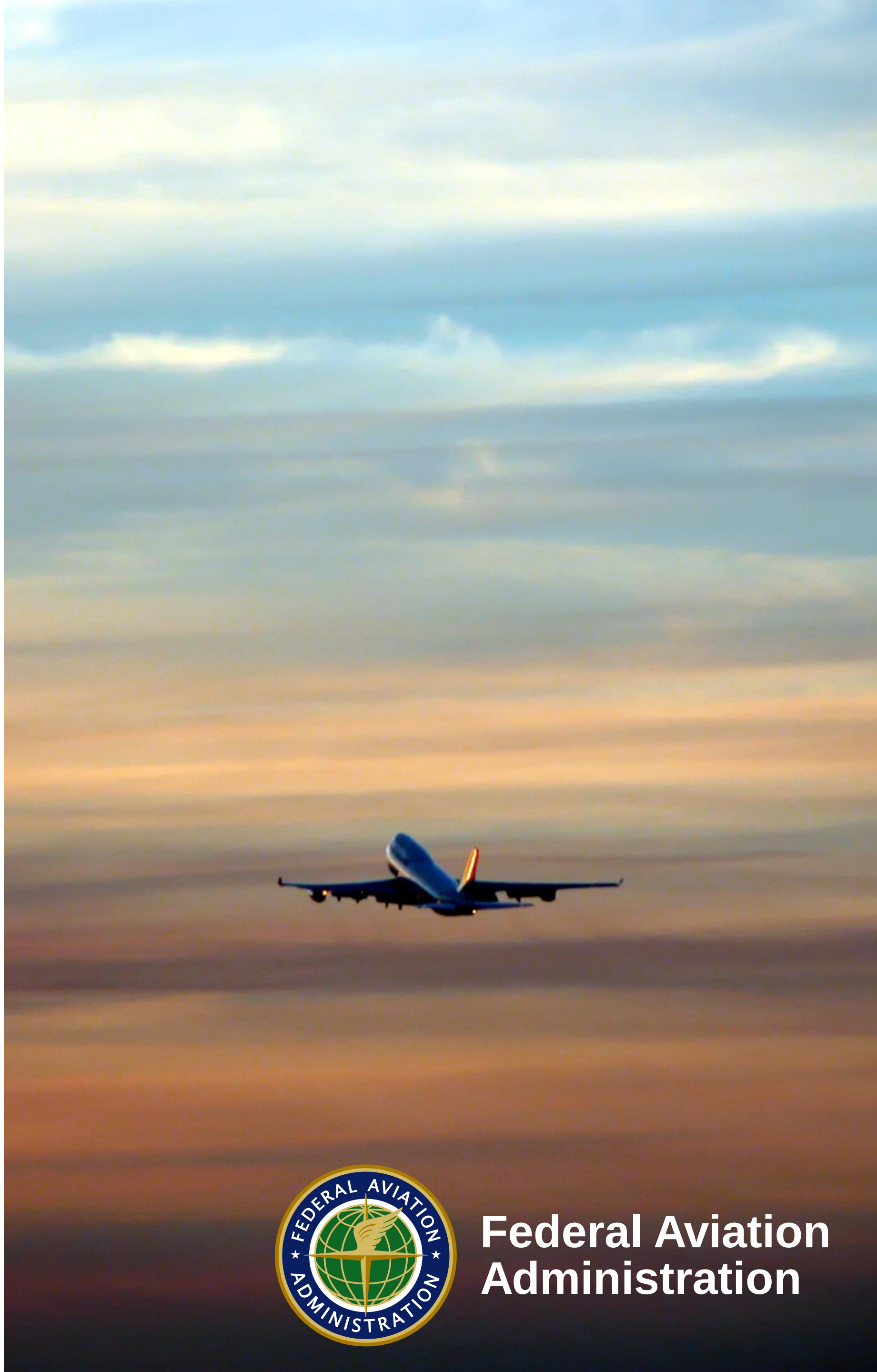
# CFRP Flammability Tests

## Test Configuration Influence on Flame Propagation

Presented to: IAMFTWG Atlantic City NJ
By: Robert I. Ochs
Date: 19 October 2015

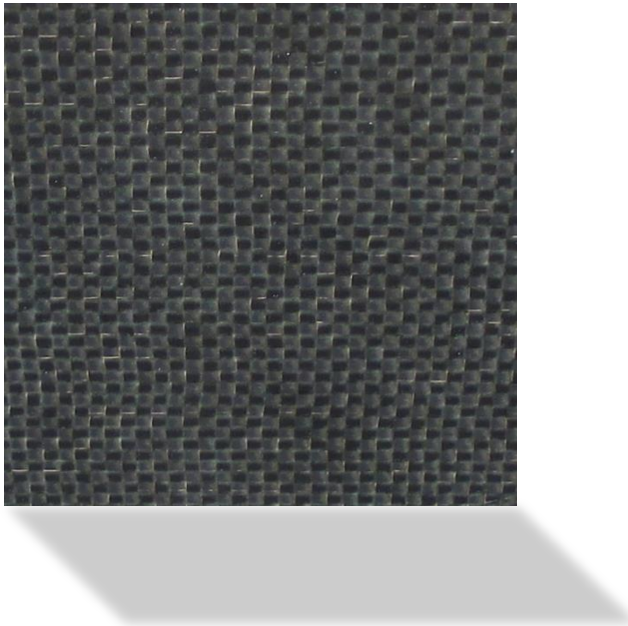


# Introduction

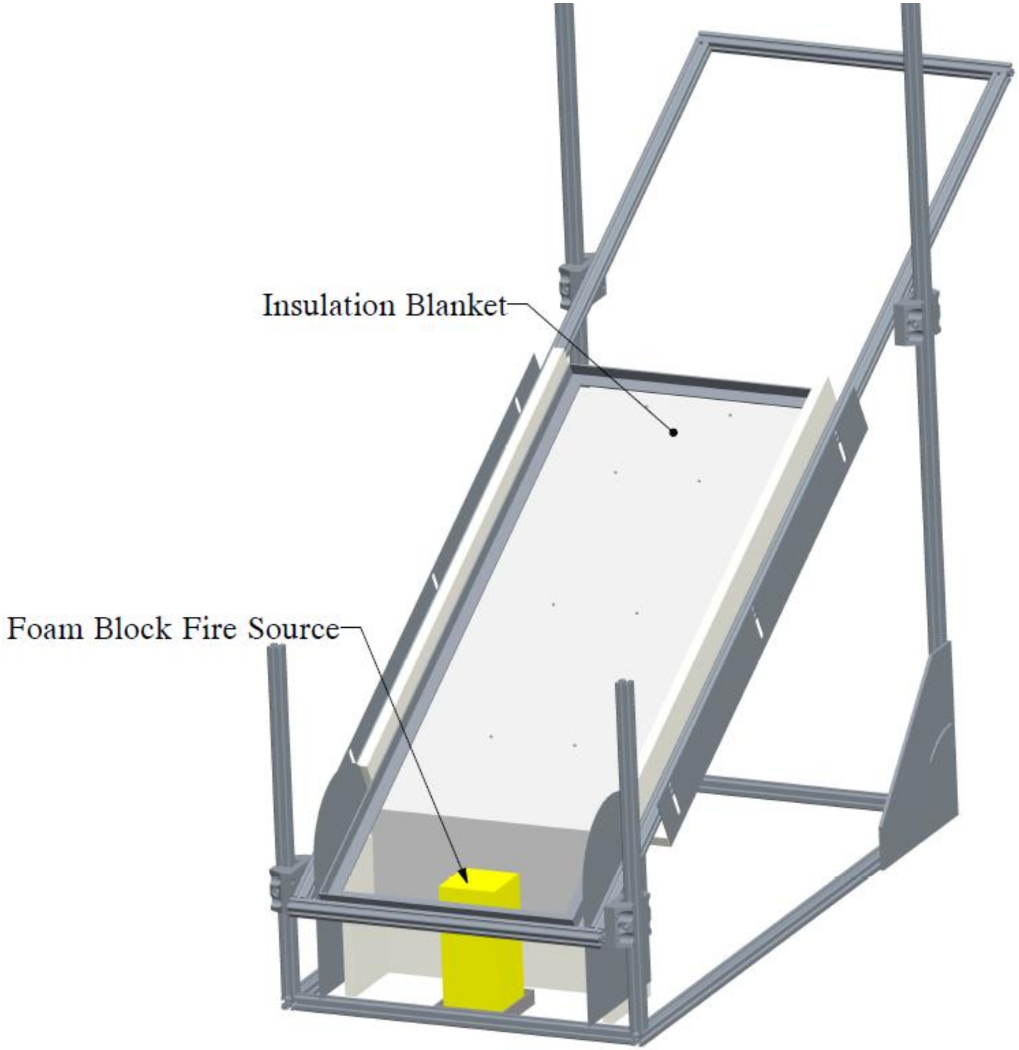
- **Tests were performed to determine the influence of a variety of configurational factors on inboard flame propagation of composite fuselage panels**
  - Insulation-panel spacing
  - Heat retention near panel surface
  - Outboard surface heat loss
- **The original foam block fire source and test rig were used**
- **CFRP panels were procured for this testing**
  - 0.1” thickness
  - Quasi-isotropic tape layup, single outer ply of woven fabric
  - 350°F cure toughened epoxy

# Test Series

- **Flat Panel Tests**
  - Baseline
  - Thermal-Acoustic insulation blanket between inboard face of test panel and test rig shroud
    - Vary gap from tightly pressed up to panel → 1” gap
  - If significant flame propagation is found,
    - Determine if increasing the rate of heat transfer from the outboard surface influences inboard flame propagation
- **Simulated Structure and Panel Tests**
  - Determine if both the structure and panel will propagate flames under conditions found previously
  - Determine if increasing the rate of heat transfer from the outboard surface influences inboard flame propagation
- **Simulated Primary Lithium Battery Powered Electronic Locator Transmitter (ELT) failure adjacent to CFRP panel**
  - Higher intensity fire source
  - Determine if this fire source will cause CFRP panel to propagate flames similar to foam block
  - Will more intense fire source overcome increased rate of heat transfer from the outboard surface?



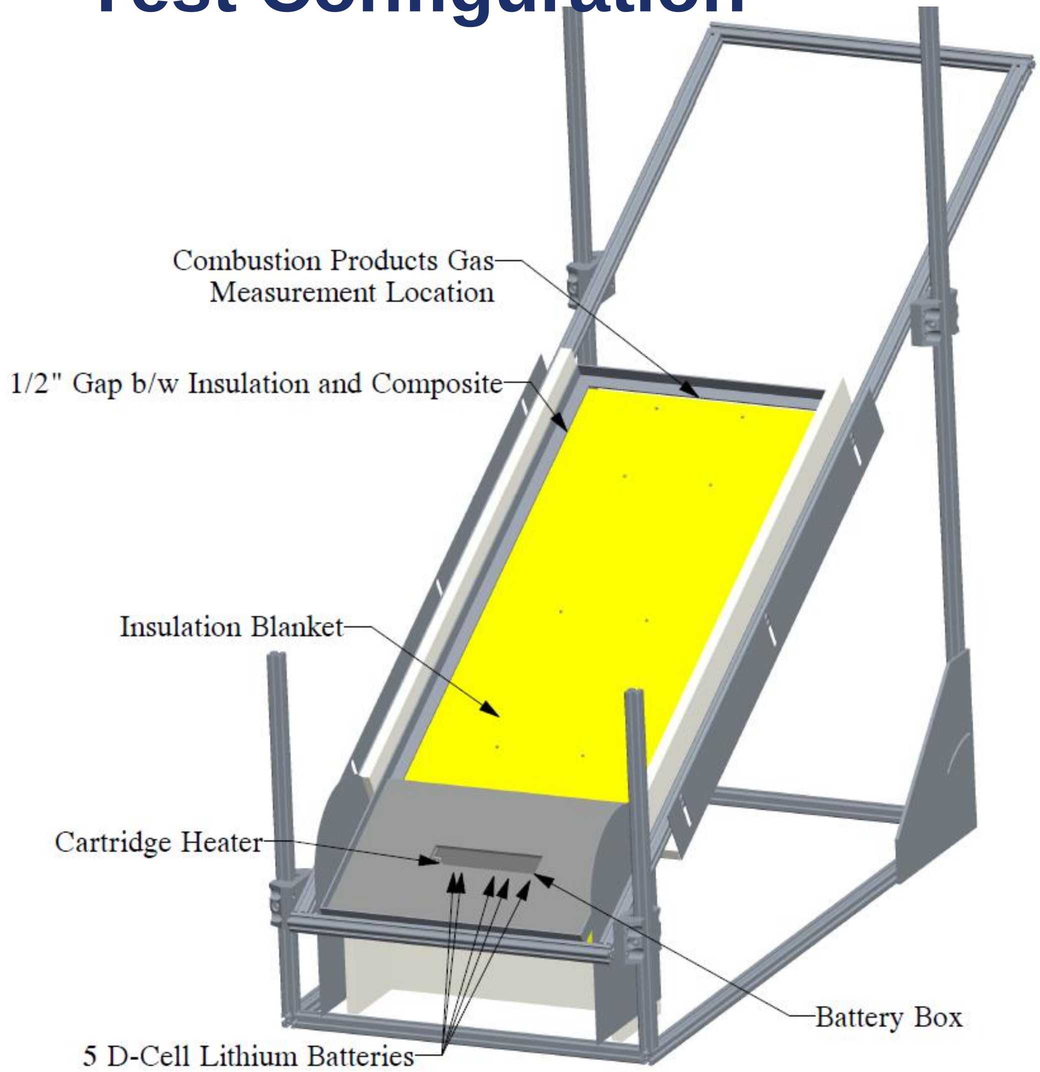
# Foam Block Test Configuration



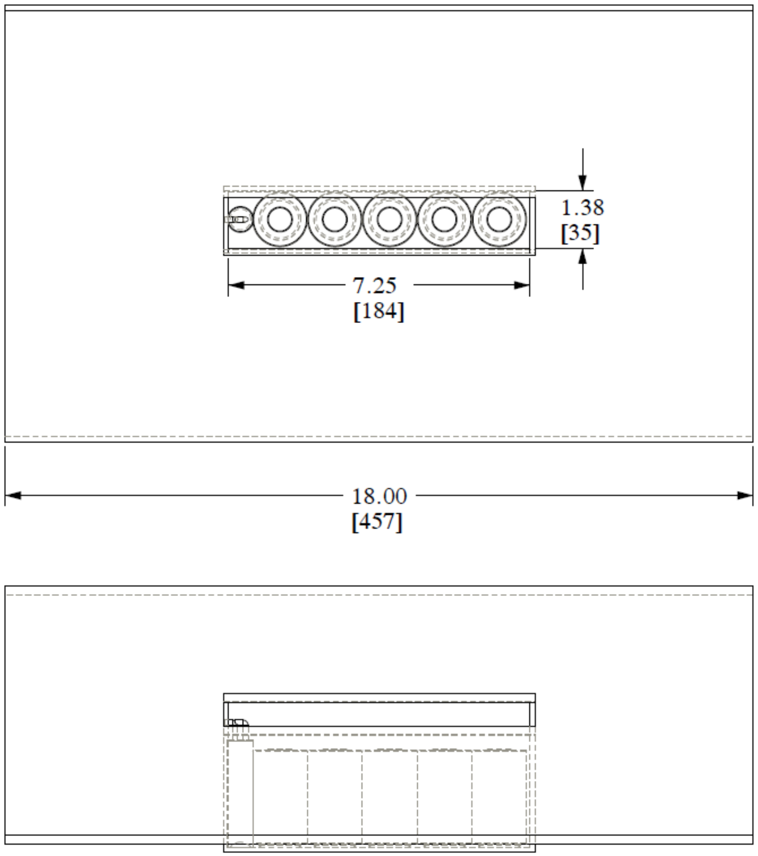
# Test Matrix:  Foam Block Ignition Source

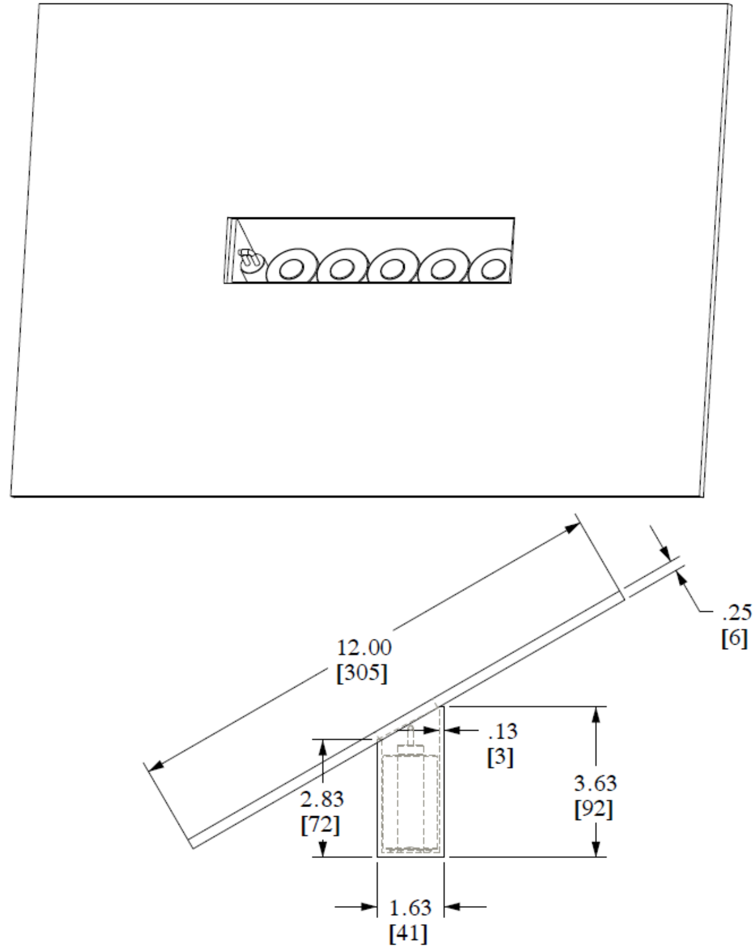
| Date | Test Name | Configuration | Insul. Dist. | Burn Length | Burn Width |
|---|---|---|---|---|---|
| 1/22/2015 | Baseline | Std. Config. | n/a | 6.5625 | 6.6875 |
| 1/22/2015 | Insulation 1 | Insul Pressed Tightly to Skin | 0 | 0 | 0 |
| 1/26/2015 | Insulation 2 | Insul Pressed Tightly to Skin | 0 | 7.5 | 15.25 |
| 1/27/2015 | Insulation 3 | Insul slightly further from skin | 0.5 | 10 | 15 |
| 1/27/2015 | Insulation 4 | Insul further from skin | 1 | 9.25 | 6.25 |
| 1/28/2015 | Insulation 5 | Insul closer, added gasket | 0.5 | 46 | 12 |
| 3/4/2015 | Insulation 6 | Insulation 5 w/water cooling | 0.5 | 0 | 0 |
| 3/9/2015 | Insulation 7 | repeat of insulation 6 | 0.5 | 0 | 0 |
| 3/17/2015 | Insulation 8 | CFRP with frames | 0.5 | 46 | 12 |
| 3/19/2015 | Insulation 9 | CFRP with frames & water cooling | 0.5 | 3 | 3 |
| 3/24/2015 | Insulation 10 | CFRP frames & stringers | 0.5 | 16 | 14 |
| 3/27/2015 | Insulation 11 | CFRP frames & stringers (flipped panel) | 1 | 2 | 5 |
| 4/2/2015 | Insulation 12 | CFRP frames & stringers | 1 | 8 | 7 |
| 4/2/2015 | Insulation 13 | CFRP frames & stringers (flipped panel) | 1 | 9 | 8 |
| 4/2/2015 | Insulation 14 | CFRP frames & stringers (sealed w/RTV) | 1 | 7 | 4 |
| 4/30/2015 | Insulation 15 | CFRP frames & stringers (flipped panel+RTV) | 0.5 | 8 | 5 |
| 4/30/2015 | Insulation 16 | CFRP frames & stringers (sealed w/RTV) | 0.5 | 33.5 | 14 |
| 5/28/2015 | Insulation 17 | Insulation 16 w/water cooling | 0.5 | 9 | 9.75 |

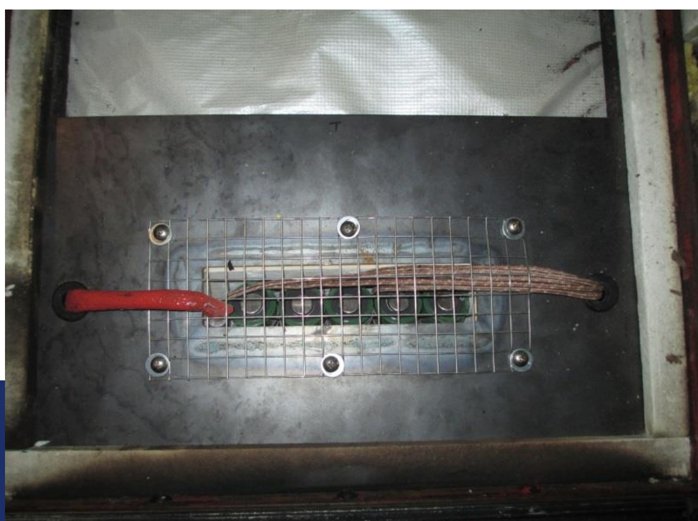
# Lithium Battery Ignition Source Test Configuration



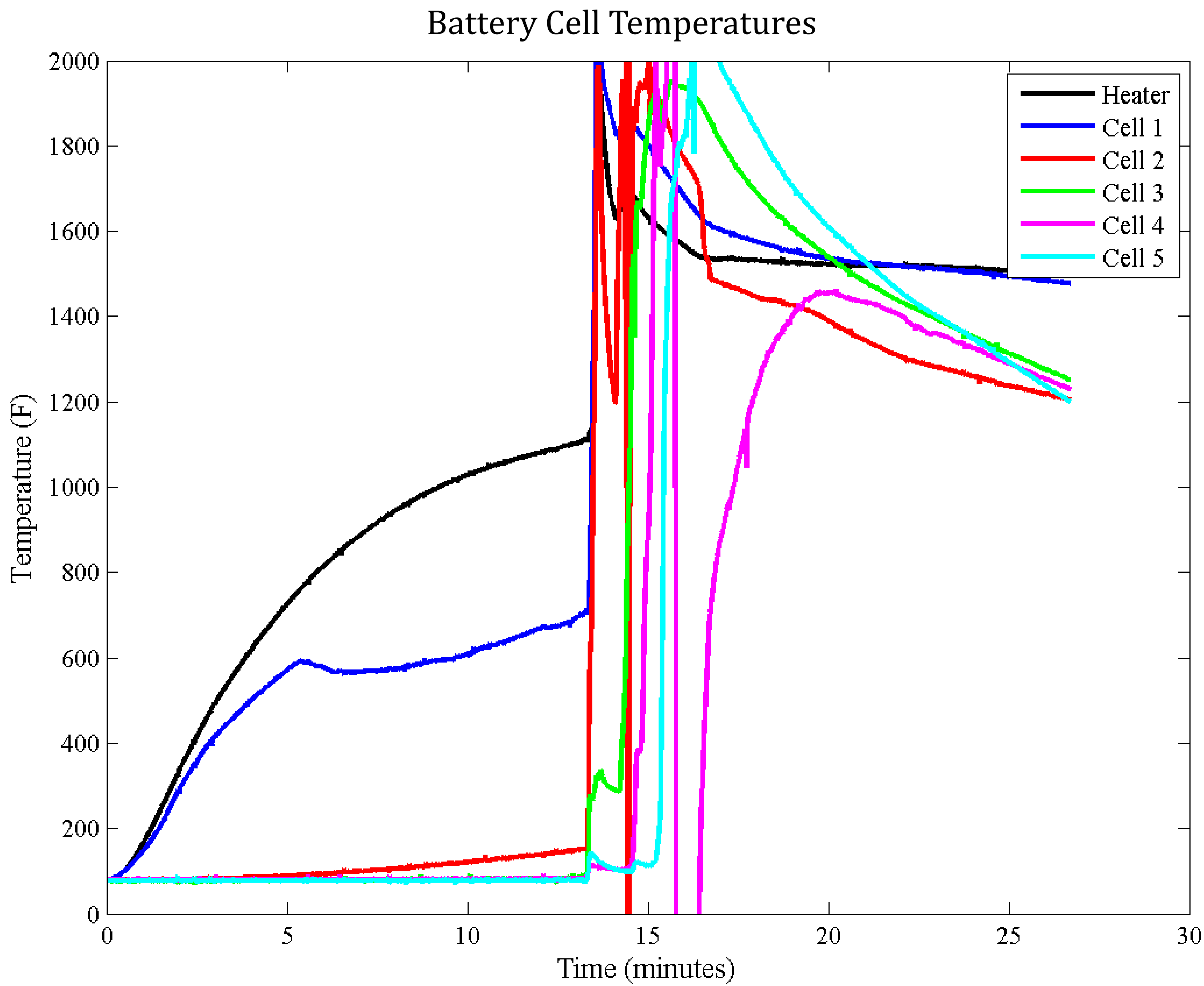

- **Lithium Battery Test Configuration**
  - 5 D-Cell Lithium batteries (non-rechargeable)
  - Battery box insulated w/ ½" ceramic fiberboard
  - Battery box surface within ½" of CFRP inboard panel surface
  - Insulation blanket placed between shroud and inboard face of CFRP panel
  - Thermocouples penetrate through insulation blanket, within ¼" of CFRP panel surface
  - Thermocouples on each battery cell and on cartridge heater



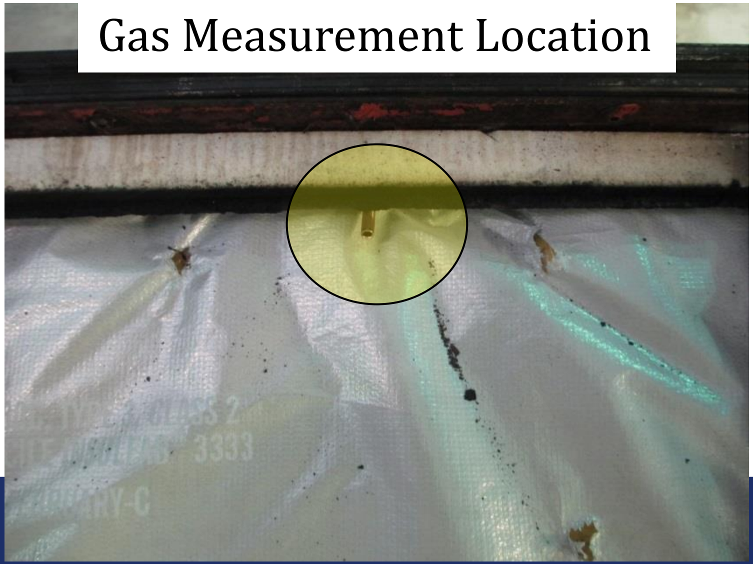



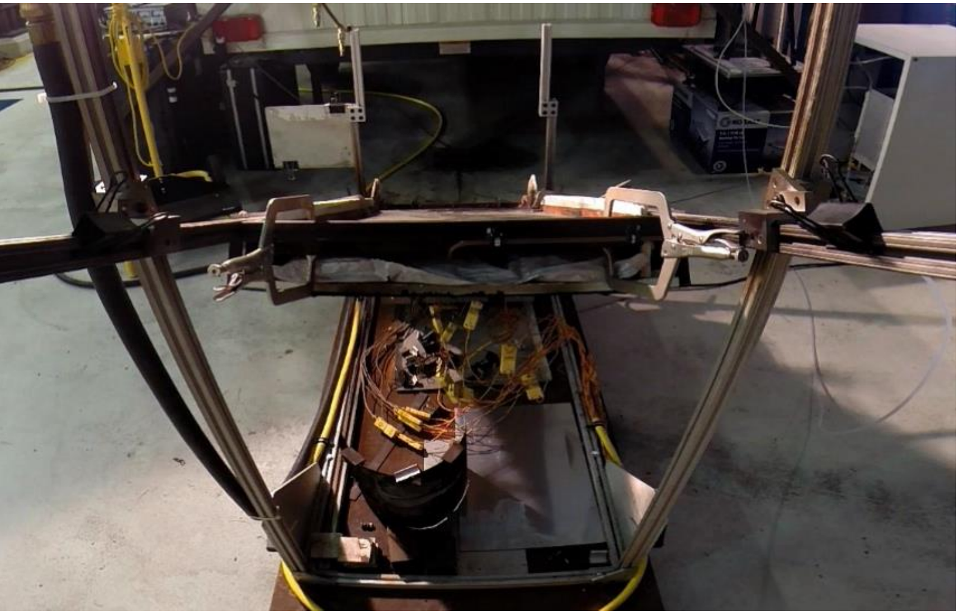
# Battery Configuration

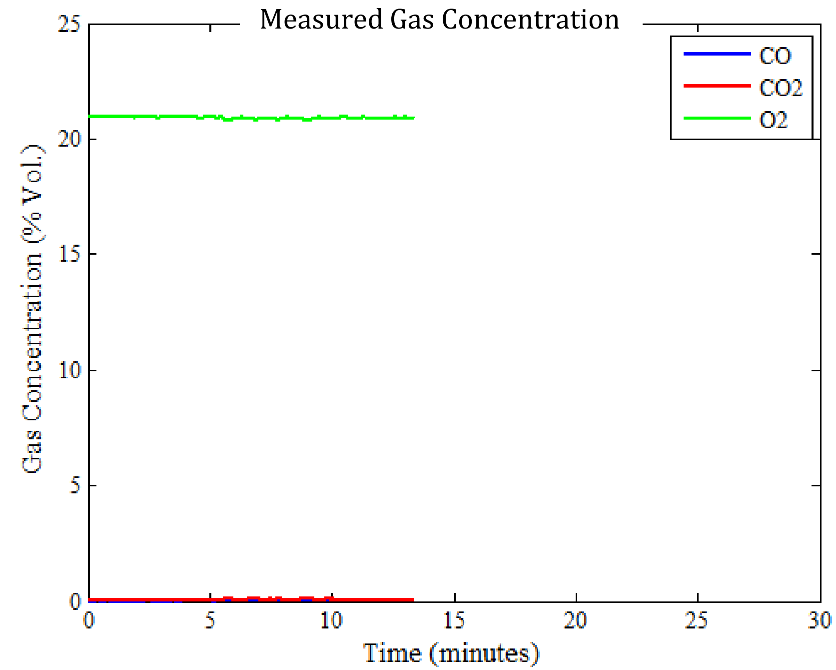

Battery Cell Temperatures
Temperature (F)
Time (minutes)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
5
10
15
20
25
30
Heater
Cell 1
Cell 2
Cell 3
Cell 4
Cell 5

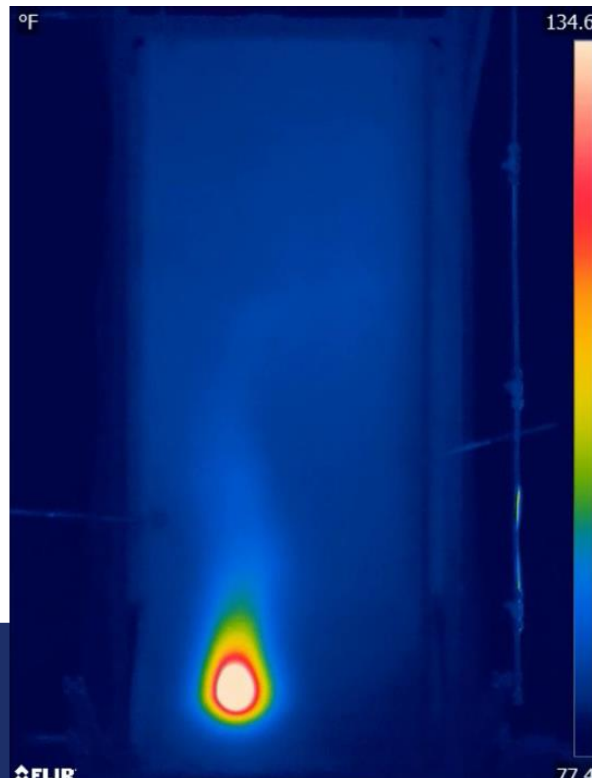
# Gas Analyzers

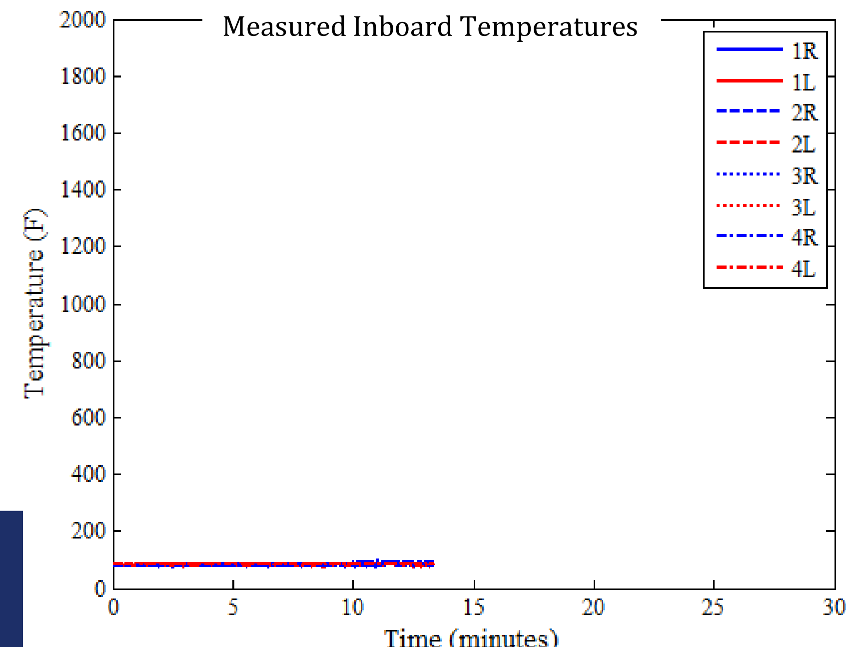



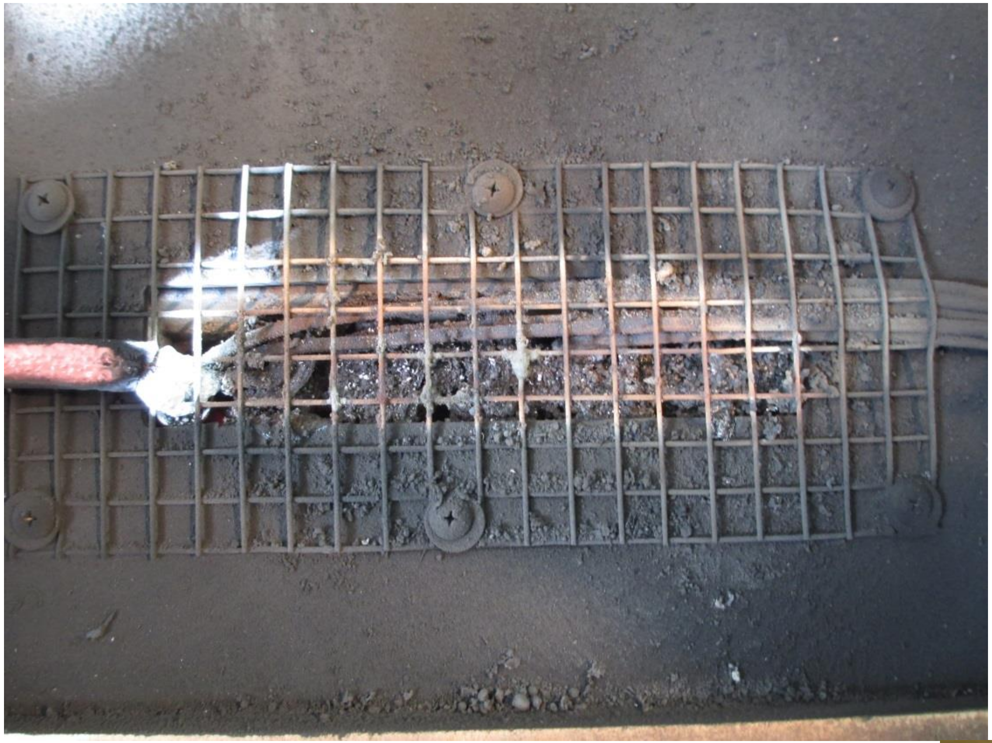

- Non-dispersive IR Measurement of CO and $CO_2$
- Paramagnetic Measurement of $O_2$
- Single stream sample plumbed in series
- Filtered and dried to 1 micron & 5°C dew point
- 6 Lpm flowrate
- Approx 20’ of ¼” sample line




Measured Gas Concentration
CO
CO2
O2
Gas Concentration (% Vol.)
0
5
10
15
20
25
30
Time (minutes)

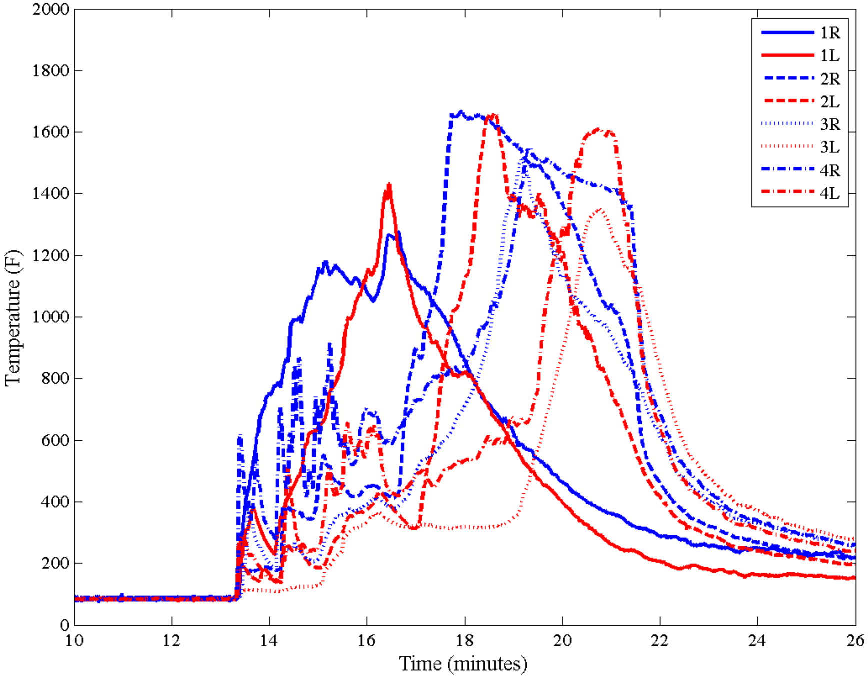

°F
134.6
77.4


Measured Inboard Temperatures
1R
1L
2R
2L
3R
3L
4R
4L
Temperature (F)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
5
10
15
20
25
30
Time (minutes)

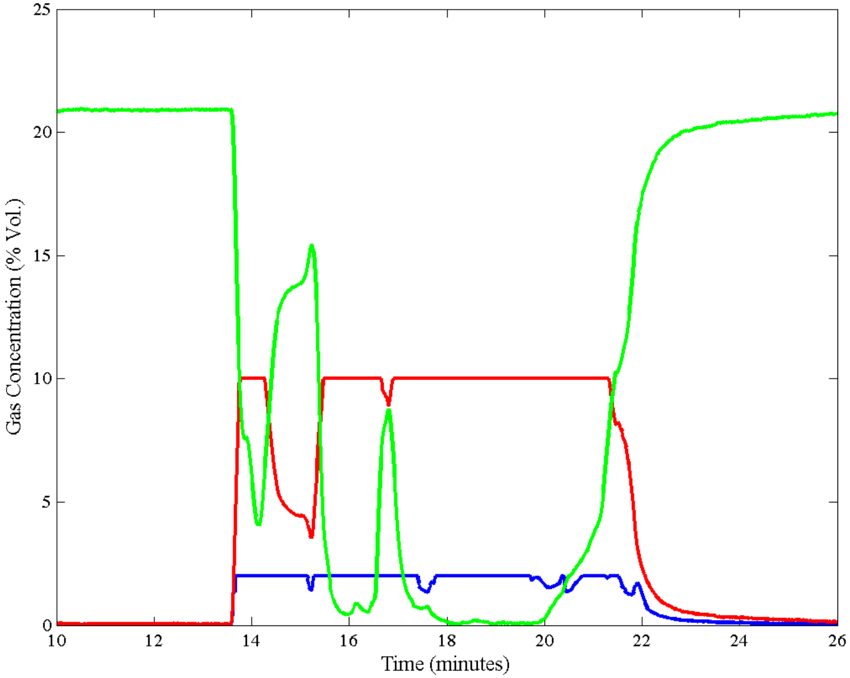



# 10 Ply CFRP, Battery Ignition Source

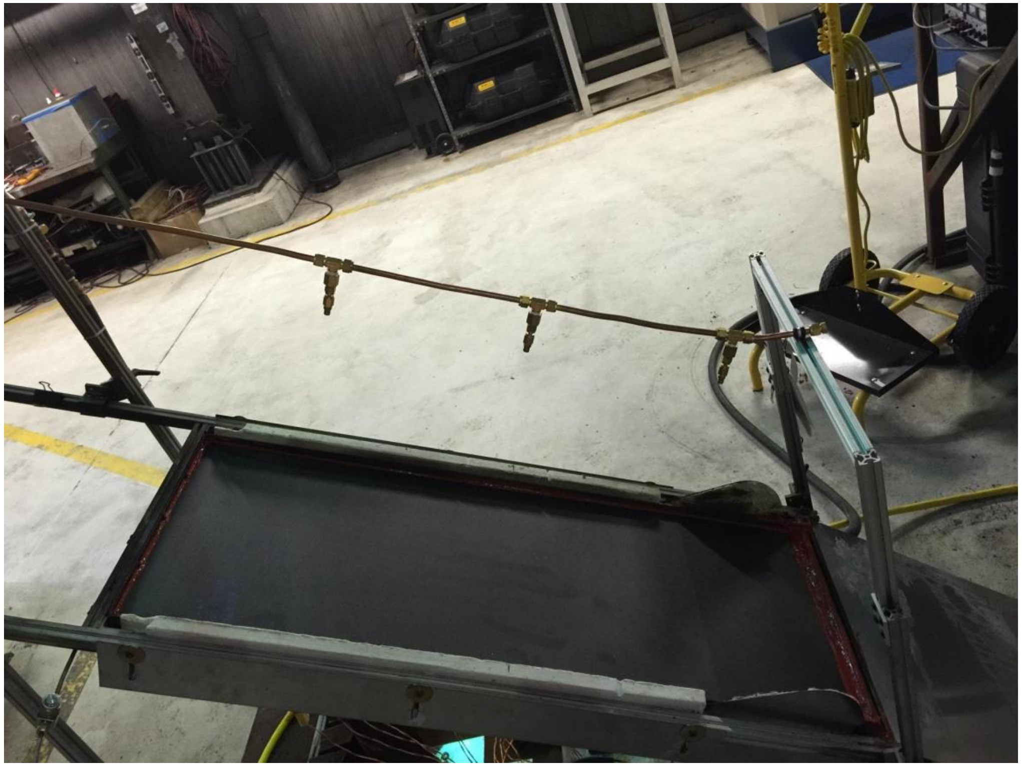
**Inboard Panel Temperatures**

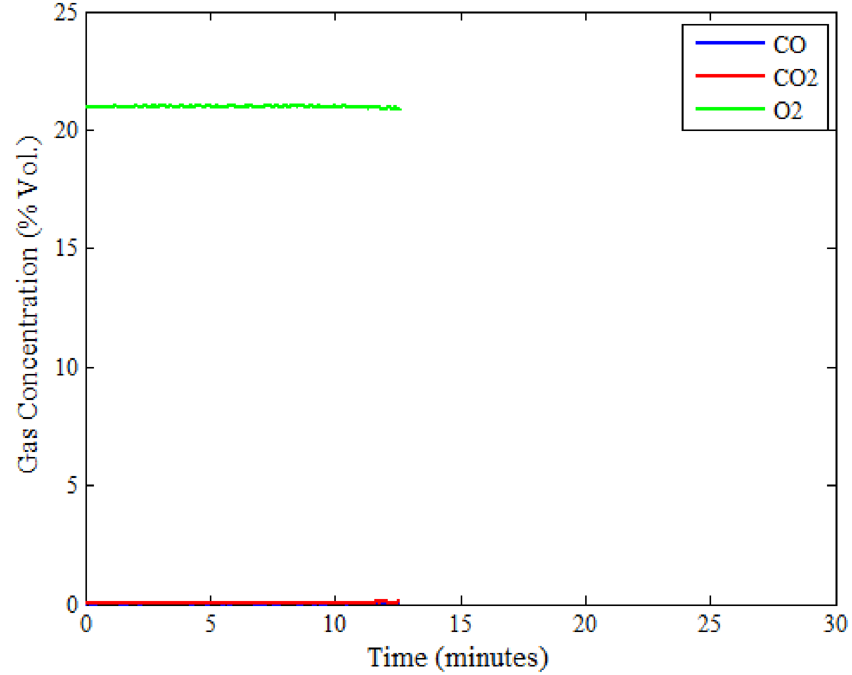



**Measured Gas Concentrations**

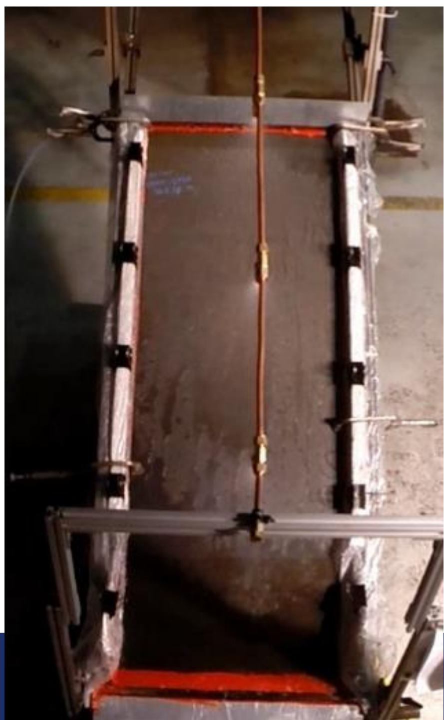


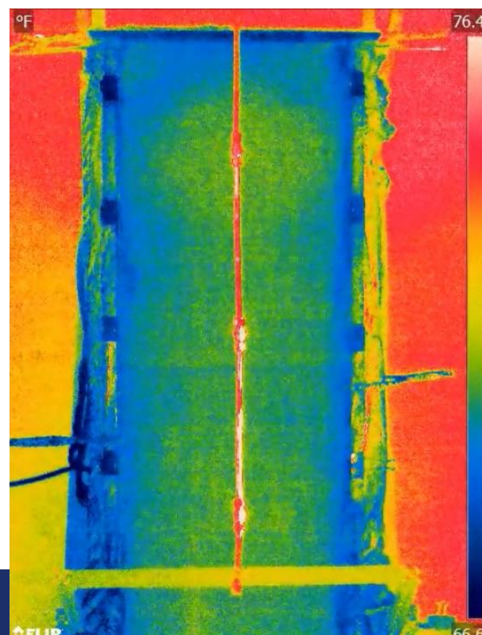
# Repeat with water spray cooling on outboard surface



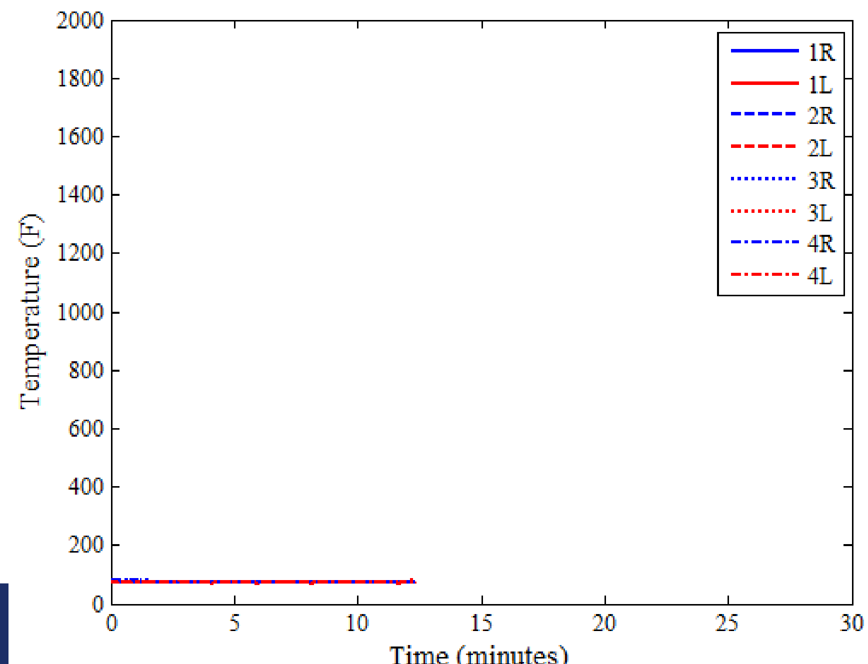


Gas Concentration (% Vol.)
Time (minutes)
0
5
10
15
20
25
30
CO
CO2
O2



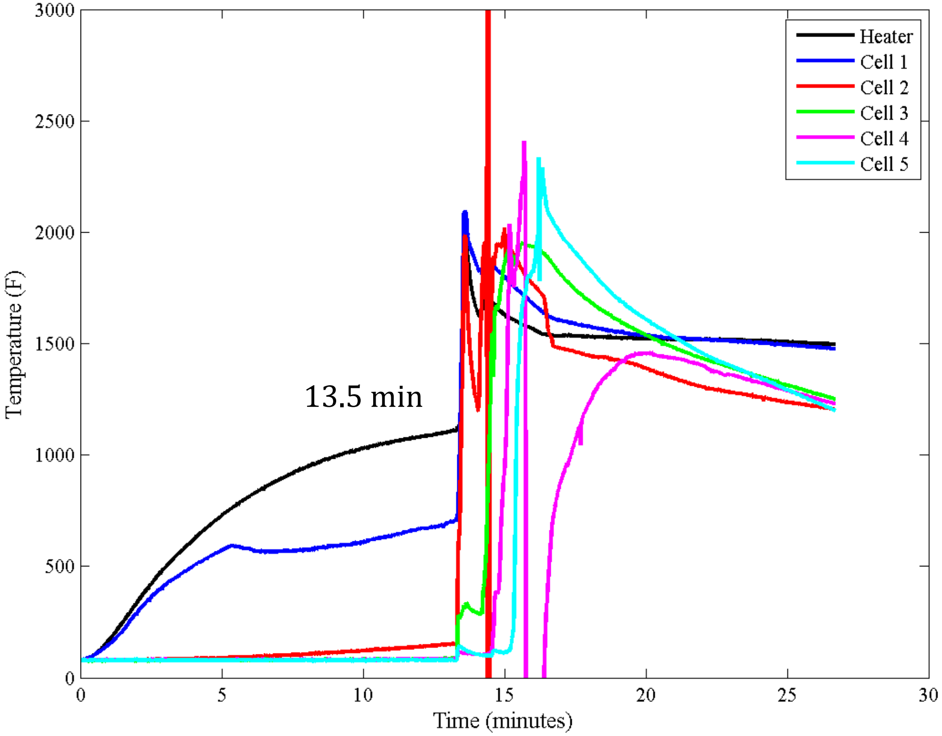
°F
76.4
66.6
FLIR

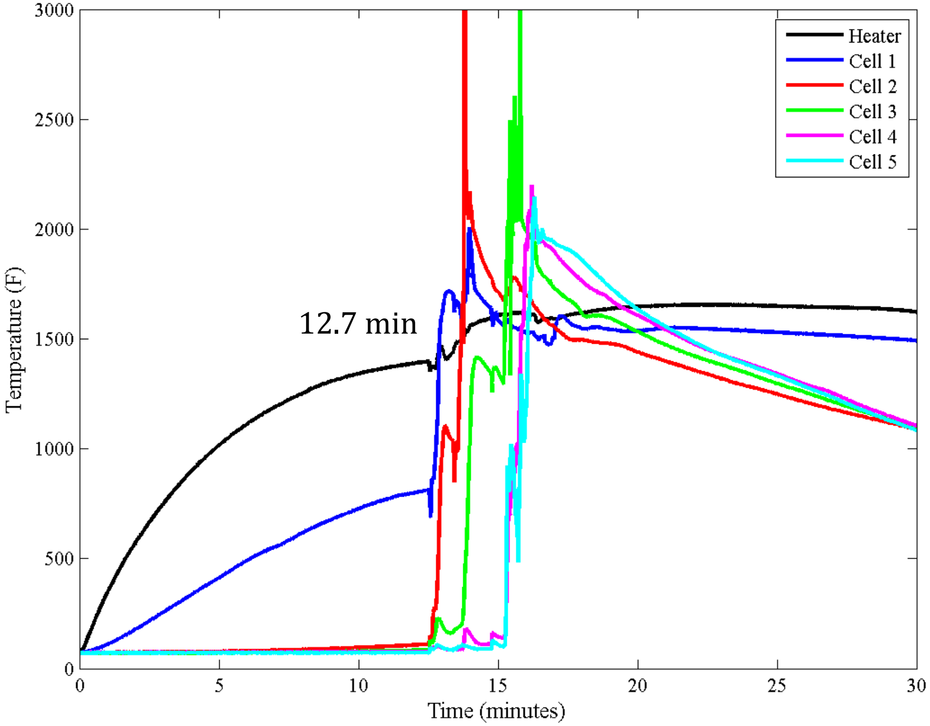
Temperature (F)
Time (minutes)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
5
10
15
20
25
30
1R
1L
2R
2L
3R
3L
4R
4L

# Comparison: Static Ambient vs. Cooled Backside
# Heater and Battery Cell Temperatures

## Static Ambient

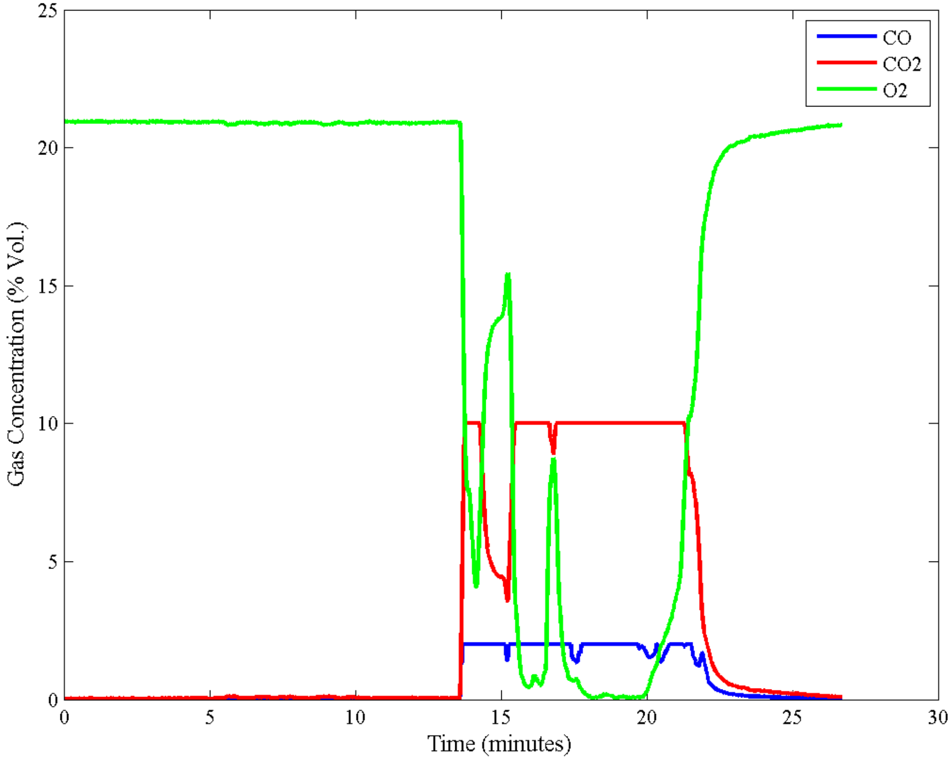



## Cooled Backside

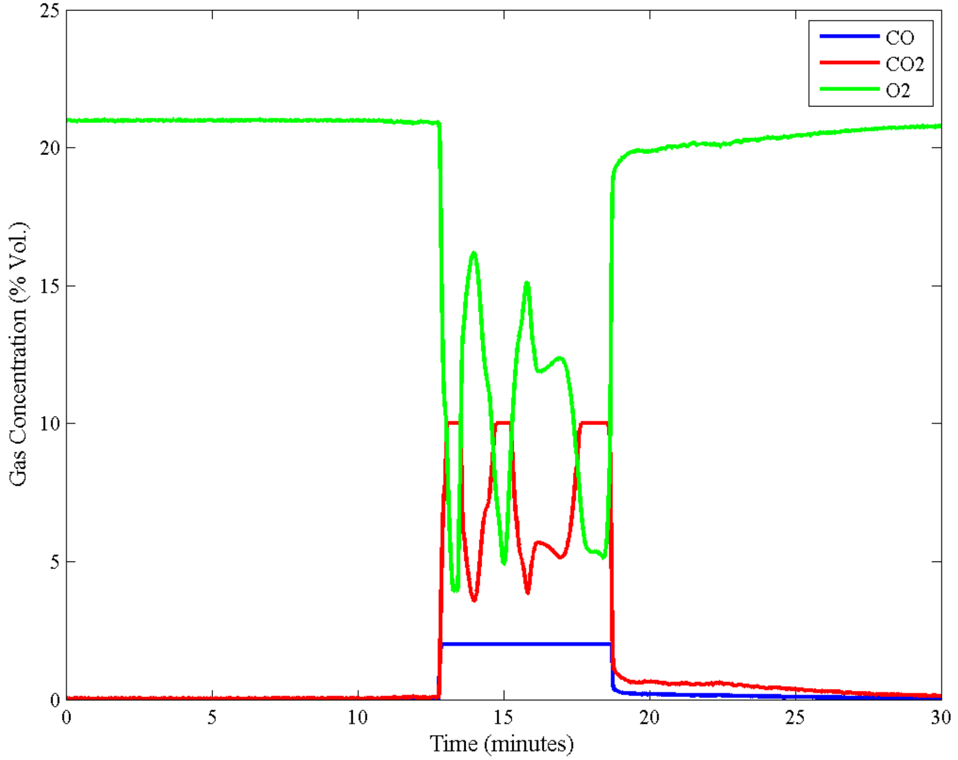


# Comparison: Static Ambient vs. Cooled Backside
# Measured Exit Gas Concentrations

## Static Ambient

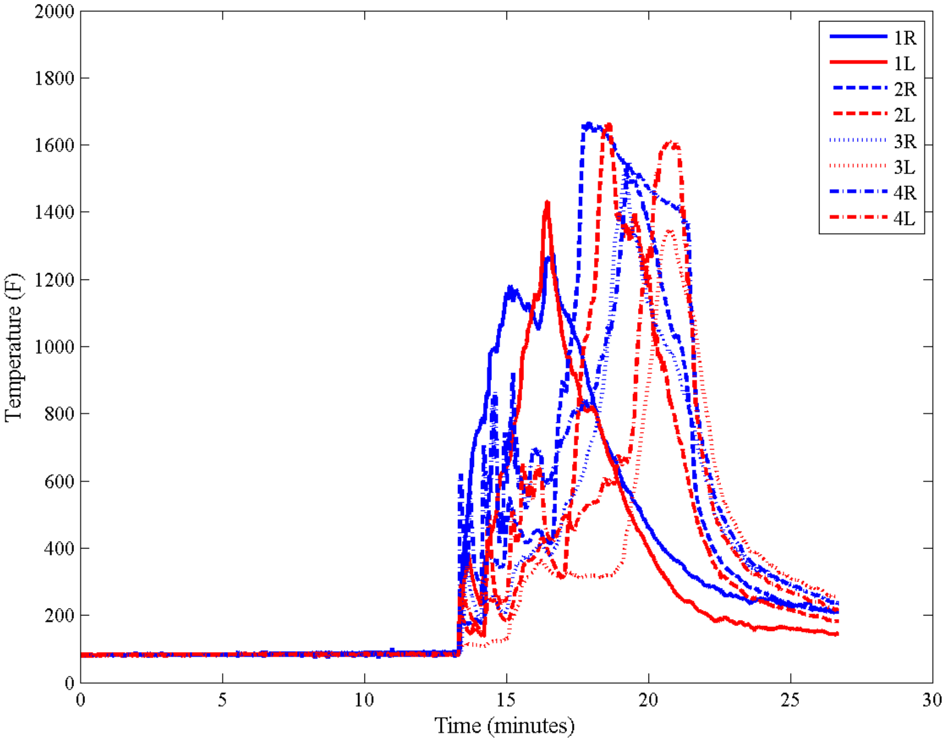



## Cooled Backside

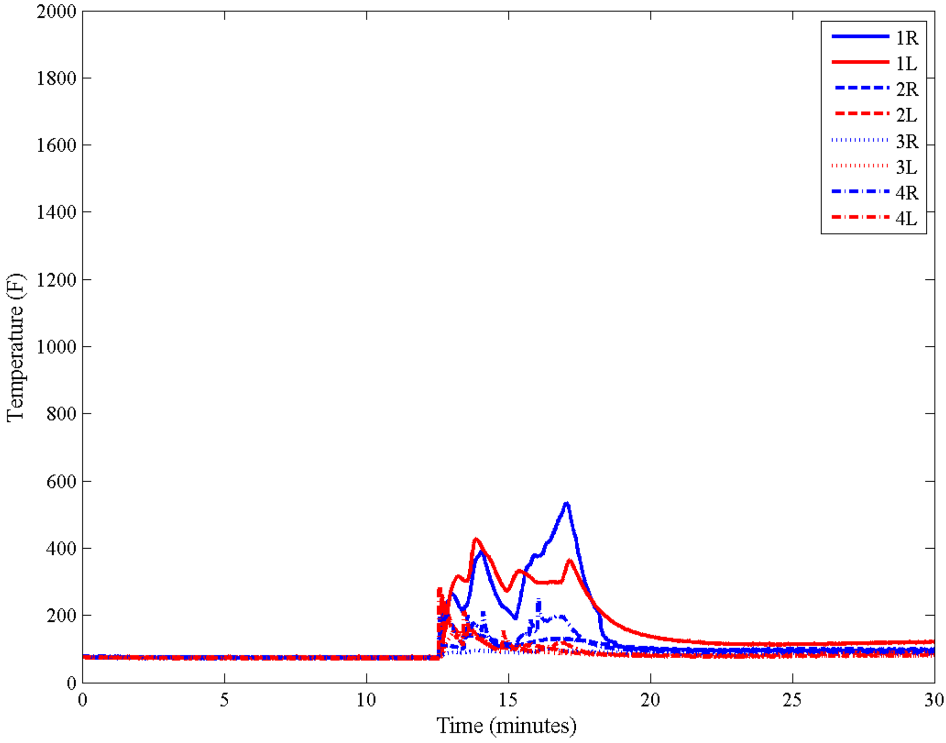


# Comparison: Static Ambient vs. Cooled Backside
# Inboard Panel Temperatures

## Static Ambient

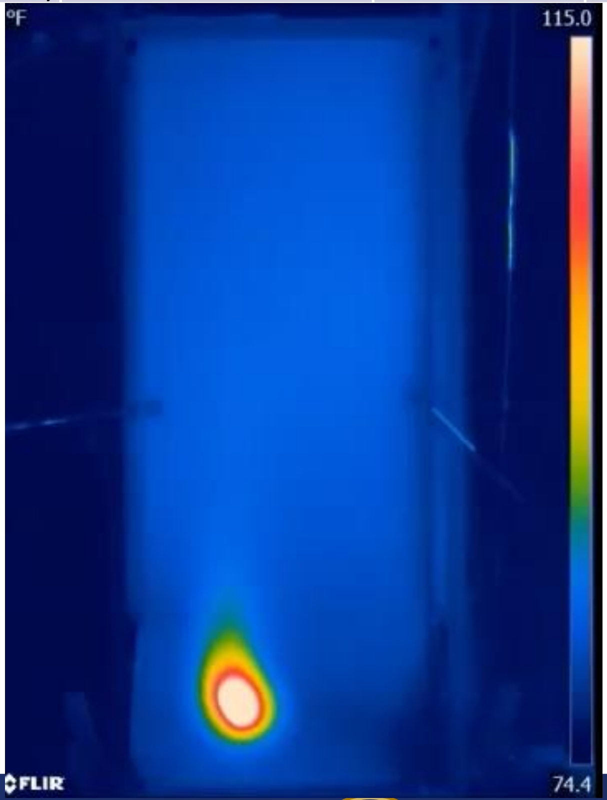



## Cooled Backside



# Test Matrix:  Lithium Battery Ignition Source

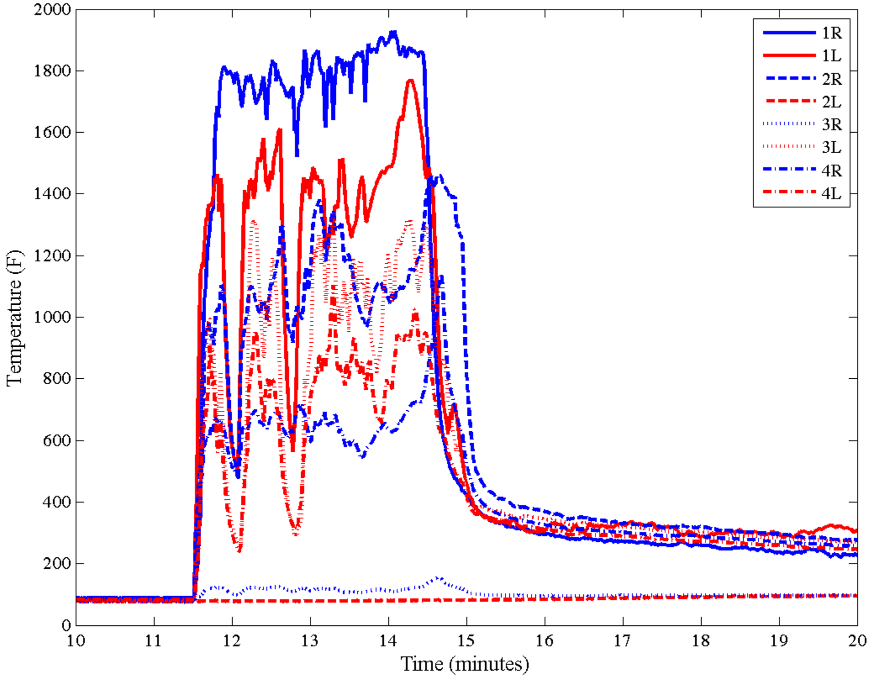
| Date | Test Name | Configuration | Panel Thickness (in.) | Insul. Dist. (in.) | Burn Length (in.) | Burn Width (in.) |
|---|---|---|---|---|---|---|
| 7/9/2015 | ELT 1 | Simulated ELT, insulation, no cooling | 0.098 | 0.5 | 46 | 15 |
| 7/16/2015 | ELT 2 | Simulated ELT, insulation, w/cooling | 0.098 | 0.5 | 3 | 6 |
| 8/6/2015 | ELT 3 | Simulated ELT, insulation, no cooling, 32 Ply | 0.366 | 0.5 | 17 | 10.5 |
| 8/13/2015 | ELT 4 | Simulated ELT, insulation, no cooling, 24 Ply | 0.275 | 0.5 | 24 | 10 |
| 8/25/2015 | ELT 5 | Simulated ELT, insulation, no cooling, 16 Ply | 0.13 | 0.5 | 43.5 | 15.5 |



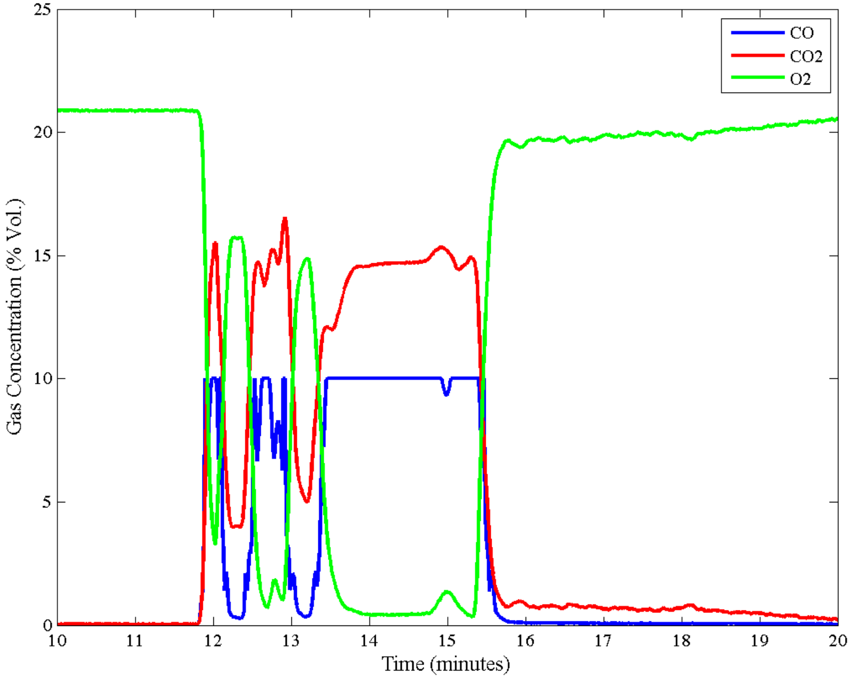

*24 Ply CFRP*

# 24 Ply CFRP, Battery Ignition Source

**Inboard Panel Temperatures**




**Measured Gas Concentrations**



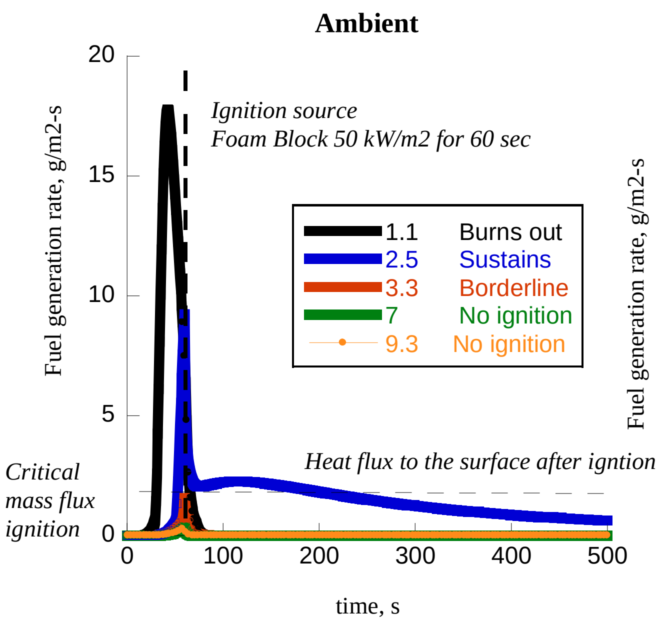
# ThermaKin set-up: Perform 1D simulations, mass loss rate (MLR) as output

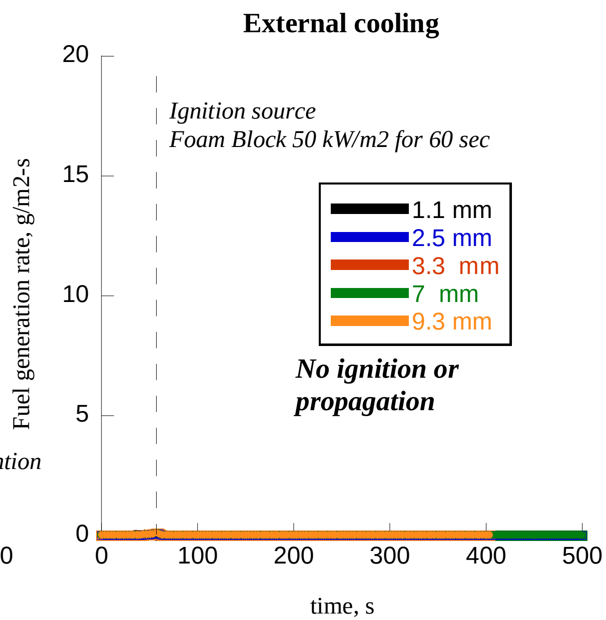
Ignition source

Composite

Outside surface

Thickness: 1-9 mm




Model Input Parameters:

- **Composite** description

Density, thermal conductivity, heat capacity, etc. Can be obtained from lab tests

- **Ignition source** (foam block, battery set). External flux, duration. Can be obtained from literature, thermocouples.

- **Boundary conditions**

➢ ***Outside*** (ambient, external cooling)
➢ ***Inside*** ( open composite, channel)

- **Heat generation process**

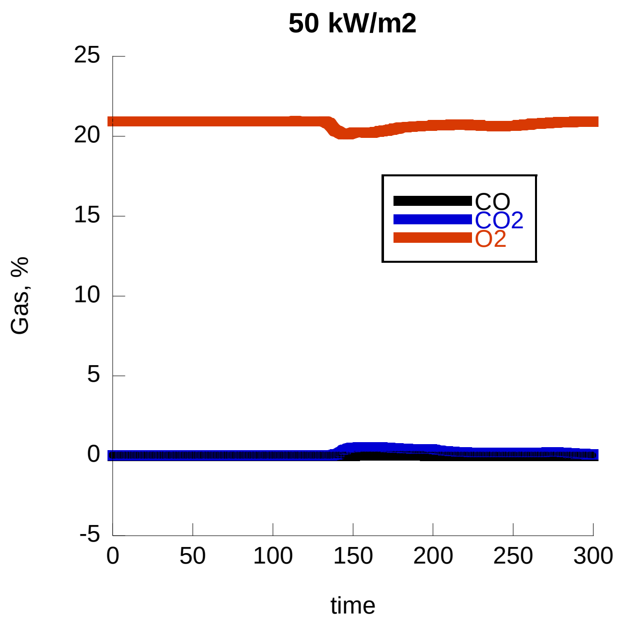
( e.g. smoldering, carbon fiber oxidation) can be obtained from $CO/CO_2/O_2$ analyzes

## Gas $CO/CO_2/O_2$ analyzers data

***Main goal for the gas analyzers data is to determine the driving force behind heat generation process***

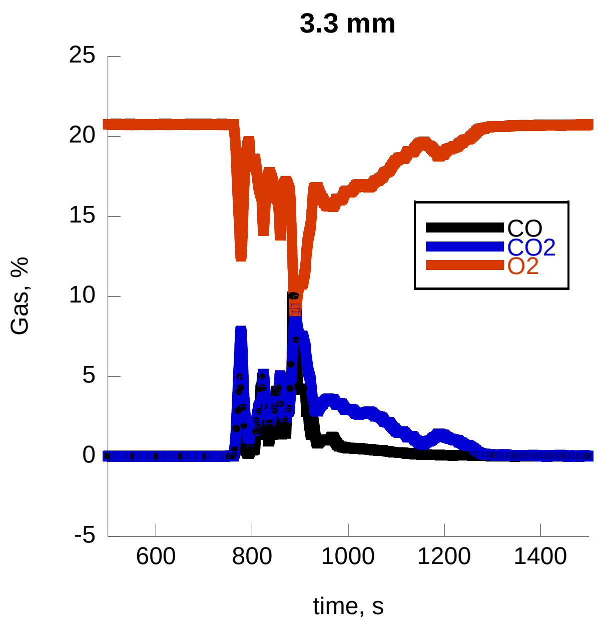
Cone calorimetry

Over-ventilated, excess $O_2$




Inaccessible Area Fire Tests

O2 starved




| Cone calorimetry | $CO_2/CO$ ratio |
|---|---|
| ➢ Flaming combustion | 30/1 |
| ➢ After flame out (smoldering) | 15/1 |
| Inaccessible area fire test (1100-1300 sec, after main battery event) | 9/1 |

***Fuel Oxidation Kinetics***

$$Fuel + \frac{1}{2}O_2 \xrightarrow{k\,CO} CO \qquad \Delta H_1\ C \rightarrow CO\ 110\ \text{kJ/mole}$$

$$CO + \frac{1}{2}O_2 \xrightarrow{k\,CO_2} CO_2 \qquad \Delta H_2\ CO \rightarrow CO_2\ 283\ \text{kJ/mole}$$

Heat generation process inside of the channel is probably **smoldering**, according to CO2/CO ratio

Need to know CO/CO2/O2 concentrations to calculate the heat released during the smoldering process

# Painted Panel Tests

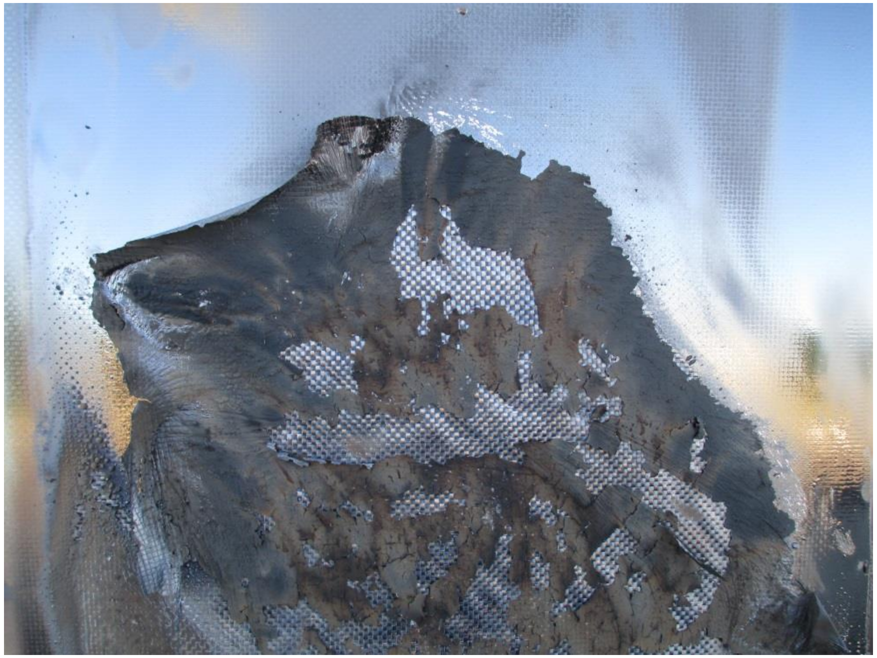
- **.1" CFRP panels painted with aircraft exterior paint (white)**
  - **Eclipse® High Solids Polyurethane Topcoat**
  - **Primer + 3 coats sprayed**
- **Foam block ignition source**
- **Nearly full-length propagation**
  - Inflation of insulation bag created restriction in channel
  - Buoyant products not able to escape freely
  - Fresh air not able to be drawn in
  - Self-extinguished due to lack of available oxygen

Exterior Surface

Interior Surface

**Outboard Surface**

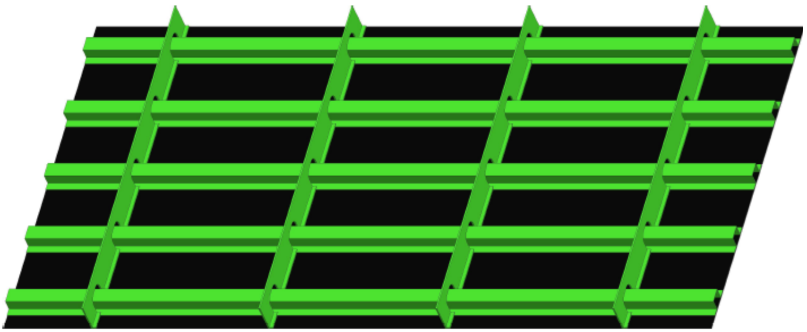
**Inboard Surface**

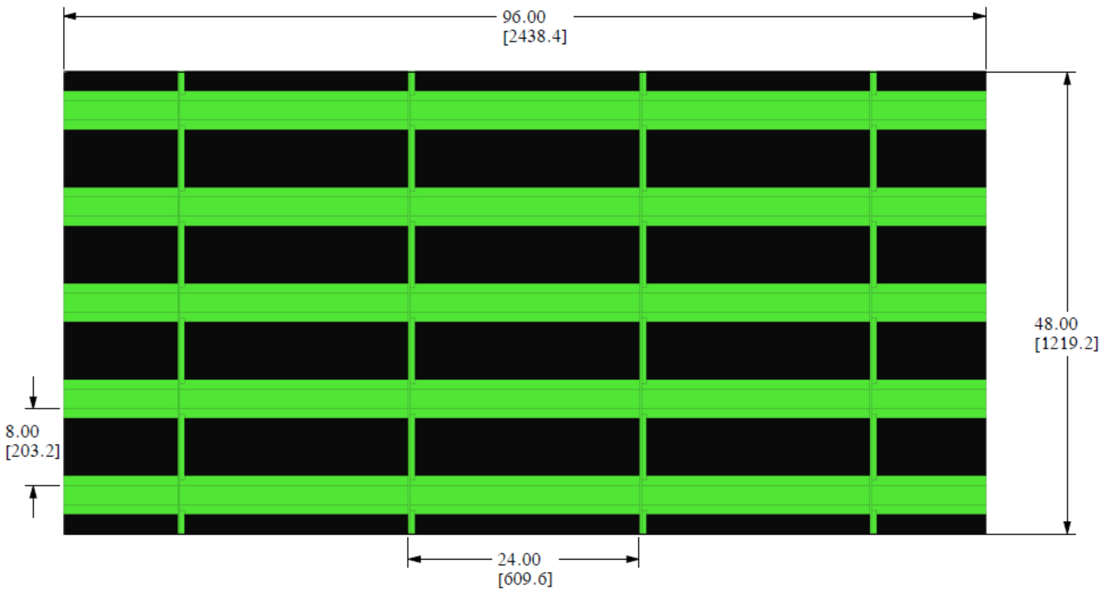


# Next Steps

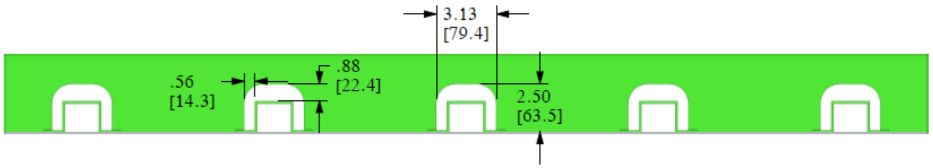
- **Increase measurement range of CO analyzer to 30%**
  - Re-test CFRP 10 ply w/foam block
- **Quantify cooling efficiency**
  - Compare to calculated and/or measured in-flight heat loss rates for CFRP airplanes
- **Once cooling rate is fixed, re-test foam block and Lithium battery configurations w/new cooling rate**

# Large Scale CFRP Skin & Structure Tests

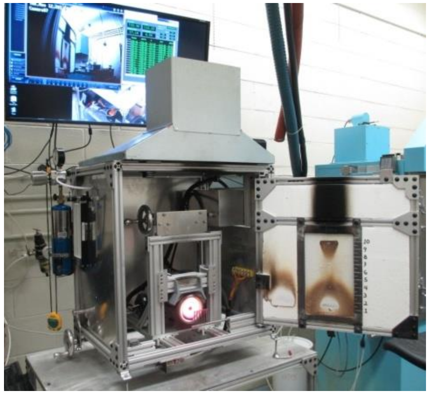





- **Large scale CFRP skin and structure test fixture**
- **Study propagation of fire from bay-to-bay with and without cooling**







Contact:
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