FAA Research of Incandescent Source Standardization for Composite Structure Lightning Testing

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FAA Research of Incandescent Source Standardization for Composite Structure Lightning Testing

- Motivation and Key Issues
  - CFR 14 25.981a(3) has driven tremendous costs into the certification of transport aircraft fuel tanks and associated systems
  - The use of composite structures in fuel tank structure has proven to be problematic using current test methods
    - 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.

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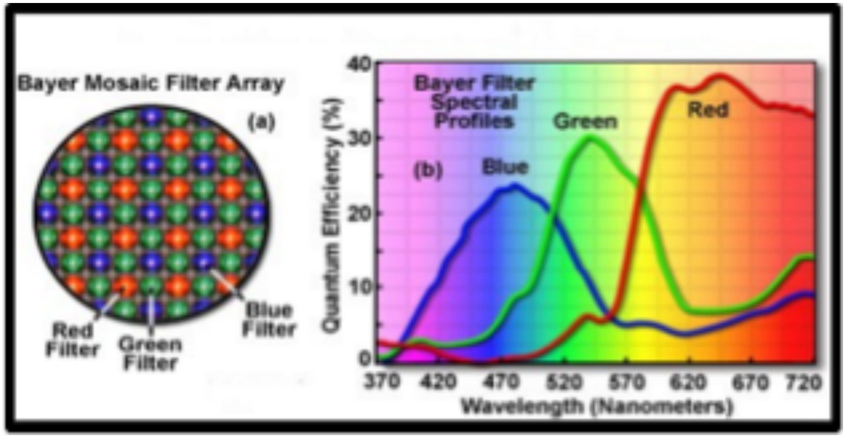
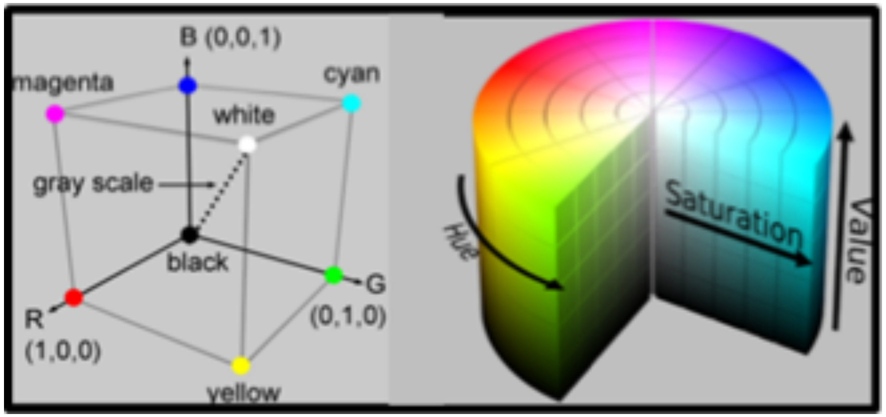
Goals

- Development of a new detection methodology for incandescent ignition sources 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
- 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)
- Possible publication of reference in CMH-17

Digital Color Imaging

- CMOS sensor filters light into primary RED GREEN BLUE colors
- Each individual pixel measures light intensity/chrominance through ONE of the color filters
- A camera-specific demosaicing algorithm interpolates individual R, G, or 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 transformed from the rectangular RGB color model
- Distribution of hue in the image based on histogram statistics
- The hue component is most important for this analysis

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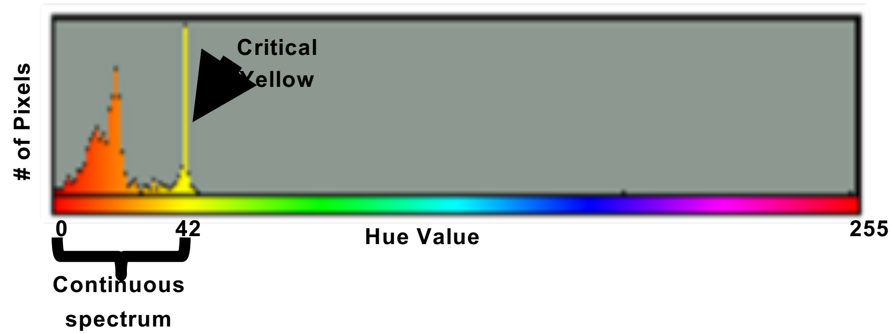
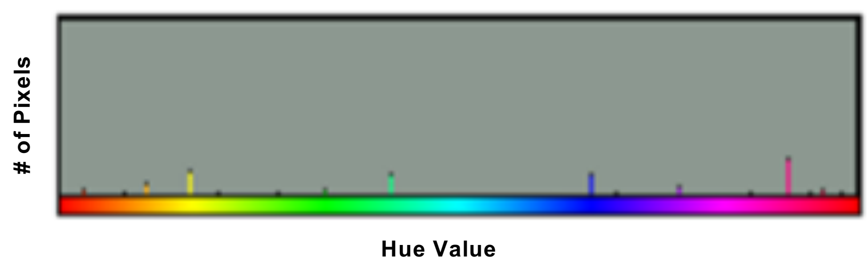
Incandescent Signature of Ignition

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

The continuous spectrum and critical yellow must BOTH be present to signal ignition



- Edge glow: No continuous spectrum, color of light due to ionization of air. Does not ignite gas



Edge Glow - CFRP Strip

Testing in flammable gas mixture (6 vol % Hydrogen)

- Edge glow was observed on the tips of protruding fibers and they didn't seem to cause ignition. These fibers are to some degree perpendicular to the current flow direction, and don't heat up incandescently.
- Ejections originate from the hot resin material/expanding air within the matrix. However, ejections were associated with the edge-glowing fibers, as the edge glow spots increased in number, size, and intensity with increased current levels and eventually initiated vaporization/ thermal ejections.
- Analysis of Brightness vs Current Level alone with a digital camera is insufficient for edge glow, due to sensor saturation observed even in glows without ejections; therefore relationship of brightness to ignition could not be established.
- The range of physical size of edge glow without ejections overlaps with that of the size of glows with thermal ejections. **Ignition will only occur upon appearance of incandescent signature**, regardless of size of the edge glow spot.

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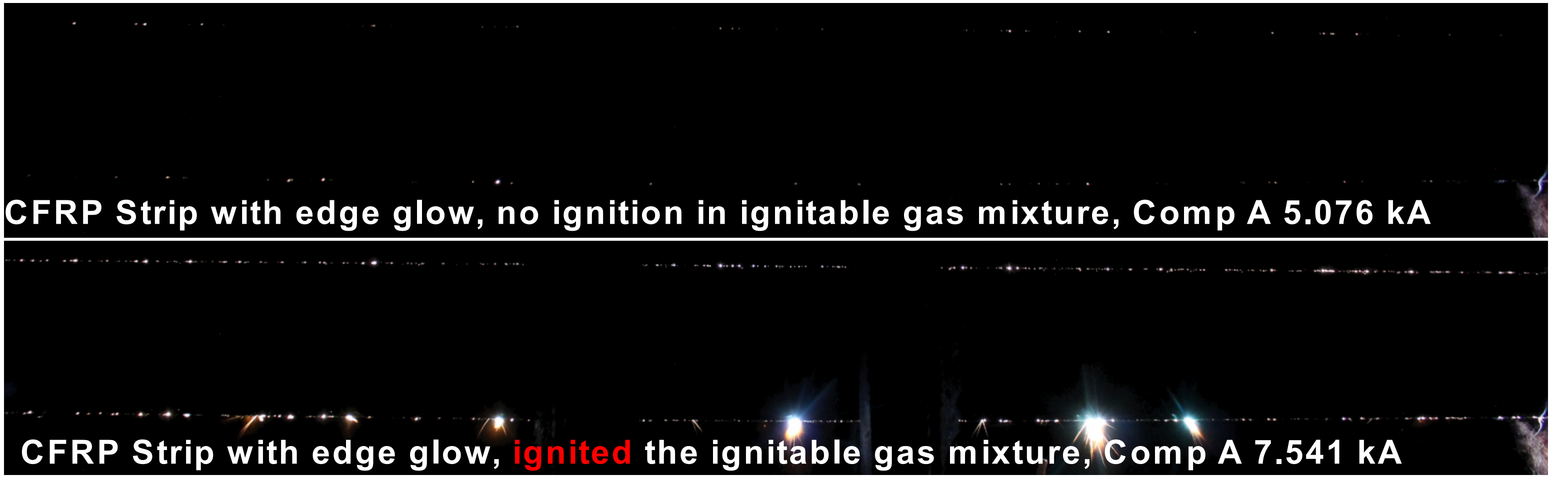
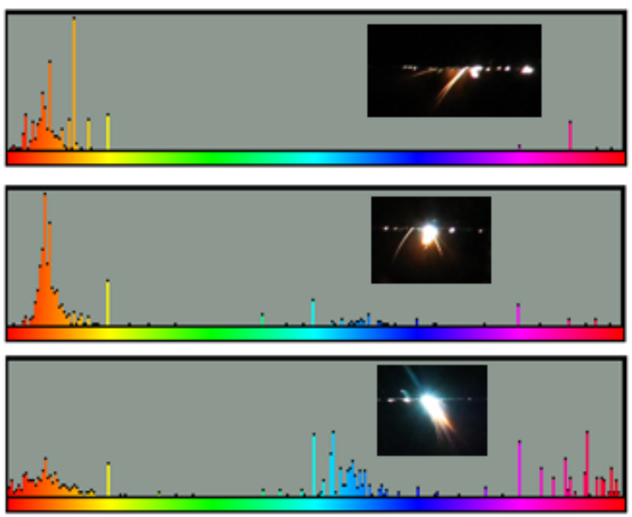
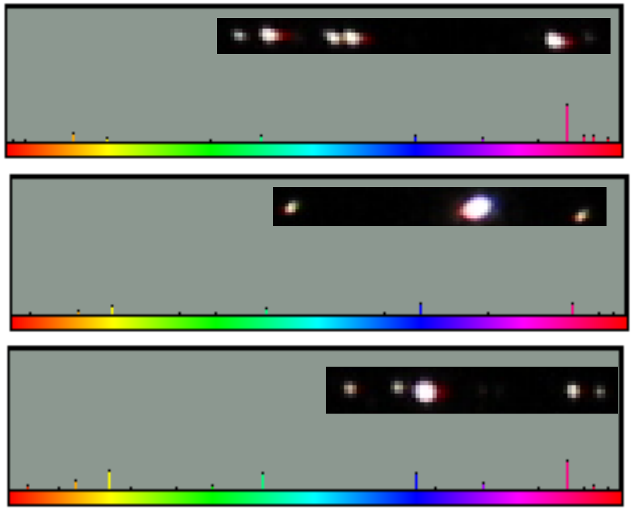
CFRP Edge Glow



Incandescent Hot Spots (Ignition)



Edge Glow (No Ignition)



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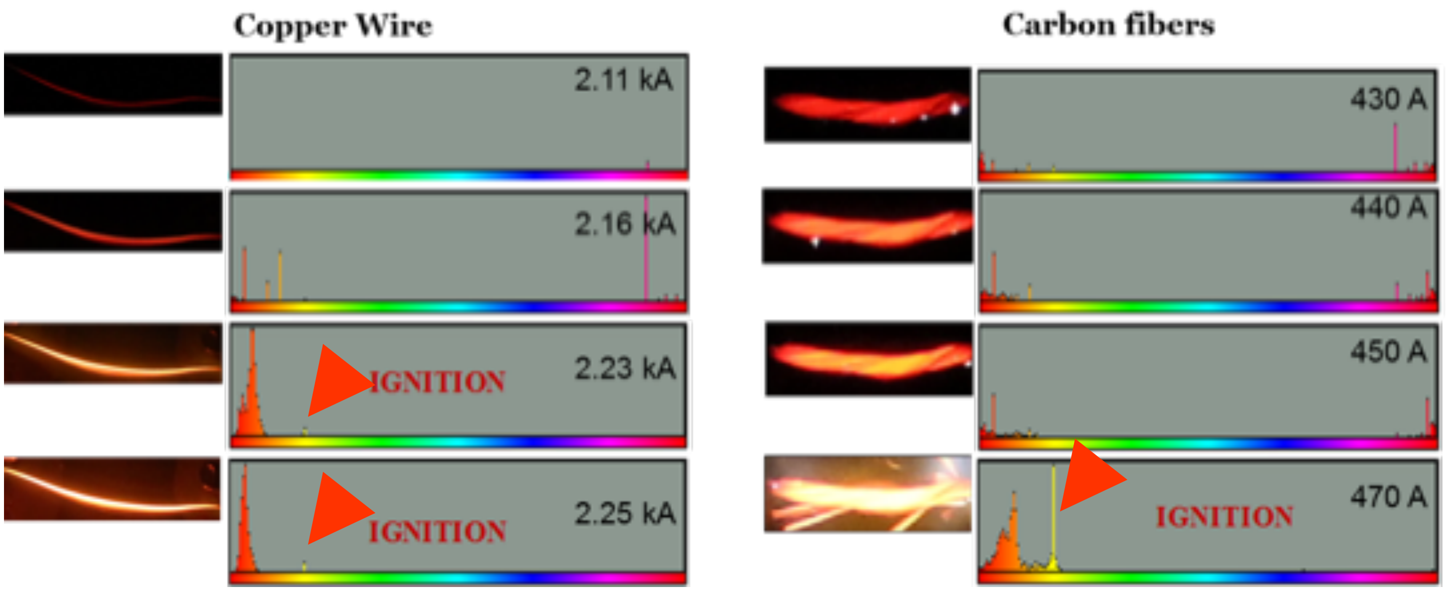
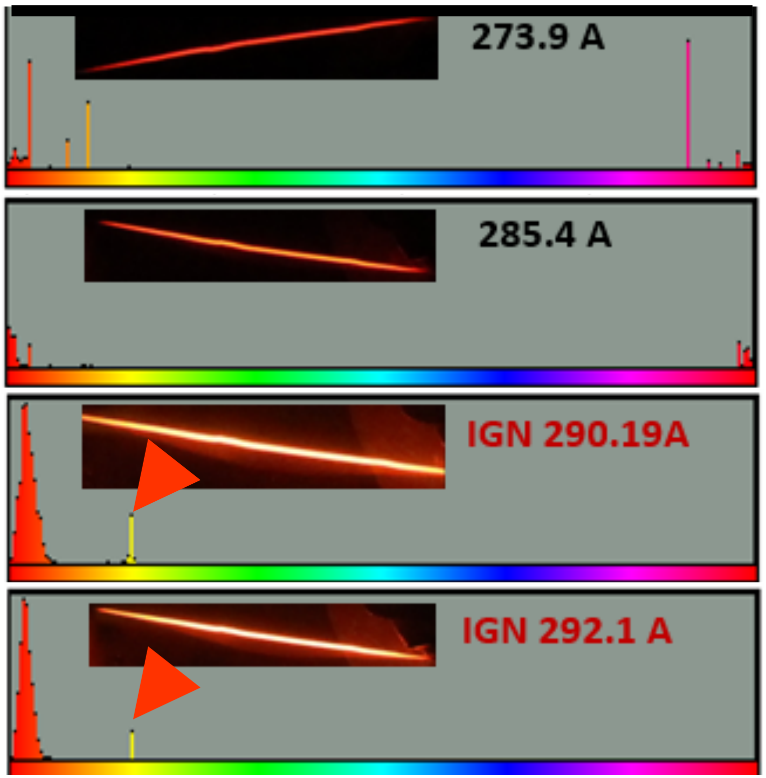
Verification of incandescent/thermal signature

- Gas ignition coincides with 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)

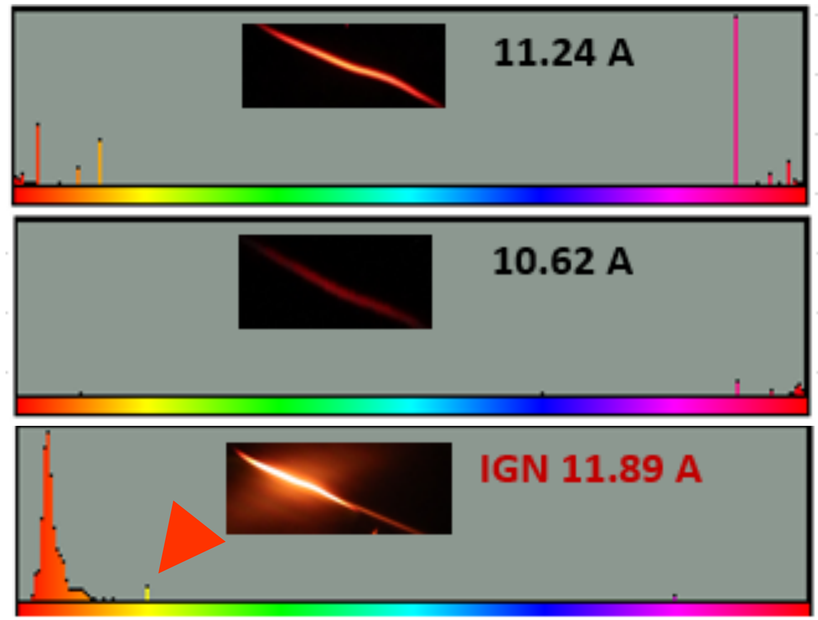


Incandescent Cu Wires

Comp BC* (0.24 ms to peak, 3 ms to decay)/Gas: Hue Histograms



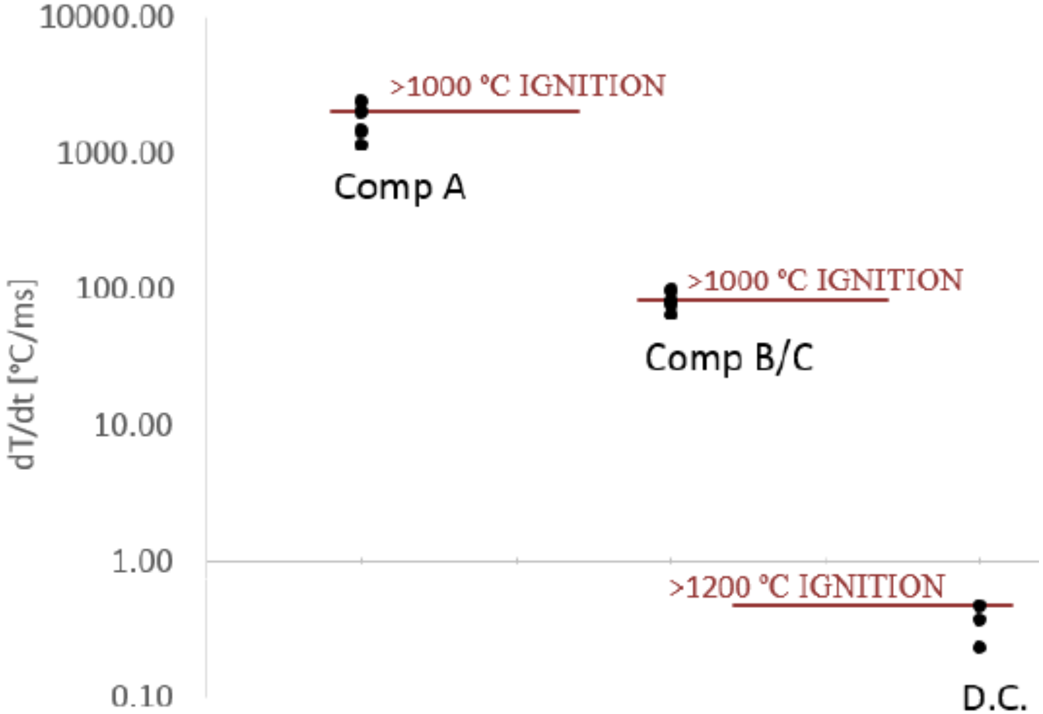
DC /Gas: Hue Histograms



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 <u>and</u> with yellow hue *ignite* gas,
4. Thermal ejections *ignite* gas.

Influence of Heating Rate



Influence of Wire Temperature Rate on Incendivity

Temperature (°C)
550
630
680
740
770
800
850
900
950
1000
1100
1200
1300

- Findings indicate that regardless of the dI/dt or dT/dt, which vary widely among three investigated current components, ignition occurs when the incandescent temperature of the wire surface exceeds 1100 ^{0}C

*Incandescent Color Chart:

1. Chapman, W. A. J. (1972). Workshop Technology, Part 1 (5th ed.). Burlington, MA: Elsevier Butterworth-Heinemann. ISBN 978-0713132694.

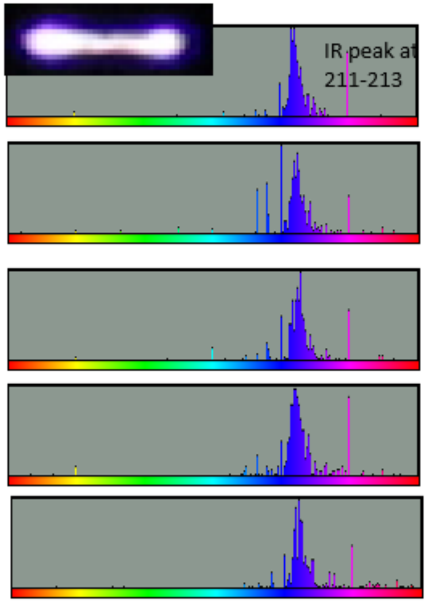
2. A Book of Steam for Engineers. Stirling Consolidated Boiler Company. 1905. ASIN B006RXDG3W.

Detailed list of investigated materials

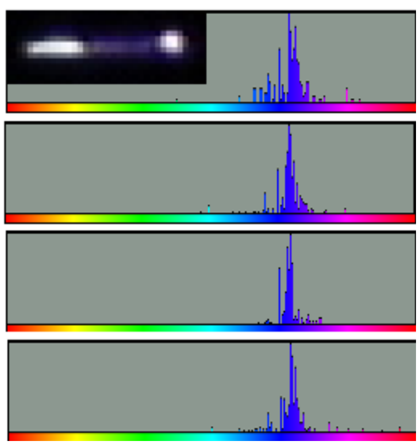
- Investigated materials
  - **Incandescence**
    - Tinned copper wire, 30 AWG (0.25 mm), 60 mm long (AlphaWire).
    - Tinned copper wire, 24 AWG (0.51 mm), 60 mm long (Belden)
    - C1085 high carbon spring tempered steel alloy (C, Mn, P, S, and Si) music wire, 0.64 mm diameter, 60 mm long (Precision 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)
  - **Edge glow**
    - CFRP laminate strip, 381 x 38 x 2 mm, quasi-isotropic eight-ply layup, pre-impregnated unidirectional carbon fiber tape MTM45-1/T-800S 24K-196 32% Rw (Advanced Composites Group). One edge of the coupon was cut to leave a rough edge with exposed fibers.
    - Carbon fiber bundle (see above).
  - **Voltage sparks (ARP 5416A)**
    - 100-400 µJ, tungsten electrodes
- For incandescence, approximate temperatures were estimated from the incandescent chart
- For incandescence, voltage drops over the wire length were measured to reveal stages of material transformations

Voltage Spark Air

400 uJ

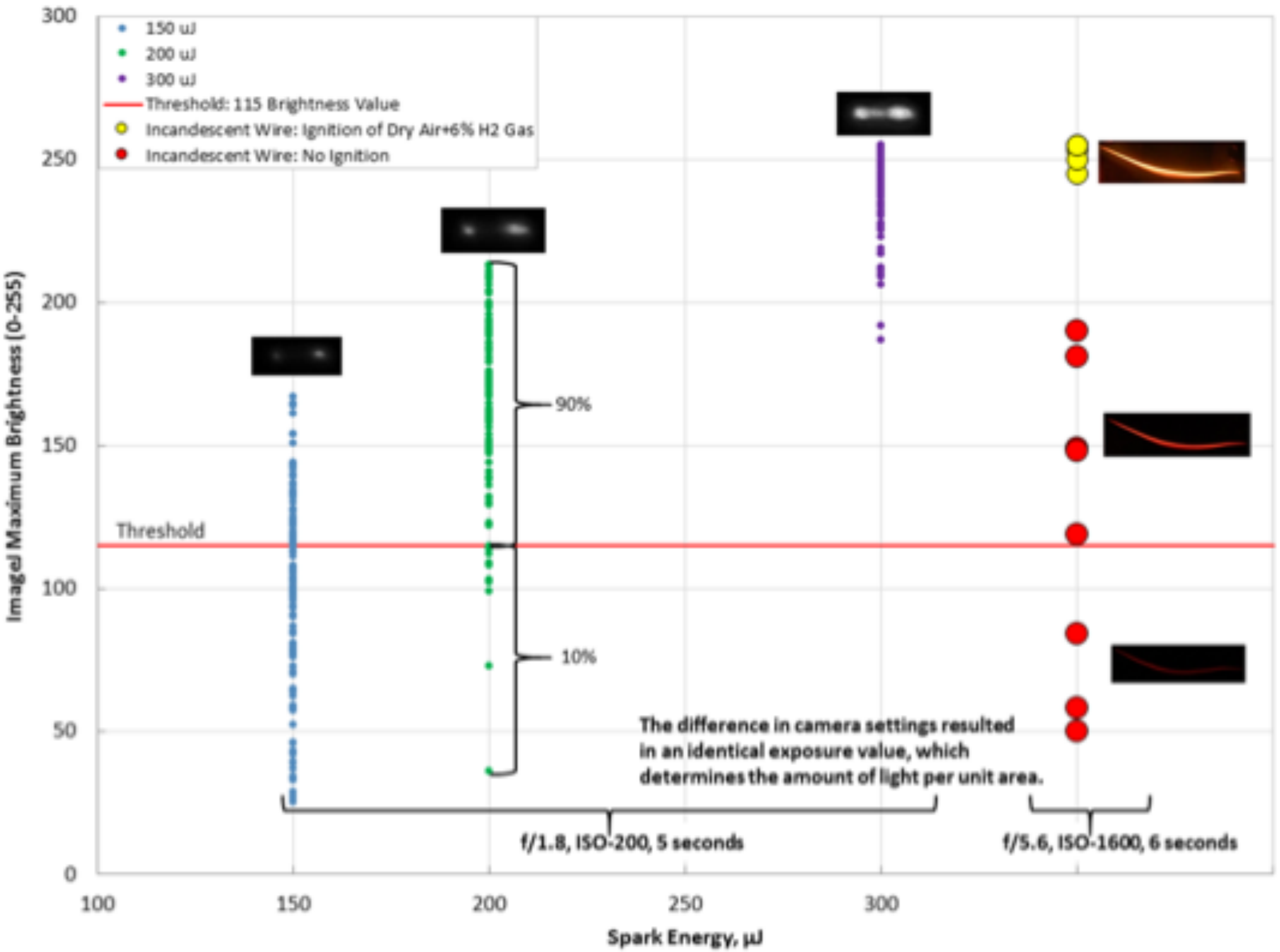


200 uJ



- Observable is energy-level difference. Allows differentiating species and energy levels.
- Ionized air is in relation to the air/material glow observed in the CFRP/carbon filament.
- Colors indicate emissions due to electronic transitions during molecular dissociation, atomic/molecular excitations, and ionization of the air constituents.
- An increase in spark energy increases spark brightness (emission intensities) and area. A corresponding increase of violet hue is due to higher-level transitions of oxygen and nitrogen.
- Purple/pink hues are due to camera sensitivity to IR and UV.

Wire Brightness vs Voltage Spark Brightness



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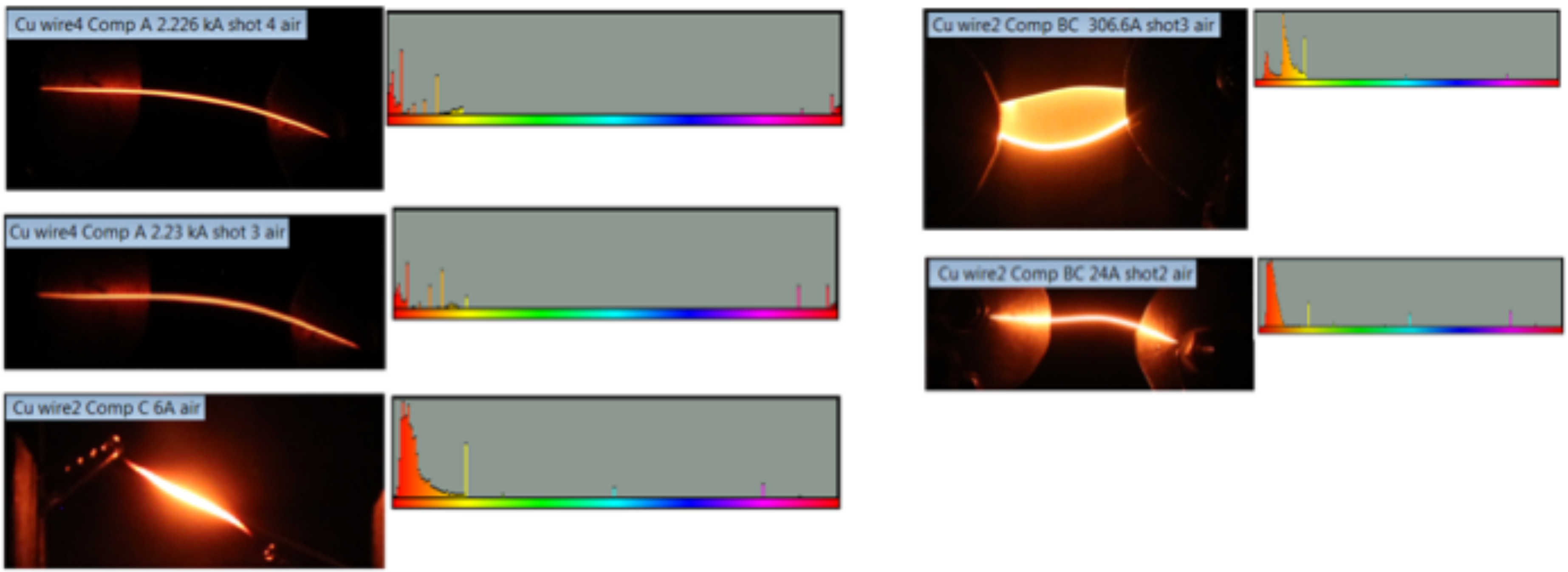
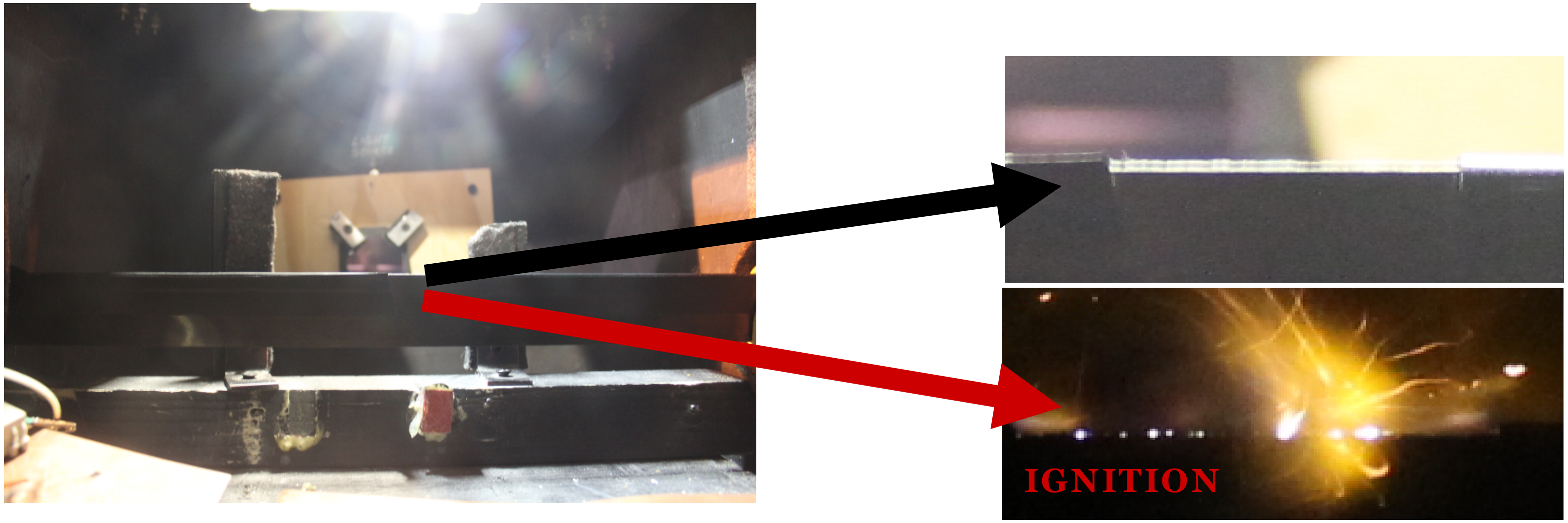
Origin of Yellow Hue

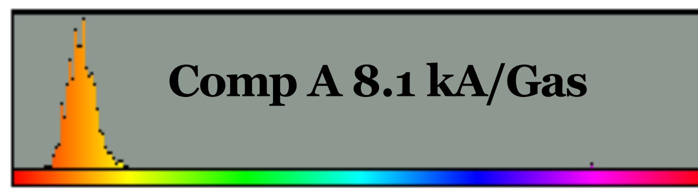
- Example histograms of copper wire tested *in air* confirm that presence of yellow hue is not an artifact of ignition of hydrogen



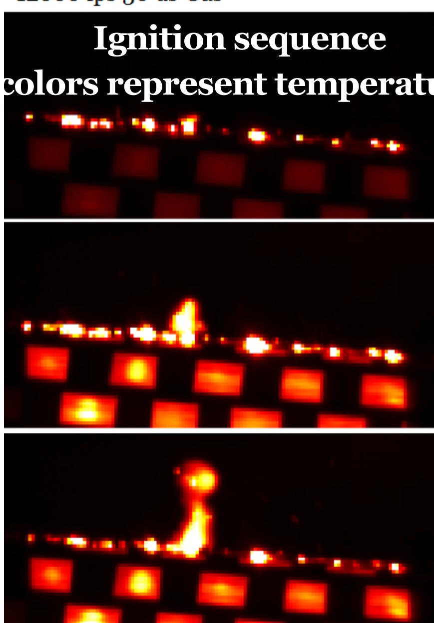
- Combustion of H2 and O2 produces invisible flames
- Ref: http://iopscience.iop.org/article/10.1088/0031-9120/48/1/22)

TELOPS High Speed Thermal Camera: Edge Glow CFRP





12000 fps 30 us Gas



- Ignition is characterized by appearance of red/orange and some yellow hue (resin evaporation and ejections)
- Presence of edge glow

Round Robin Testing

- Goals and Expected Outcome of Round Robin testing
  - Validate results from NIAR's preliminary testing, that ignition of gas mixture coincides with the incandescent signature consistently across different labs, cameras, and test articles.
  - More strictly define the "continuous spectrum" that makes up the incandescent signature.
    - Does it have to span the entire hue range from 0-42, can it be any continuous span of 15 or so hue values between 0 & 42?
  - Determine if the presence of ANY yellow signifies ignition, or if there is a minimum threshold
  - Determine applicability of method to hybrid metal & composite
  - Revise the procedure for publication
- Immediate Goals
  - Define articles to be tested and where they will be built
  - Obtain Agreement and commitment on the final procedure at SAE/EUROCAE meetings (05/18)
    - Possible participating laboratories USA: NIAR, Boeing, DNB, NTS(LTI); Europe: Cobham, DGA.

Round Robin Procedure

- Conduct testing on specified test materials to evaluate edge glow using gas and digital color emission spectroscopy method simultaneously to allow color emitted by ignition source to be directly compared with ignition/no ignition of gas
  - Current component A
  - Use cameras calibrated with the “white light” photographic method whitepaper
- 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)
- Analyze images in ImageJ to determine if the hue matches the incandescent signature in the cases when the gas ignited, and does not match the incandescent signature when no ignition occurred.

Questions and comments are encouraged.

Thank you.

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