Development of a Flame Propagation Test Method for Inaccessible Area Materials

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IAMFTWG
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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
$T_{measured} = \sum Radiation + Convection$

- Furnace → TC
- Furnace → Board
- TC → Surroundings

Ceramic Fiberboard

Thermocouples

Pilot Burner

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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.

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
# Test Matrix

<table>
<thead>
<tr>
<th>Apparatus</th>
<th>B203</th>
<th>B277</th>
<th>Away</th>
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<td><strong>1</strong></td>
<td>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, 12 tests) T700/TC350: 3x(4, 8, 12, 16 ply, 12 tests)</td>
<td>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, 12 tests) T700/TC350: 3x(4, 8, 12, 16 ply, 12 tests)</td>
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<tr>
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Overall Results
MCC and Cone Calorimeter Study: Evaluation of Repeatability of Material Properties

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<th>Property</th>
<th>% Standard Deviation</th>
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<td>Glass Epoxy</td>
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<td>HRC (J/g-K)</td>
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<tr>
<td>PEAK HRR (W/g)</td>
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<tr>
<td>TOTAL HR (kJ/g)</td>
<td>3.91</td>
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<tr>
<td>T_p (°C)</td>
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<table>
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<th>Property</th>
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<td>Glass Epoxy</td>
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<tr>
<td>PEAK HRR (kW/m²)</td>
<td>27.39</td>
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<tr>
<td>TOTAL HEAT RELEASE (MJ/m²)</td>
<td>14.07</td>
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- 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: Composite Flame Propagation Test Method

Apparatus Dimension Check

1. Measure distance from heater to inner surface of sample holder
   a. Distance is 2.75" (70.025 mm)
2. Measure height from center of coil heater
   a. 1 11/16" (42.8025 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 1/3" 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 1.5 psig
8. Set gas to approx. 25-30 gpm 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

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Draft Test Method Procedure

Pre-Heat Procedure
1. Switch on AC voltage
2. Begin data collection
3. Adjust AC voltage to achieve 876 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 is within ±5%
6. Once the chamber has stabilized, place the vane anemometer holder over the exhaust duct
7. Record the average flow velocity through the entrance
   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 ring
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 30 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 flame 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 layers 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 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
### Minimum 80% Passing Samples

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<th>10</th>
<th>15</th>
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3KPV-8 PLY
4-inch Pass/Fail

100% Passing
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3KPW-8 PLY
3-inch Pass/Fail

39% Passing
3KPW-8 PLY
2.5-inch Pass/Fail

6% Passing
# Varying Pass/Fail Criteria

Overall Pass/Fail for Entire Data Set

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

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Pass / Fail on each apparatus at 2 labs

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<th>Material</th>
<th>Overall Average</th>
<th>Unit 1 203</th>
<th>Unit 1 277</th>
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<td>3KPW-4</td>
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<td>4.36 0% Fail</td>
<td>4.12 33% Fail</td>
<td>4.32 0% Fail</td>
<td>4.15 0% Fail</td>
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<td>3KPW-8</td>
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<td>3.25 67% Fail</td>
<td>3.37 100% Pass</td>
<td>2.90 100% Pass</td>
<td>2.26 100% Pass</td>
<td>2.94 100% Pass</td>
<td>3.45 67% Fail</td>
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<tr>
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Ducts

Cut from duct, flattened  Cut from duct, not flattened  Intact Hoses
Duct Materials – Flat Sheets

![Graph showing foam block burn length and VRP burn length for Duct Sample IDs D1 to D10]
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”

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<th>Identifier</th>
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<td>M81044</td>
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<tr>
<td>M5086</td>
<td>PVC/Nylon</td>
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<tr>
<td>BMS13-60</td>
<td>PTFE/Polyimide</td>
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</table>

**Heat Release Capacity**
- M81044: 373 J/gK
- M5086: 281 J/gK
- BMS13-60: 32 J/gK

**Specific Heat of Combustion**
- M81044: 16 kJ/g
- M5086: 18.6 kJ/g
- BMS13-60: 2.1 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
Contact:
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T 609 485 4651
E robert.ochs@faa.gov