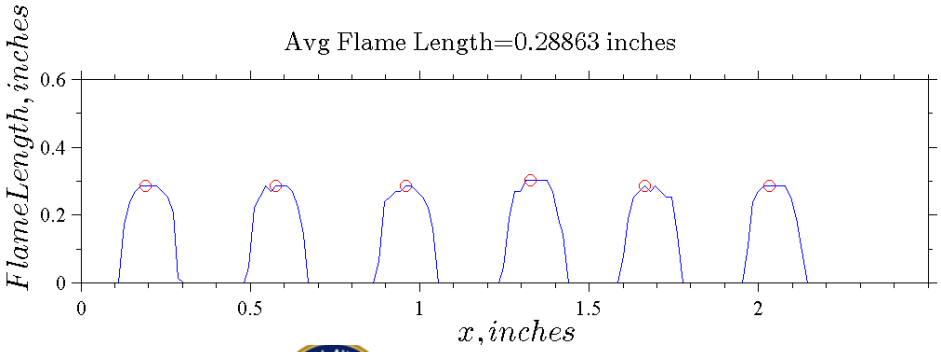
Set threshold value (100)



Assign all pixels above threshold to 1
Assign all pixels below threshold to 0



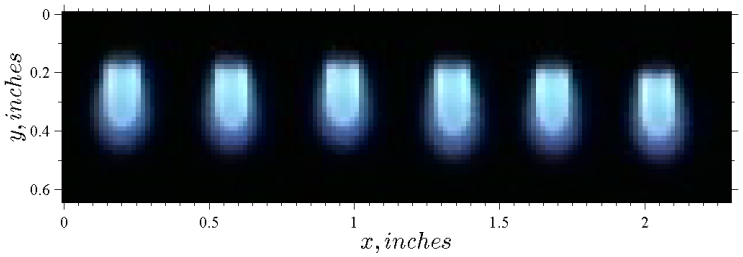
Sum all columns, highest values for each flamelet are peaks

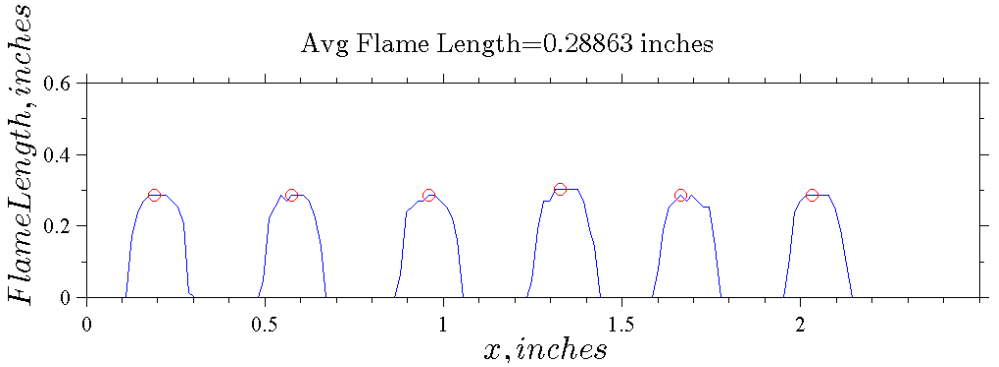


Federal Aviation Administration

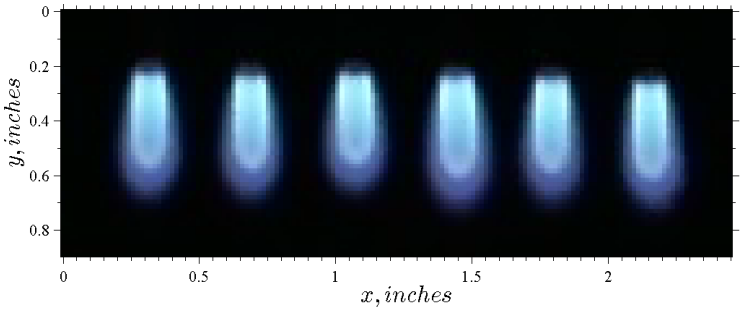
Flamelet Length Measurement

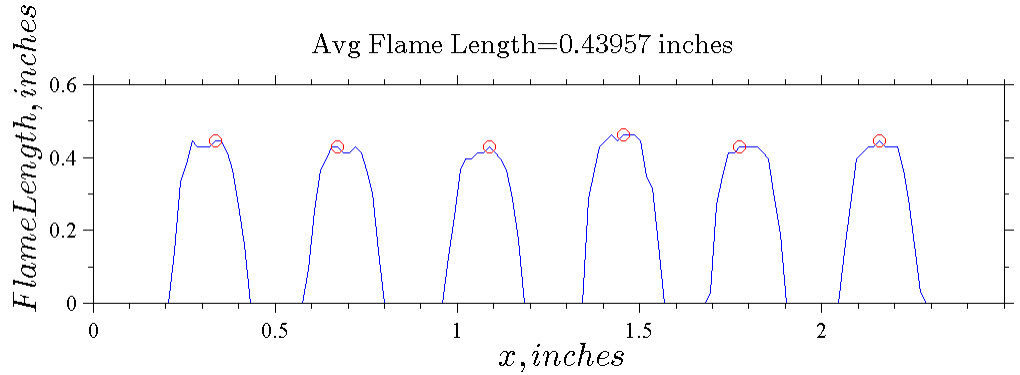
Fuel 25 ccm, Air 50 ccm



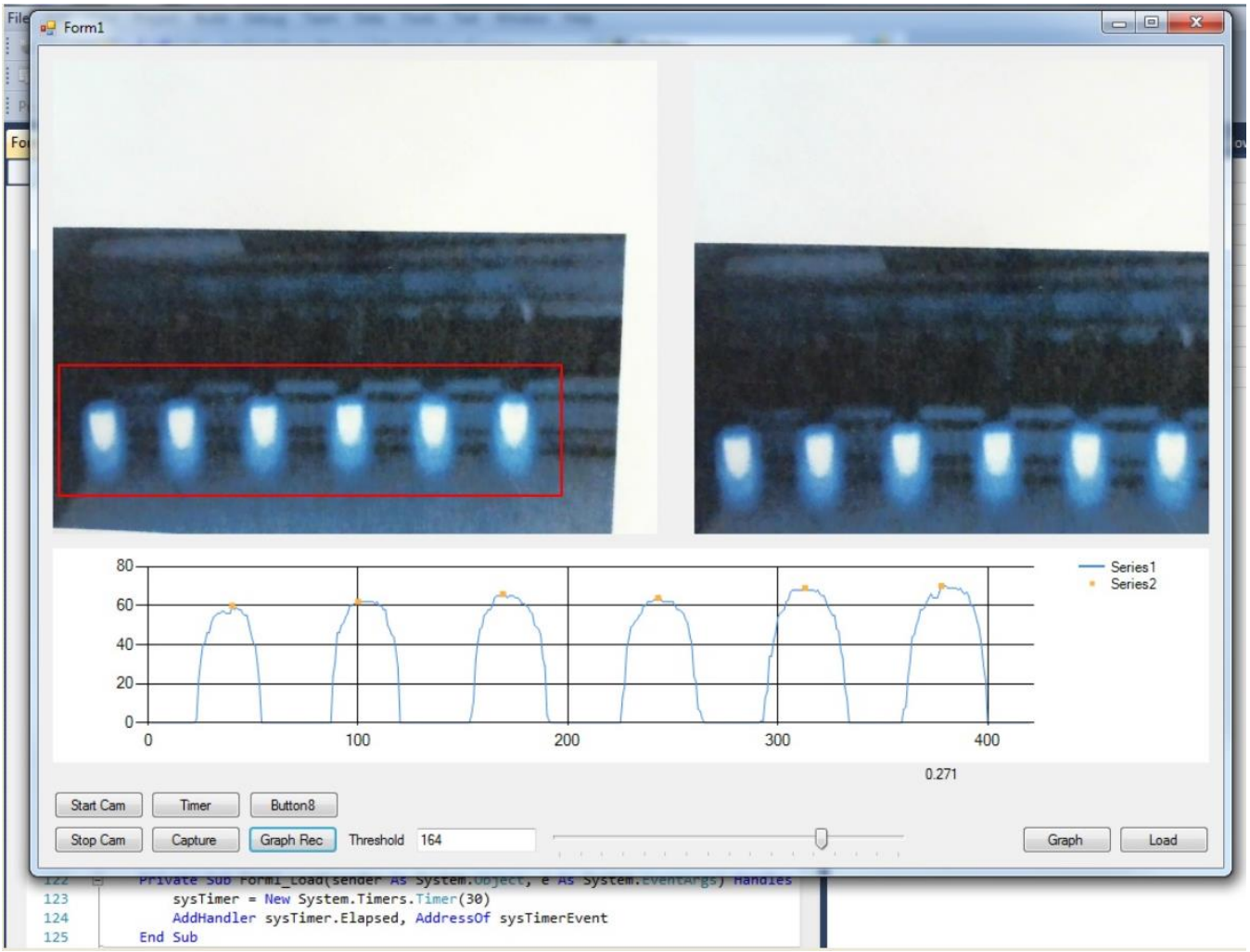


Fuel 35 ccm, Air 70 ccm





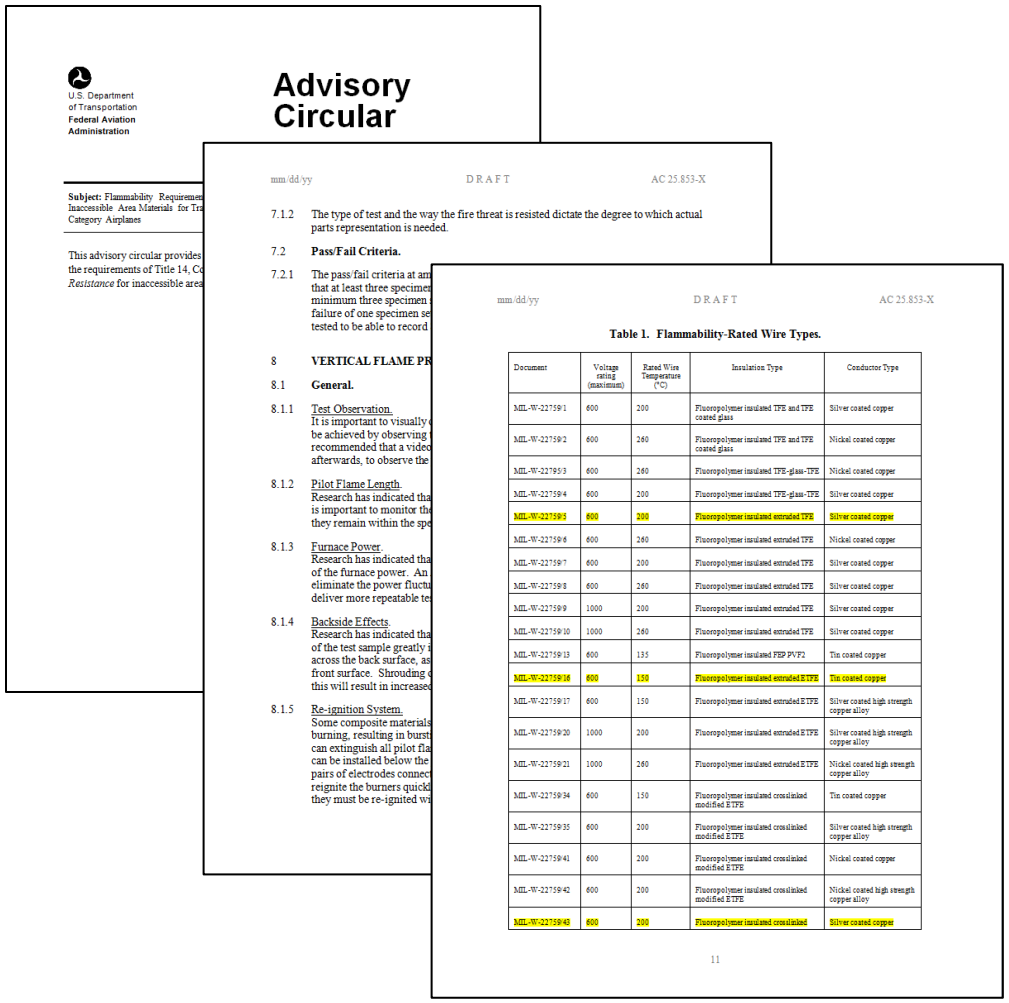
Integration into Software



Planned Work

- Evaluate flame temperature with traversing thermocouple
  - Determine ideal pilot flame-sample distance for best repeatability
- Refine flame length measurement technique
- Continue comparative testing between labs
  - FAATC
  - Boeing
  - Airbus

Development of Advisory Circular



U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: Flammability Requirements for Inaccessible Area Materials for Transport Category Airplanes

This advisory circular provides ... the requirements of Title 14, Co... *Resistance* for inaccessible area...

mm/dd/yy D R A F T AC 25.853-X

7.1.2 The type of test and the way the fire threat is resisted dictate the degree to which actual parts representation is needed.

7.2 **Pass/Fail Criteria.**

7.2.1 The pass/fail criteria at am... that at least three specimen... minimum three specimen... failure of one specimen se... tested to be able to record...

8 **VERTICAL FLAME PR...**

8.1 **General.**

8.1.1 Test Observation. It is important to visually ... be achieved by observing ... recommended that a video ... afterwards, to observe the...

8.1.2 Pilot Flame Length. Research has indicated tha... is important to monitor the... they remain within the spe...

8.1.3 Furnace Power. Research has indicated tha... of the furnace power. An... eliminate the power fluctu... deliver more repeatable te...

8.1.4 Backside Effects. Research has indicated tha... of the test sample greatly i... across the back surface, as... front surface. Shrouding ... this will result in increase...

8.1.5 Re-ignition System. Some composite materials... burning, resulting in burst... can extinguish all pilot fla... can be installed below the... pairs of electrodes connect... reignite the burners quickl... they must be re-ignited wi...

mm/dd/yy D R A F T AC 25.853-X

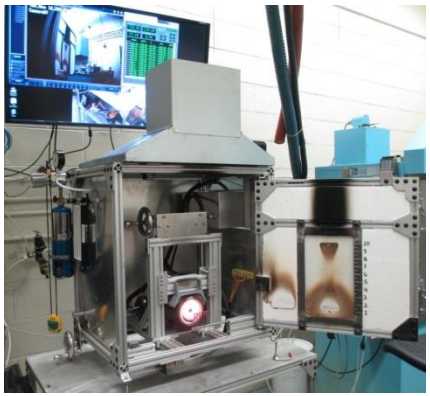
Table 1. Flammability-Rated Wire Types.

Document	Voltage rating (maximum)	Rated Wire Temperature (°C)	Insulation Type	Conductor Type
MIL-W-22759/1	600	200	Fluoropolymer insulated TFE and TFE coated glass	Silver coated copper
MIL-W-22759/2	600	260	Fluoropolymer insulated TFE and TFE coated glass	Nickel coated copper
MIL-W-22759/3	600	260	Fluoropolymer insulated TFE-glass-TFE	Nickel coated copper
MIL-W-22759/4	600	200	Fluoropolymer insulated TFE-glass-TFE	Silver coated copper
MIL-W-22759/5	600	200	Fluoropolymer insulated extruded TFE	Silver coated copper
MIL-W-22759/6	600	260	Fluoropolymer insulated extruded TFE	Nickel coated copper
MIL-W-22759/7	600	200	Fluoropolymer insulated extruded TFE	Silver coated copper
MIL-W-22759/8	600	260	Fluoropolymer insulated extruded TFE	Silver coated copper
MIL-W-22759/9	1000	200	Fluoropolymer insulated extruded TFE	Silver coated copper
MIL-W-22759/10	1000	260	Fluoropolymer insulated extruded TFE	Silver coated copper
MIL-W-22759/13	600	135	Fluoropolymer insulated FEP PVF2	Tin coated copper
MIL-W-22759/16	600	150	Fluoropolymer insulated extruded ETFE	Tin coated copper
MIL-W-22759/17	600	150	Fluoropolymer insulated extruded ETFE	Silver coated high strength copper alloy
MIL-W-22759/20	1000	200	Fluoropolymer insulated extruded ETFE	Silver coated high strength copper alloy
MIL-W-22759/21	1000	260	Fluoropolymer insulated extruded ETFE	Nickel coated high strength copper alloy
MIL-W-22759/34	600	150	Fluoropolymer insulated crosslinked modified ETFE	Tin coated copper
MIL-W-22759/35	600	200	Fluoropolymer insulated crosslinked modified ETFE	Silver coated high strength copper alloy
MIL-W-22759/41	600	200	Fluoropolymer insulated crosslinked modified ETFE	Nickel coated copper
MIL-W-22759/42	600	200	Fluoropolymer insulated crosslinked modified ETFE	Nickel coated high strength copper alloy
MIL-W-22759/43	600	200	Fluoropolymer insulated crosslinked	Silver coated copper

11

- Currently developing guidance material
  - General VFP Guidance
  - Composite Fuselage & Structure
  - Ducts
  - Wire Insulation
    - Approved wire list from AC 43.13-1B
- Input from task group welcome
  - *It's your AC, help make it great!*





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Federal Aviation Administration