Incandescent Ignition Source Detection Method for Composite Structure Lighting Testing

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JAMS Technical Review

September 23, 2021

Federal Aviation Administration

Joint Centers of Excellence for Advanced Materials

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CECAM center of excellence for composites and advanced materials

Introduction

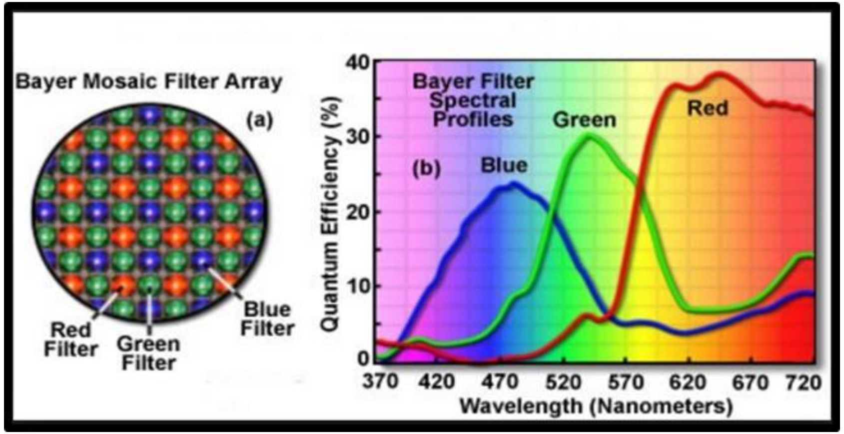
- Incandescent Ignition Source Detection Method for Composite Structure Lightning Testing
- Project Participants:
  - Alyssa Gonzalez – Principle Investigator
  - Rebeka Khajehpour – Research Engineer
- FAA Technical Monitor – Lynn Pham
- Industry Partnerships/Other Collaborations – Boeing, DNB, Element, LCOE, Subaru Corporation
- Source of matching contribution for the current award – AE-2 Committee involvement, and round robin participation from Boeing, DNB, Element, LCOE, and Subaru Corporation.

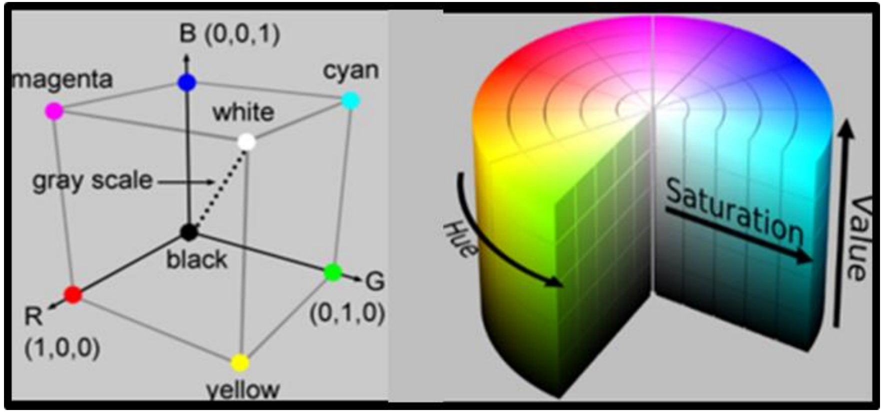
Background

- Motivation and Key Issues
  - Incandescent particles, hot spots, and edge glow procedure by carbon fiber composites have not been characterized by their ability to ignite fuel causing unnecessary failure with current test method.
- Objective and Scope
  - Develop a new detection methodology for incandescent ignition sources to reduce the number of edge glow failures that occur with current photographic method.
  - 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
- Approach
  - Utilize an augmented photographic method to predict ignition conditions of flammable gas mixture imposed by an incandescent heat source.

Background: 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.

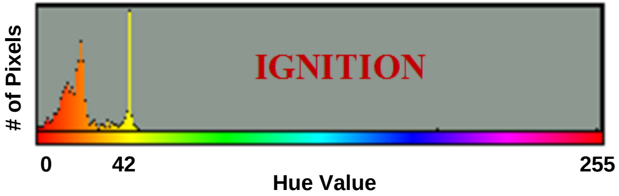
Previous Work: Years 1-2 Preliminary Test Data

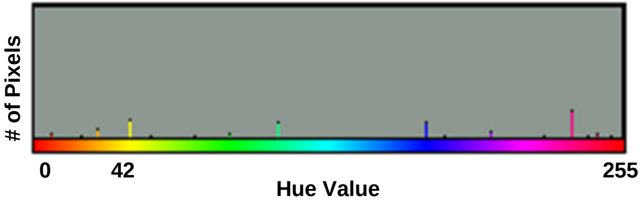
Incandescent Signature of Ignition

1. Continues 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

Continuous range of hue demonstrating a thermal signature





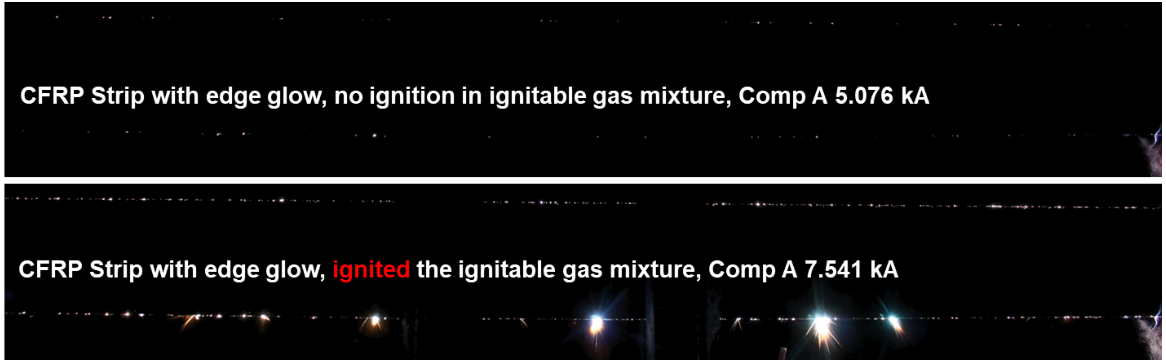
No continuous range is present in the histogram on the right, signaling an absence of a thermal source. The hue spikes can be loosely tied to the emission lines to ionization of air. Does not ignite gas

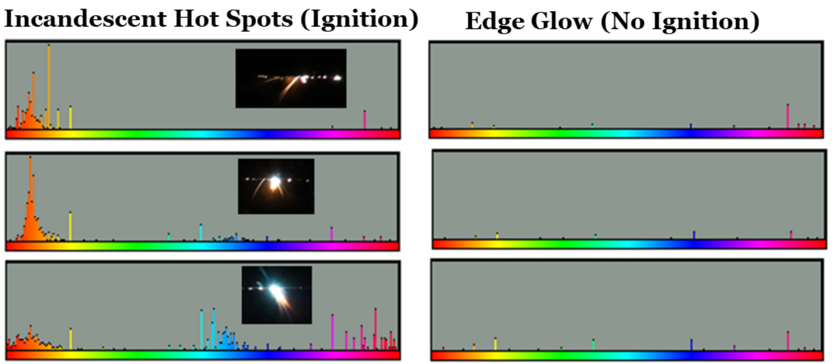
Sample Photos of Edge Glow – CFRP Strip

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,

Sample Photos of Edge Glow – CFRP Strip

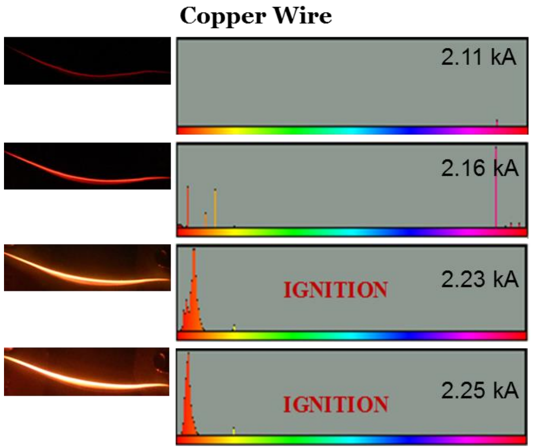


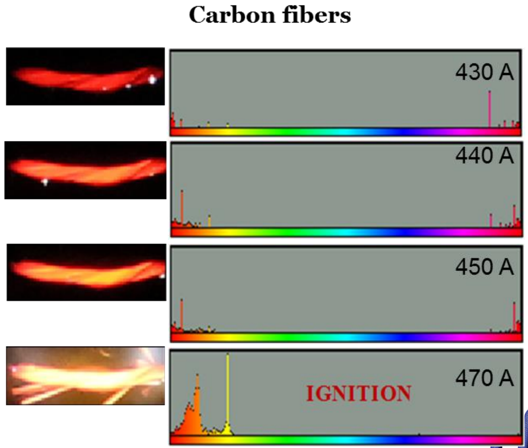


Incandescent/Thermal Signature Verification on Other Materials

Gas ignition coincides with the appearance of an 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)





Additional Observations

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1. **Particle ejections ignite gas**

2. **Edge glow without continuous hue spectrum observable in CFRP and carbon fibers does not ignite gas**

3. **CFRP, carbon fibers, and metal wires with continuous hue spectrum but <u>without</u> critical yellow hue do not ignite gas**

4. **CFRP, carbon fibers, and metal wires with continuous hue spectrum <u>and</u> critical yellow hue ignite gas**

Previous Work: Year 3 Round Robin

Round Robin - Purpose

- Validate the performance of the incandescent method and the results of preliminary testing across different labs, cameras, and test articles:

- Refine incandescent signature definition
  - Continuous spectrum and critical yellow:
    - Compare results from multiple cameras to determine better criteria to define the requirement of the incandescent signature.

- Revise the procedure for potential inclusion in the photographic method test standard in SAE ARP 5416

Round Robin - Summary

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- Participating laboratories
  - USA: NIAR, Boeing, DNB. Europe: Element, LCOE. Japan: Subaru Corporation
- NIAR provided test articles to all participants
- Flammable gas and incandescent photographic detection methods simultaneously
  - Allows 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 and will not interfere with the photographic technique)
  - Conducted current used to generate edge glow
  - Use cameras calibrated according to the existing photographic detection method
- Images analyzed in ImageJ to determine if the incandescent signature consistently coincides with ignition

Round Robin - Results

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- For CFRP edge glow test which:
  - Ignited the flammable mixture: false failures were reduced from 95.9% with the brightness method to 45.1% with the incandescent method. This is the primary goal of implementing this method.
  - Did not ignite the flammable gas mixture: the false pass rate was 0% for the brightness method and 5.6% with the incandescent method. This needs to be improved to ensure conservative ignition detection.
- For all materials tested:
  - Ignited the flammable mixture: false failures were reduced from 90.4% with the brightness method to 19.2% with the incandescent method.
  - Did not ignite the flammable gas mixture: the false pass rate was 1.7% for the brightness method and 1.8% with the incandescent method. This should be 0% to ensure conservative ignition detection.

Brightness Method for CFRP		
	Brightness threshold exceeded	Brightness threshold not met
Ignition	True fail (100%)	False pass (0%)
Non-Ignition	False Fail (95.9%)	True pass (4.1%)

Incandescent Method for CFRP		
	Incandescent Signature Present	No Incandescent Signature Present
Ignition	True fail (94.4%)	False pass (5.6%)
Non-Ignition	False Fail (45.1%)	True pass (54.9%)

Current Work: Year 4 Further Studies

Further Studies - Purpose

- Evaluate areas of uncertainty with method:
    - Camera resolution
        - evaluated through comparison of similar cameras from the same manufacturer, one with smaller overall sensor dimensions and one with a larger sensor
    - Lens type
        - compared two identical cameras with different lenses, one variable zoom 18-55mm lens and one 24mm prime lens, viewing the same ignition events to determine the relative sharpness of the resulting images
    - Distance to test article
        - evaluated by photographing a target of known size at three distance increments. This was repeated with multiple cameras and lenses
    - Test material for incandescent signature calibration
        - recommendations for calibrating camera signature were made through comparison of test images from round robin testing and preliminary testing, as well as CFRP test coupon configurations tested for further studies
    - Appropriate flammable gas mixture for detection of incandescent edge glow
        - Literature review
    - Thermal ignition source size relative to minimum temperature of ignition
        - Literature review

Further Studies - Results

•Camera resolution,

•resolution made little to no difference on the apparent size of edge glow spots, and their brightness was not significantly affected.

•Lens type,

•a minor difference in sharpness occurred at edge of the images but did not affect the appearance of the continuous incandescent hue range for this testing

•Distance to test article,

•Causes a linear change in effective resolution of the test article and potential ignition source. Recommendation is to minimize the distance from camera to test article to maximize the resolution

•Test material for incandescent signature calibration,

•Recommended to repeat the “incandescent signature verification” for each composite material under test using a sample of the test material (layup, fiber orientation at cut edge, edge finish qualities, and sealant).

•Appropriate flammable gas mixture for detection of incandescent edge glow,

•Recommendations for test gas mixture for CFRP incandescent sources are use of either hydrogen-air or hydrogen-nitrogen-oxygen mixtures or an ethylene-air mixture, rather than the hydrogen-argon-oxygen mixture recommended by ARP 5416A.

•Thermal ignition source size relative to minimum temperature of ignition.

•variation in size of incandescent edge glow spots has not been shown to reduce the appearance of the incandescent signature of ignition in a manner that would reduce the effectiveness of incandescent signature in detecting them as compared to smaller spots.

Conclusions and Recommendations for Future Work

- Incandescent method shows promise for reliable and repeatable incandescent ignition source detection on the simple CFRP coupons that have been evaluated

- Additional work is recommended before this method be implemented for the purpose of ignition source detection for aircraft certification
  - Method requires additional evaluation to determine whether it can consistently detect incandescent ignition sources for more complex test articles
  - All testing to this point has been on simple carbon fiber composite coupons
  - Further simple coupon configurations should be evaluated with additional layups and materials
  - Method needs evaluation for parts containing metallic structure, fasteners, paint/primer, sealant, lightning strike protection, or parts with splices
  - Tests with camera orientation facing the cut edge of the fibers should be considered