JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

Standardization of Incandescent Ignition Source Detection Methodology for Composite Structure Lightning Testing

Alyssa Gonzalez

NIAR – Wichita State University

JAMS 2019 Technical Review

May 22-23, 2019

Standardization of Incandescent Ignition Source Detection Methodology for Composite Structure Lightning Testing

- Motivation and Key Issues
  - Incandescent particles, hot spots, and edge glow produced by carbon fiber composites have not yet been characterized by their ability to ignite fuel, causing unnecessary failure with current test method.

- Objective
  - Development of a new detection methodology for incandescent ignition sources to reduce the number of edge glow failures that occur with current photographic method.

- Approach
  - Utilize an augmented photographic method to predict ignition conditions of the flammable gas mixture imposed by an incandescent heat source.

CECAM

JAMS
JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

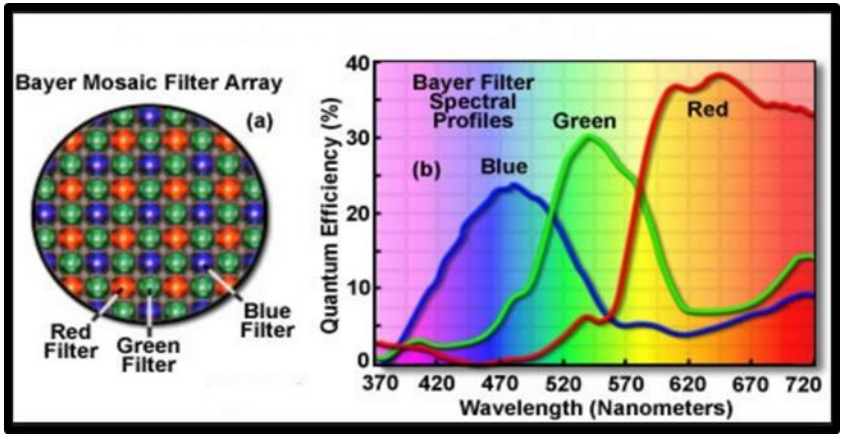
A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

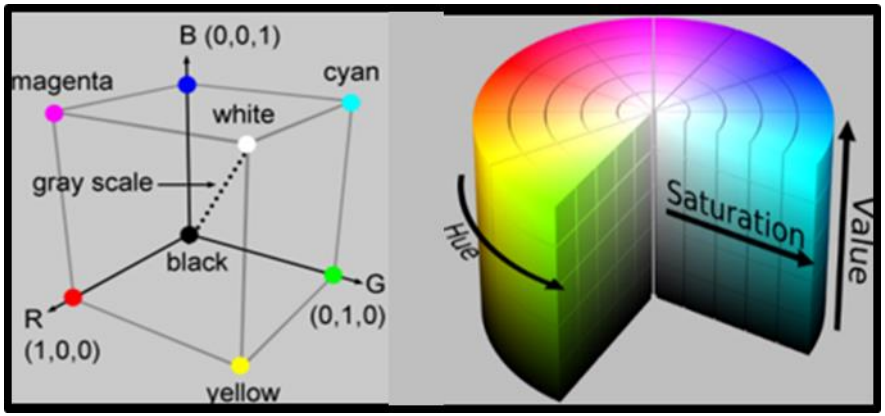
Goals

- Develop a new detection methodology for incandescent ignition sources in order to reduce the number of edge glow failures that occur with current photographic method
  - Current test method deems any light (above the threshold determined through calibration) a failure, which is not closely related to thermal ignition sources found in composites.
- Retain the 200 µJ-based ignition reference, utilize the existing photographic sensor.
- Augment existing SAE ARP 5416A standard
- Reference in the FAA guidance material (AC 20-155A)
- Publication in CMH-17

Digital Color Imaging

- CMOS sensor filters light through red, green, and blue (RGB) filters.
- Each individual pixel measures light intensity through ONE of the color filters.
- An internal camera-specific demosaicing algorithm interpolates individual R, G, and B values for each pixel into a full color image.





- Transformation from RGB color to HSB (Hue, Saturation, Brightness) color space.
- HSB space is a cylindrical-coordinate representation of colors in the rectangular RGB color model.
- The hue component is most important for this analysis.
- Hue histograms are used to determine the hue signature present in the image.

CECAM

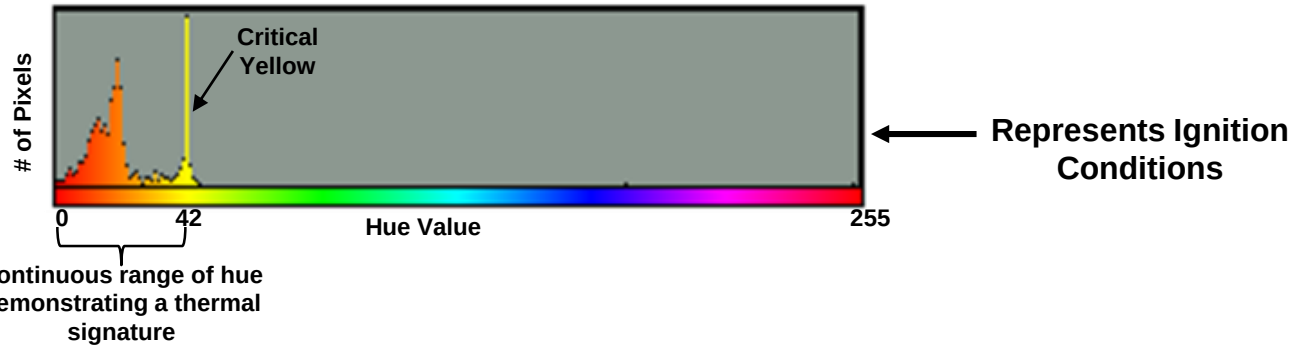
JAMS
JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

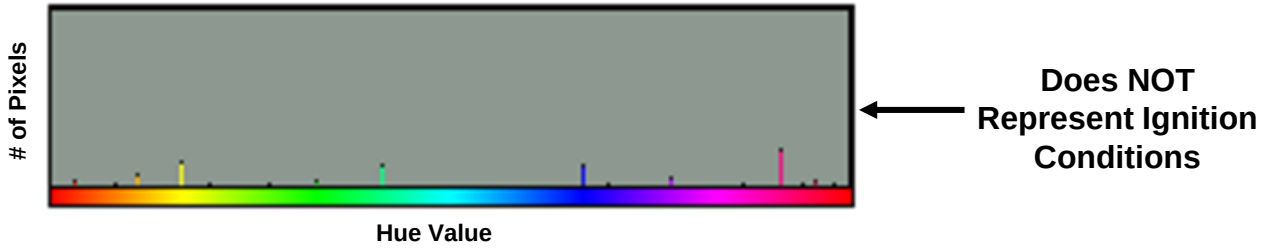
Incandescent Signature of Ignition

1. Continuous range of hue between red-orange-yellow
   – Demonstrates the “red hot” glow of incandescent material
2. Presence of “critical” yellow hue
   – Signals that the material has reached temperature of ignition

The “continuous range” and “critical yellow” must BOTH be present to signal ignition



- Edge glow: No continuous range is present, signaling an absence of a thermal source. The hue spikes can be loosely tied to the emission lines to ionization of air. Does not ignite gas

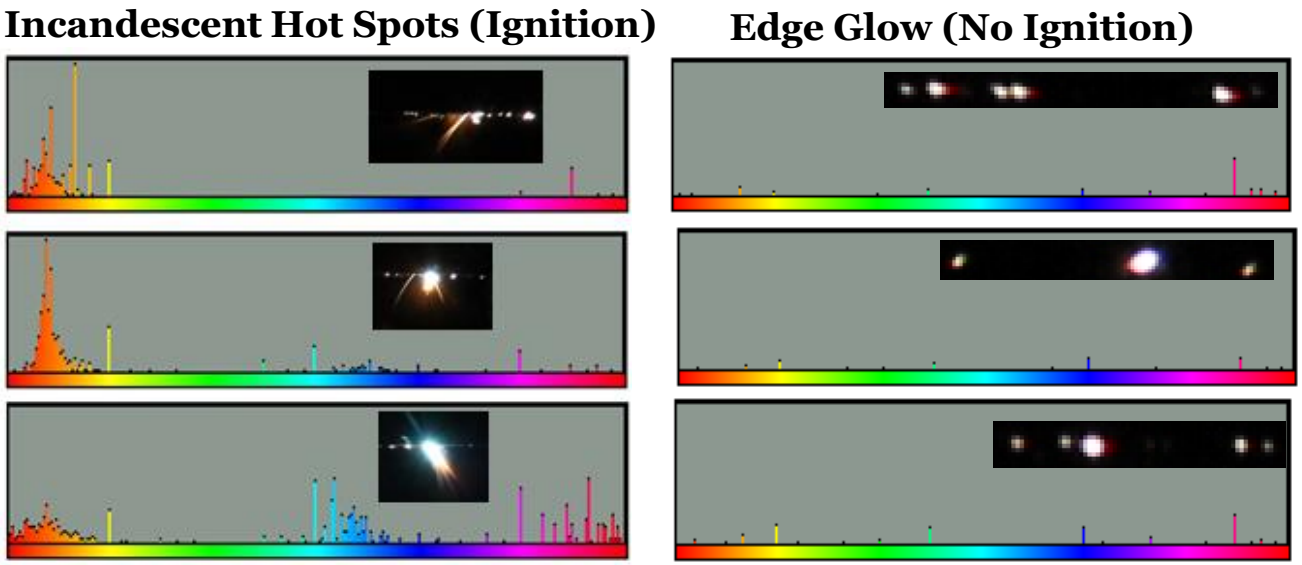


Edge Glow - CFRP Strip

Testing in flammable gas mixture (6 vol % Hydrogen and dry air)

- Ejected particles originate from the hot resin material/expanding air within the matrix.
- Due to complexity of analysis of ejected particles on their ability to cause ignition (size, temperature, velocity, material, etc.) the presence of any ejected matter is excluded from analysis and considered a failure.
- A relationship between brightness of thermal ignition sources with ignition of gas was not established. Sensor saturation was observed even in glows without ejections; therefore the hue component of the image is utilized.

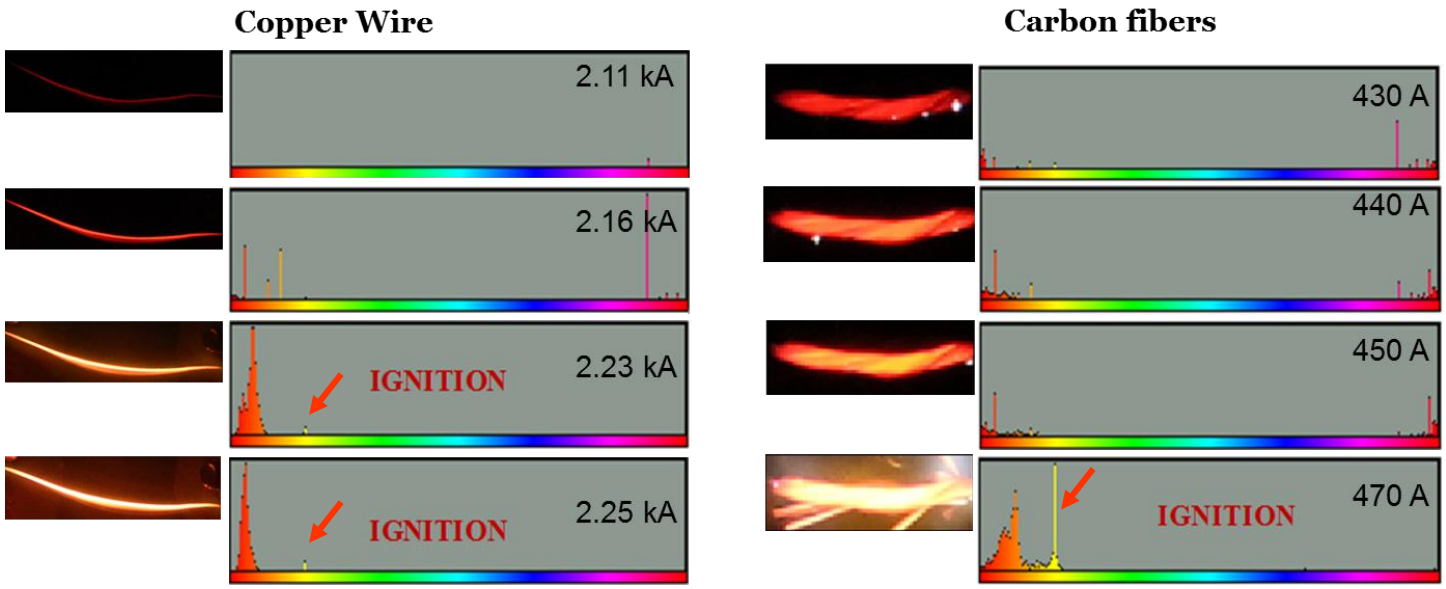
CFRP Edge Glow



Verification of incandescent/thermal signature

Gas ignition coincides with the appearance of the incandescent signature for all investigated materials:

- Tinned copper wire
- Nickel titanium wire
- Steel wire
- Carbon fiber filament bundle
- Carbon fiber filament bundle pre-cut
- CFRP laminates
- CFRP-LSP (ALS and PBLS)



CECAM

JAMS
JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

AMTAS
A Center of Excellence
Advanced Materials in Transport Aircraft Structures

Additional Observations:

1. Metal wires and carbon fiber with continuous spectrum in red-orange but without yellow hue **do not** ignite gas,

2. Edge glow without continuous spectrum in red-orange observable in CFRP and carbon fibers **does not** ignite gas,

3. Metal wires, carbon fibers, and thermal hot spots with continuous spectrum in red-orange and with yellow hue **ignite** gas,

4. Thermal ejections **ignite** gas.

Detailed list of investigated materials

- **Incandescence**
  - Copper wire, 30 AWG (0.25 mm), 60 mm long (AlphaWire & Arcor).
  - Tinned copper wire, 24 AWG (0.51 mm), 60 mm long (Belden)
  - High carbon spring tempered steel wire, 0.64 mm diameter, 60 mm long (Precision Brand Products).
  - Carbon fiber (bundle) 0.22-0.27-mm diameter, 60 mm long (A&P Technology: biaxial carbon fabric BIMAX-H-48.
  - Nitinol wire, 30 AWG (0.25 mm), 60 mm long (Memry)
  - Nichrome wire, 30 AWG (0.025 mm), 60 mm long

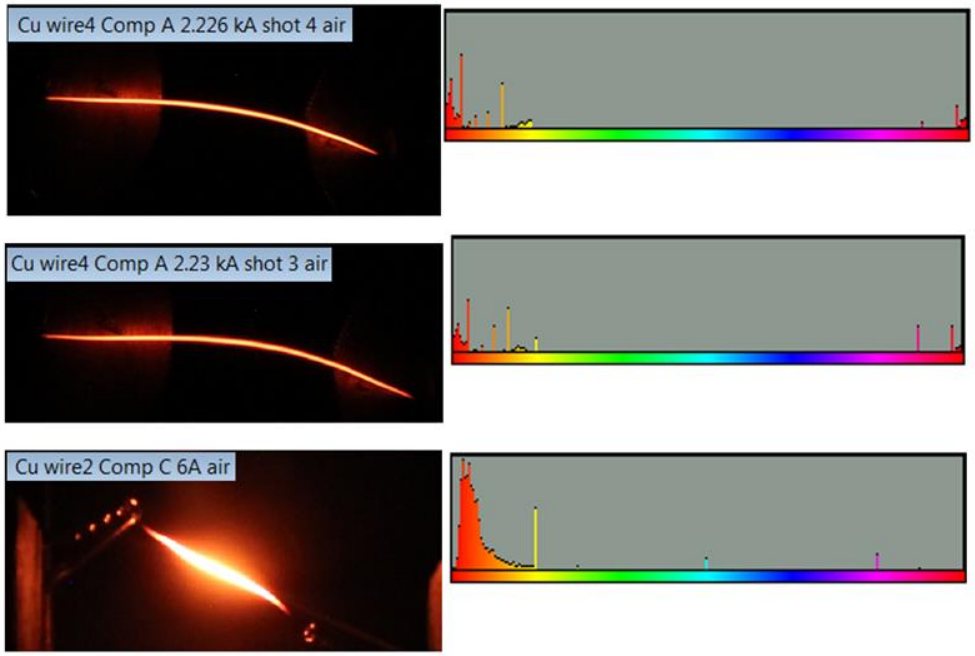
- **Edge glow**
  - CFRP laminate strip, 381 x 38 x 2 mm, quasi-isotropic eight-ply layup, pre-impregnated unidirectional carbon fiber tape (Advanced Composites Group). One edge of the coupon was cut to leave a rough edge with exposed fibers.
  - CFRP Laminate Strip, 5” x 0.5” x 0.05”. Cycom 5320-1 Unitape, Cycom 5320-1 PW (0/90) Uni (90,0,90)s

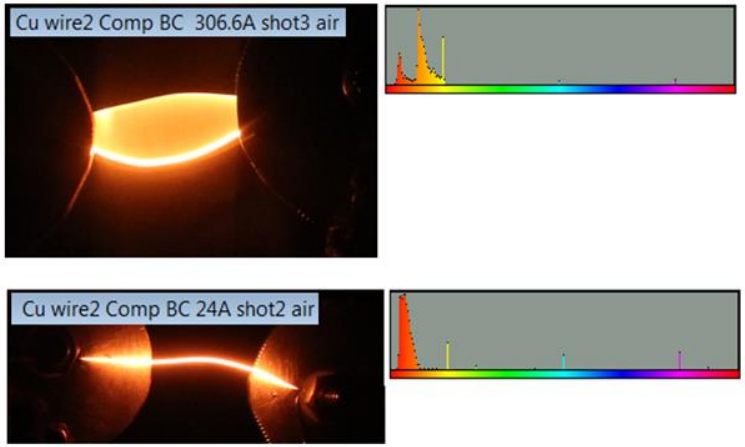
- **Voltage sparks (ARP 5416A)**
  - 100 µJ – 1mJ, tungsten electrodes

Origin of Yellow Hue – Testing in Air

- **Presence of incandescent signature is not a result of hydrogen combustion.**

  Examples of tests performed in air (no flammable gas) with hue histograms displaying the incandescent signature.





- Combustion of lean H2 and O2 produces faintly visible flames primarily in UV and blue range which does not introduce incandescent hue to test images.

Ref: http://iopscience.iop.org/article/10.1088/0031-9120/48/1/22

CECAM

JAMS JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

A Center of Excellence AMTAS Advanced Materials in Transport Aircraft Structures

Round Robin Test – Goal and Expected Outcome

- Validate the results of preliminary testing across different labs, cameras, and test articles:
  - Ignition of the flammable gas mixture coincides with the incandescent signature consistently.

- Refine incandescent signature definition
  - Continuous spectrum:
    - Compare results from multiple cameras to determine requirements.
  - Critical yellow:
    - Determine the minimum threshold that signifies ignition, and ensure it is sufficiently conservative.

- Revise the procedure for potential publication as a test standard for SAE ARP 5416.

CECAM

JAMS
JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

Round Robin Test Status

- Participating laboratories
  - USA: NIAR, Boeing, DNB, NTS/LTI;
  - Europe: Element, DGA, LCOE;
  - Japan: Subaru Corporation

- Testing is currently underway with results expected prior to July 2019.

- Discussion with participants at SAE and EUROCAE lightning committee meetings.

- Tabulation of results will be completed prior to August 2019.

- Final DOT report to be submitted September 2019.

Round Robin Procedure

- Test articles were developed to produce incandescence, edge glow, or both.
  - NIAR provided test articles to the round robin participants.
    - CFRP test coupons, loose carbon fibers, copper wire.
- Use the flammable gas and digital color emission spectroscopy detection methods simultaneously to allow color emitted by ignition source to be directly compared with ignition/no ignition of gas.
  - Testing must be conducted in hydrogen mixture (hydrogen flame is nearly invisible, other fuel gases may burn with a yellow color which will interfere with the photographic technique).
  - Waveform 5A will be used to generate edge glow.
  - Use cameras calibrated according to the existing photographic detection method.
- Analyze images in ImageJ to determine if the incandescent signature consistently coincides with ignition

Planned Progress

- Complete round robin testing
- Analyze test results
- Update incandescent test procedure based on results and feedback
- Update the DOT report
- Further study in areas of uncertainty
- Provide a procedure in the ARP5416 format
- Present to SAE AE-2/WG-31 for inclusion into the standard

CECAM

JAMS
JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

Questions?

Don’t forget to fill out the feedback form in your packet or online at www.surveymonkey.com/r/jamsfeedback

Thank you.

CECAM
center of excellence for composites and advanced materials

JAMS
JOINT ADVANCED MATERIALS & STRUCTURES
CENTER OF EXCELLENCE

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures