How Do LED and Incandescent Light Fixtures Compare in Good and Bad Visibility?

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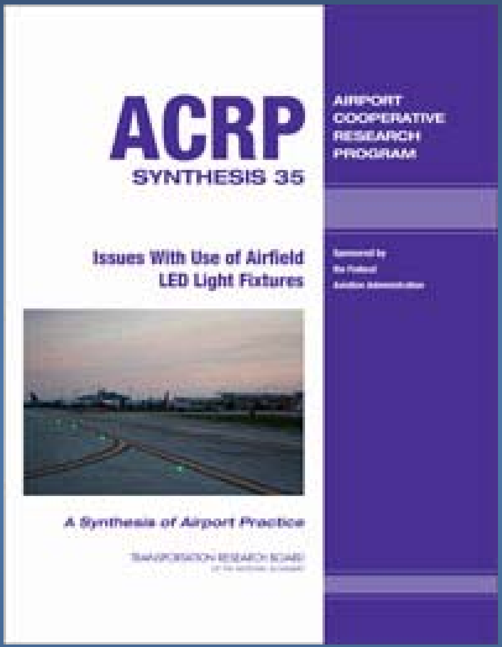
Background

- LED lighting technology is increasing in use for airfield lighting
  - Potential for maintenance and energy benefits
- LEDs differ from incandescent sources in several important ways:
  - Spectral (color)
  - Temporal (onset/offset times)
- What are the brightness/luminous intensity characteristics of LED aviation signal light colors, relative to incandescent?
- Are there issues with perception of LEDs in fog/haze conditions?



(Bullough 2012)

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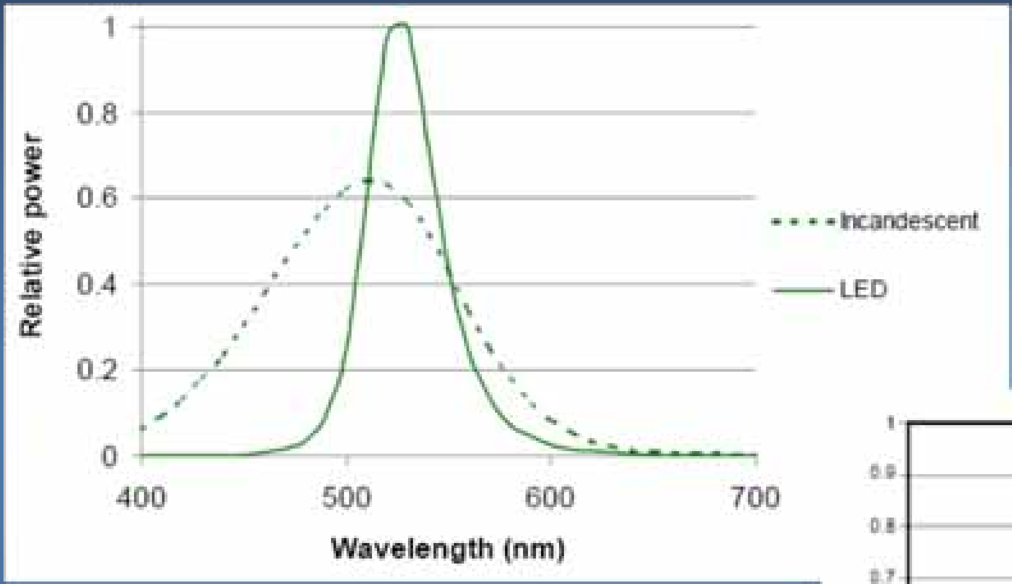
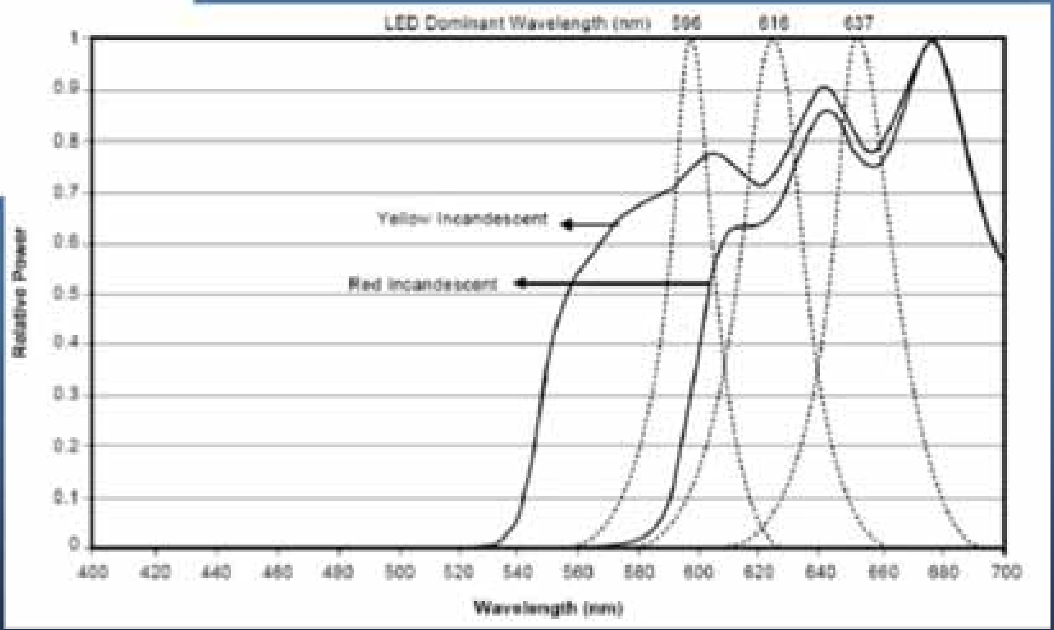
Representative Spectral Distributions of LED and Incandescent Signal Lights



Green



Yellow and Red

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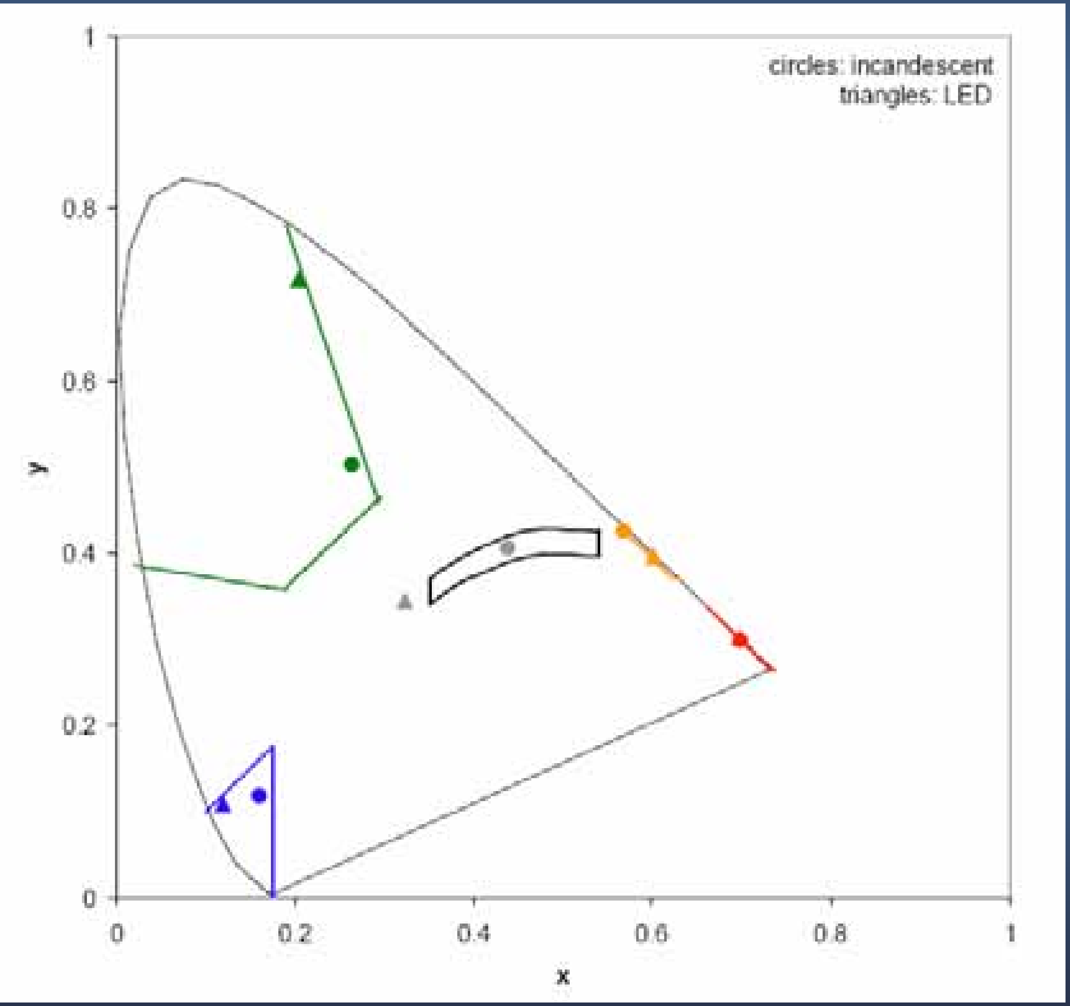
Representative Incandescent and LED Signal Chromaticities



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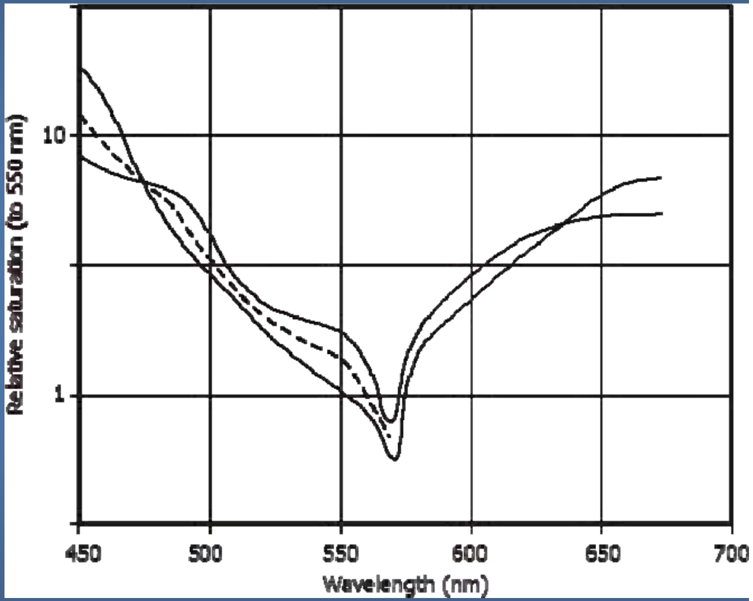
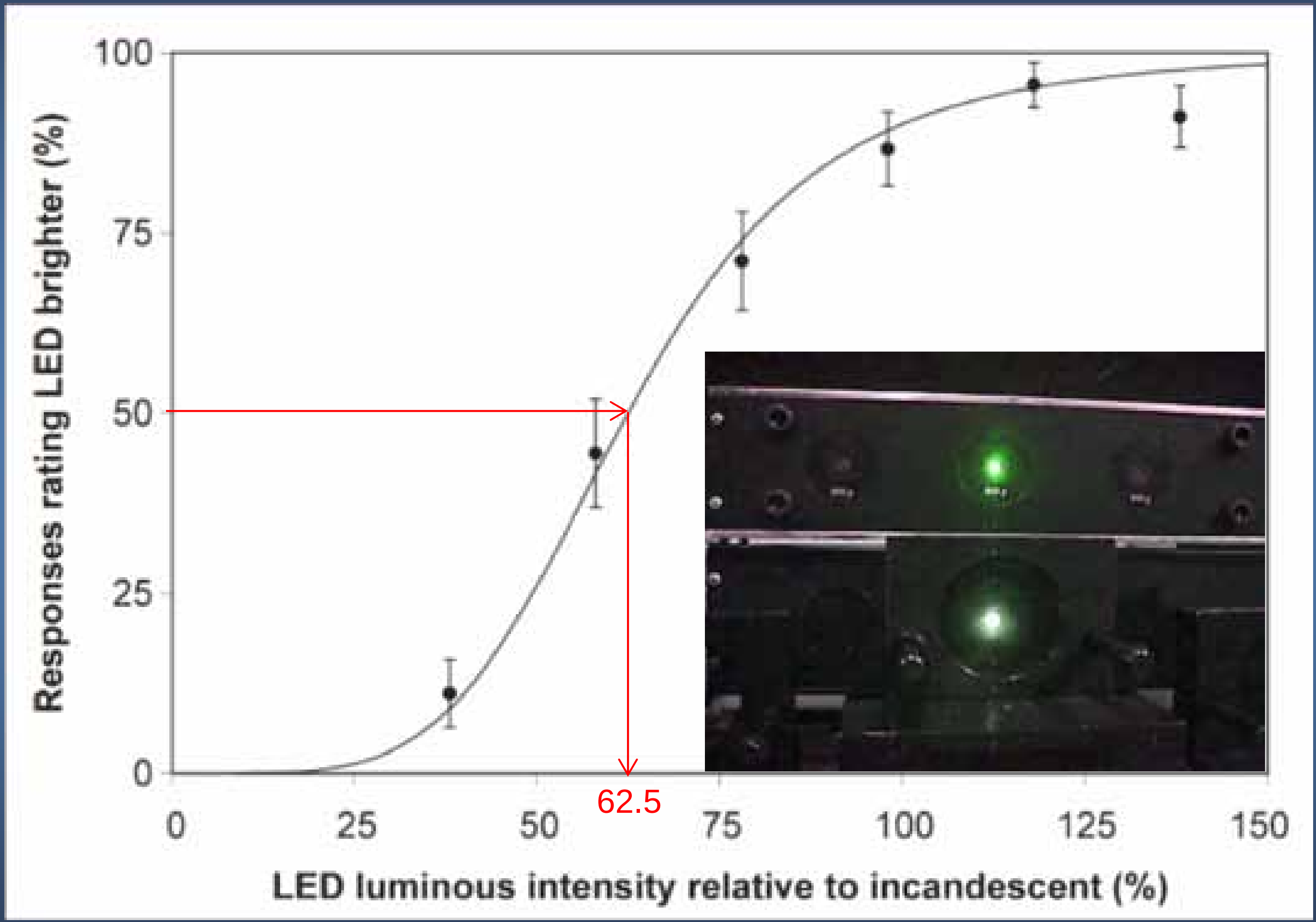
What Influences Brightness?

- Factors related to brightness include (Kaiser and Boynton, 1996):
  - Excitation purity (saturation)
  - Hue
- LED signal lights can differ from incandescent signals of the same nominal color in both saturation and hue
  - For some colors (particularly white, blue and green), more than one LED type might be able to be used

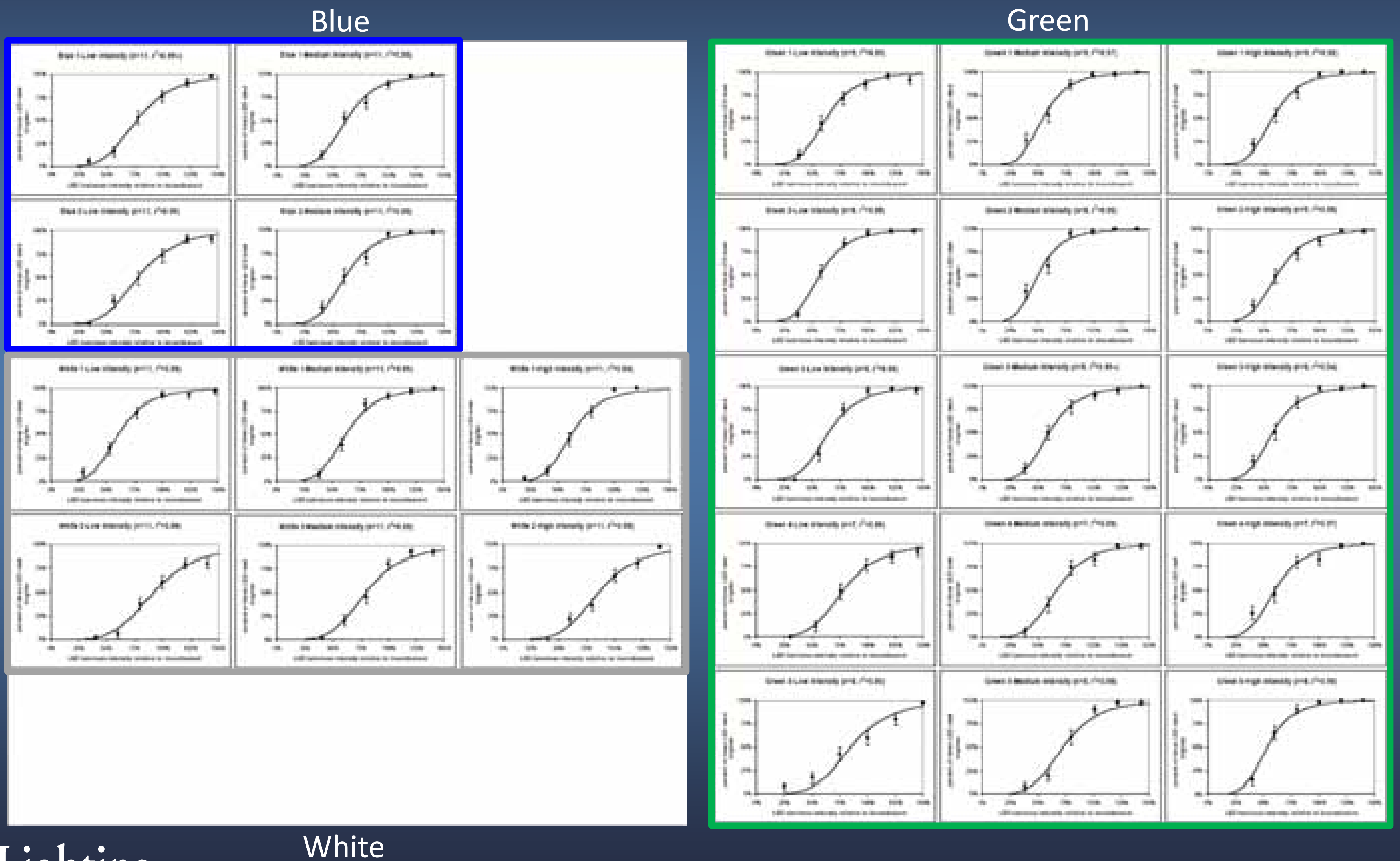


Psychophysical Brightness Measurement



(Bullough et al. 2007)

Experimental Data



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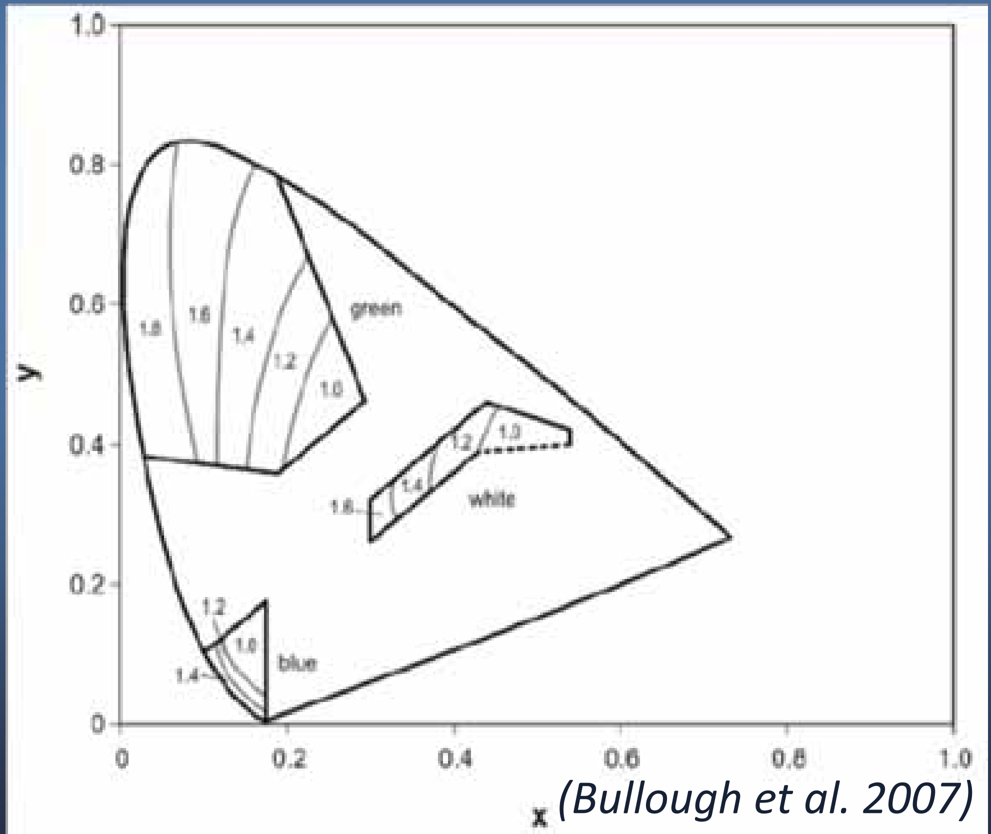
Brightness-to-Luminous Intensity (B/L) Values

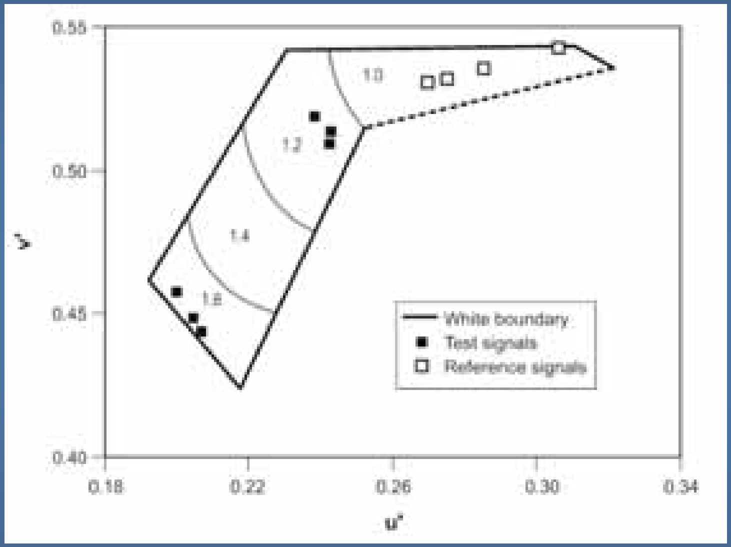
- B/L value for an LED source is defined as the reciprocal of the relative luminous intensity needed to achieve equal brightness as an incandescent source of equal nominal color



(Bullough et al. 2007)

B/L for White LEDs

- Incandescent white signals have CCTs of 2700 K (lower when dimmed); white LEDs range from 2700 K to 8000 K
- 3300 K LED: B/L = 1.2
  - LED intensity can be **83%** of incandescent
- 7100 K LED: B/L = 1.6
  - Outside present white boundary
- 6100 K LED: B/L = 1.5 (near left edge of chromaticity region for white specified by Engineering Bulletin 67D)
  - LED intensity can be **67%** of incandescent



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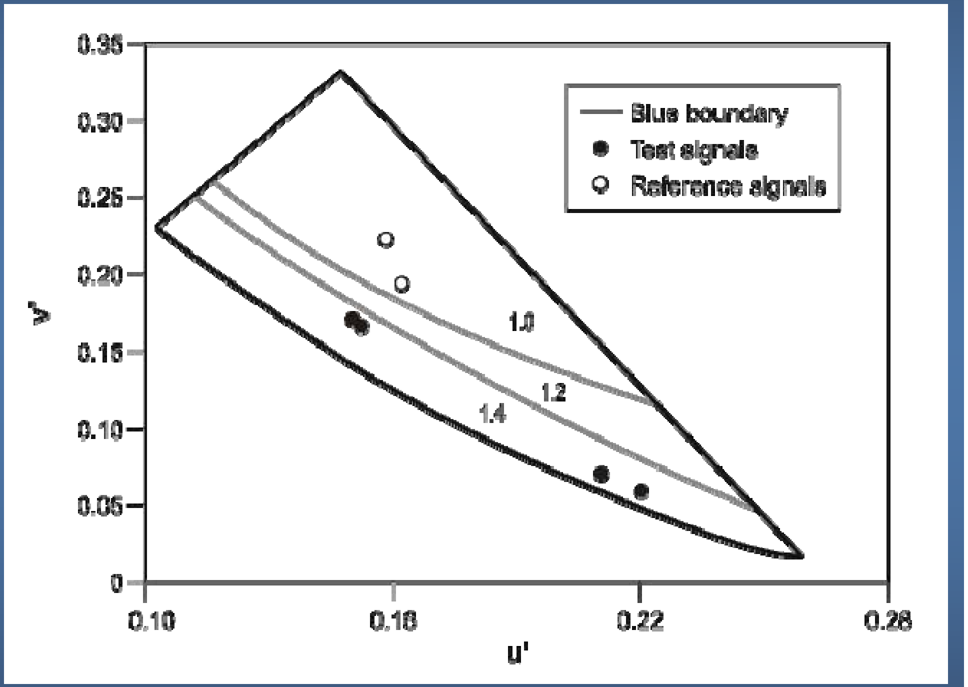
B/L for Blue LEDs

- Blue LEDs can have peak wavelengths of 470 nm ("blue") or 450 nm ("royal blue")
- 470 nm (Blue) LED: B/L = 1.4
  - Intensity can be **72%** of incandescent
- 450 nm (Royal Blue): B/L = 1.4
  - Intensity can be **72%** of incandescent



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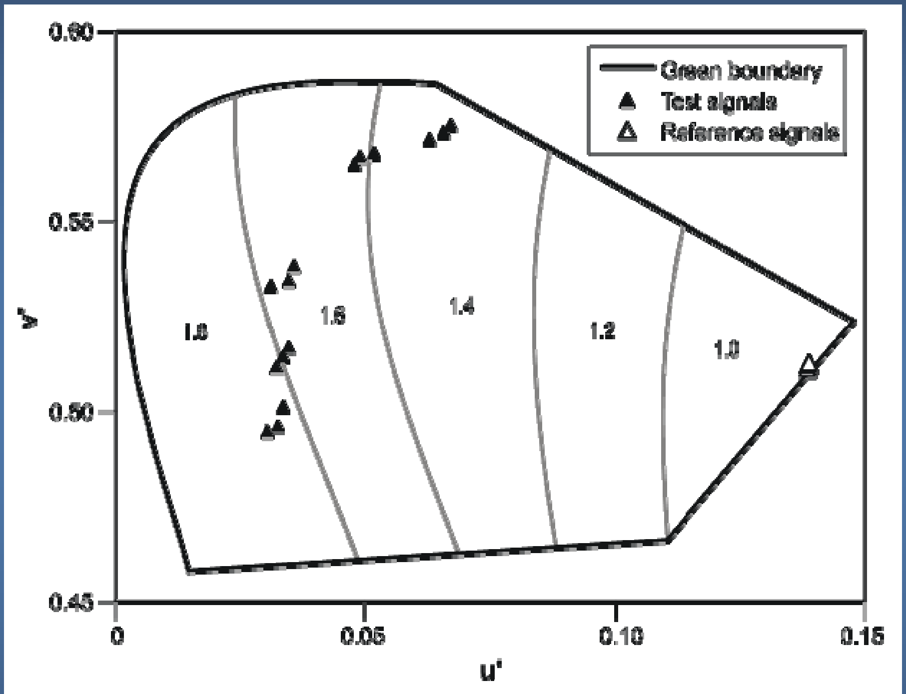
B/L for Green LEDs

- Green LEDs can have peak wavelengths from 525 nm ("green") to 505 nm ("cyan")
- 525 nm (Green) LED: B/L = 1.4
  - Intensity can be **72%** of incandescent
- 505 nm (Cyan): B/L = 1.65
  - Intensity can be **61%** of incandescent



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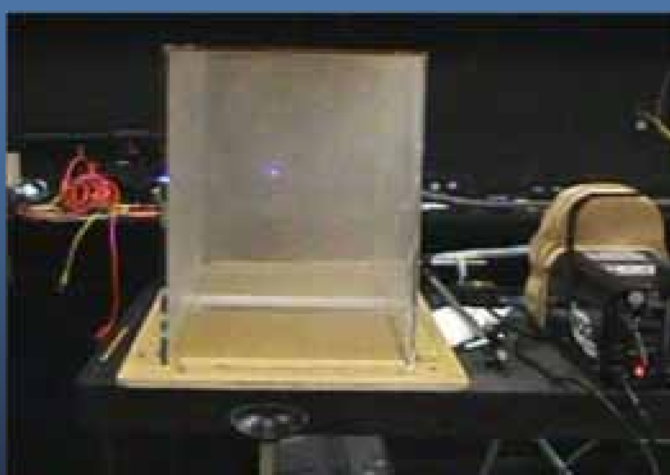
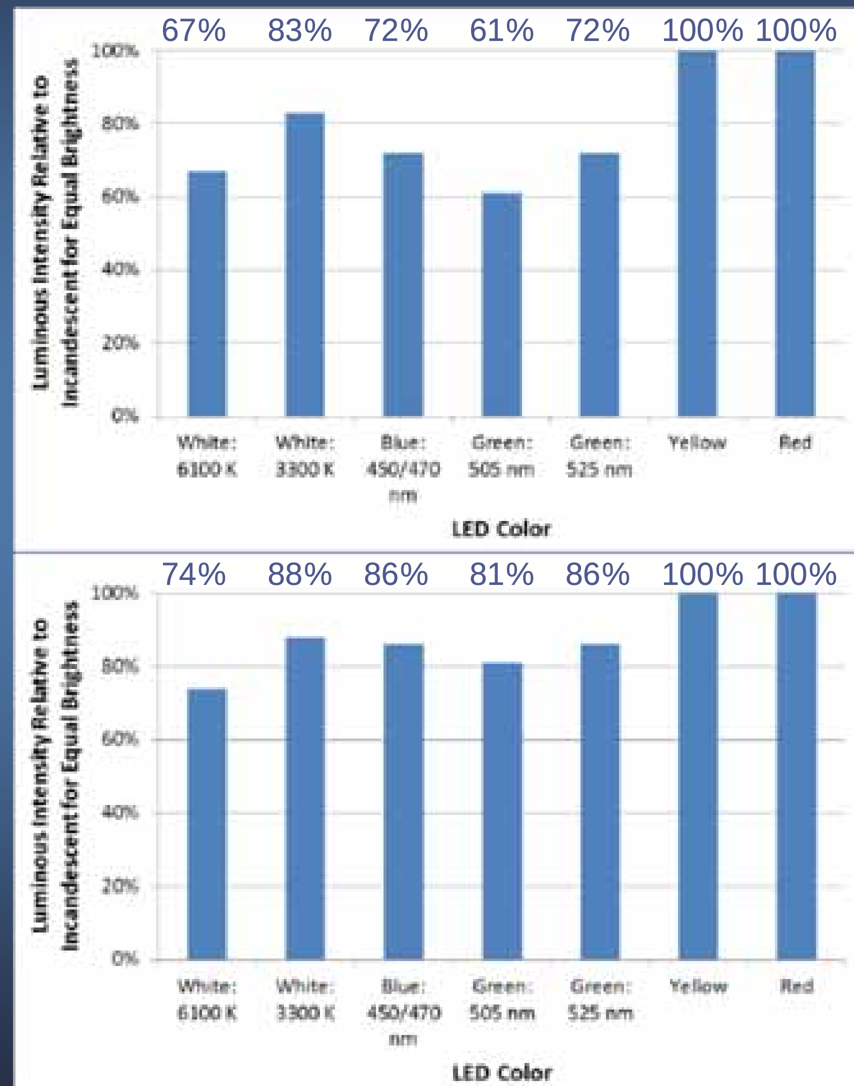
B/L for Yellow and Red LEDs

- LED and filtered incandescent spectra for yellow and red signal light colors do not result in dramatically different chromaticities (Bullough et al. 2000)
  - Yellow LED: B/L = 1.0
    - Intensity must be **100%** of incandescent
  - Red LED: B/L = 1.0
    - Intensity must be **100%** of incandescent

Influence of Fog

- Scattered light in fog is superimposed over signal light images, reducing the differences between their chromaticities (and relative brightness)





(Bullough et al. 2007)

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Discussion of Brightness Perception

- For the same luminous intensity, LED signals will tend to produce equivalent or higher perceived brightness than incandescent signals of the same nominal color
  - Specific differences depend upon the hue and saturation characteristics of the specific LED types used
  - For white, blue and green LEDs, intensity could be reduced while maintaining brightness equal to incandescent
- Brightness differences are reduced in fog conditions
  - Operational control to equalize LED and incandescent intensity in fog may be desirable to prevent LED signals from appearing less bright than incandescent signals

Color Identification

- LEDs tend to produce more saturated colors and higher correlated color temperatures (CCT) than filtered incandescent sources
  - Generally beneficial for color identification in clear conditions, especially for white and green LED signal lights (*Technical Note DOT/FAA/TC-TN12/61*)
- What about non-clear conditions?
  - Fog
  - Haze

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Color Identification in Fog

- Fog scatters light and thus reduces the apparent intensity of a signal light, overlaying scattered light from other sources over the signal image
  - Scatter is wavelength-independent (Arnulf et al. 1957)
  - Fog particles are large relative to visible wavelengths (Middleton 1952)

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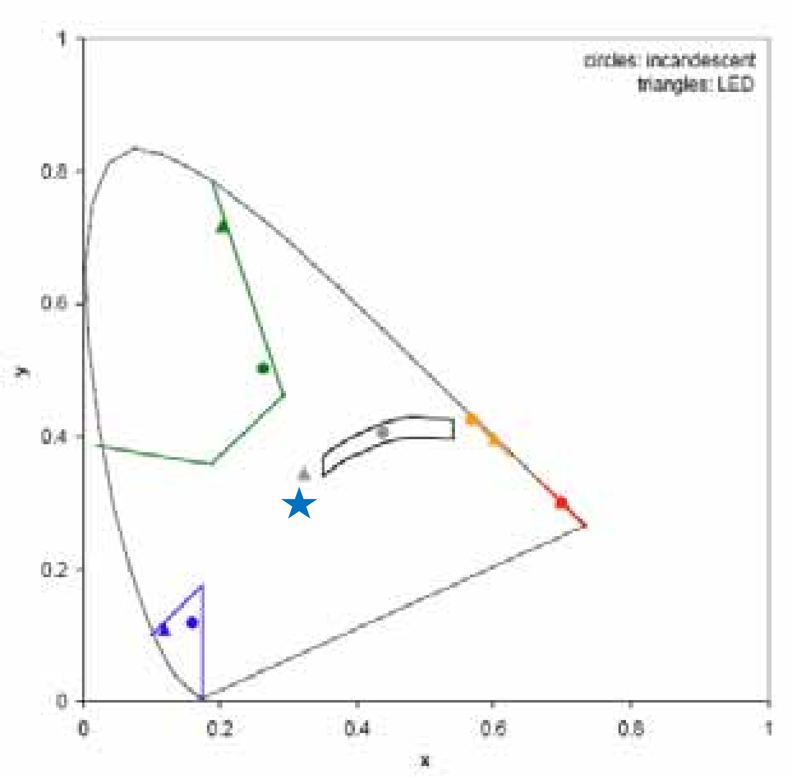
Color Identification in Fog: Daytime

- In daytime, scatter overlaying the light is white (★), so fog will desaturate signal color
  - Desaturation of some incandescent colors (like green) will make them appear white (Bullough et al. 2012)
  - LED green signals start out more saturated in color so the same amount of fog will have a smaller impact on LED color than on incandescent color



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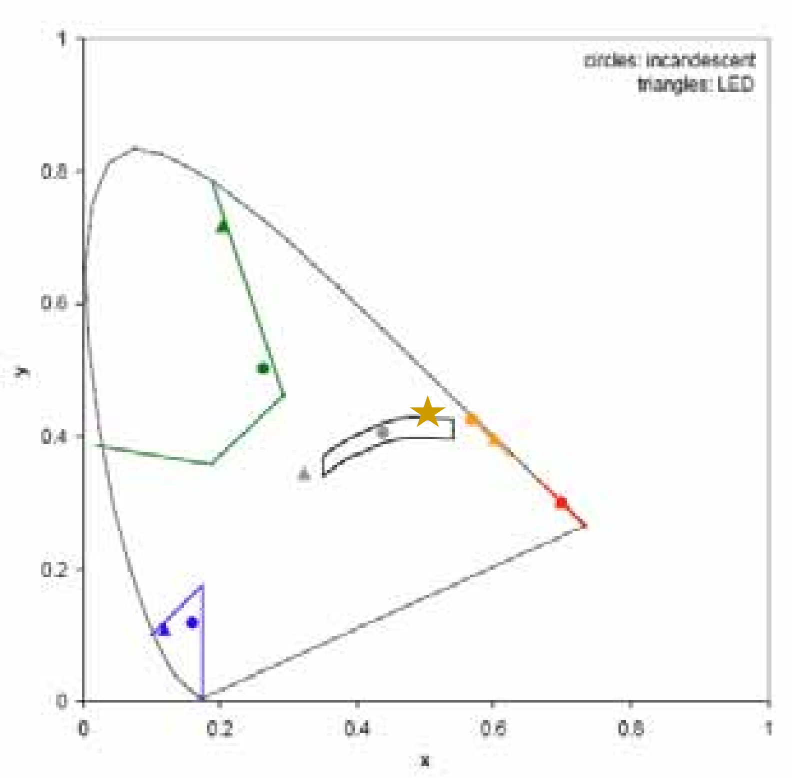
Color Identification in Fog: Nighttime

- At night, the color of scattered light depends upon the predominant nighttime light source
  - In urban areas, likely to be high pressure sodium [yellowish light] (★)
  - In rural areas, likely to be a mixture of signal light colors on the airfield
  - Central tendency likely to be "whitish" but chromaticity shift likely to be smaller



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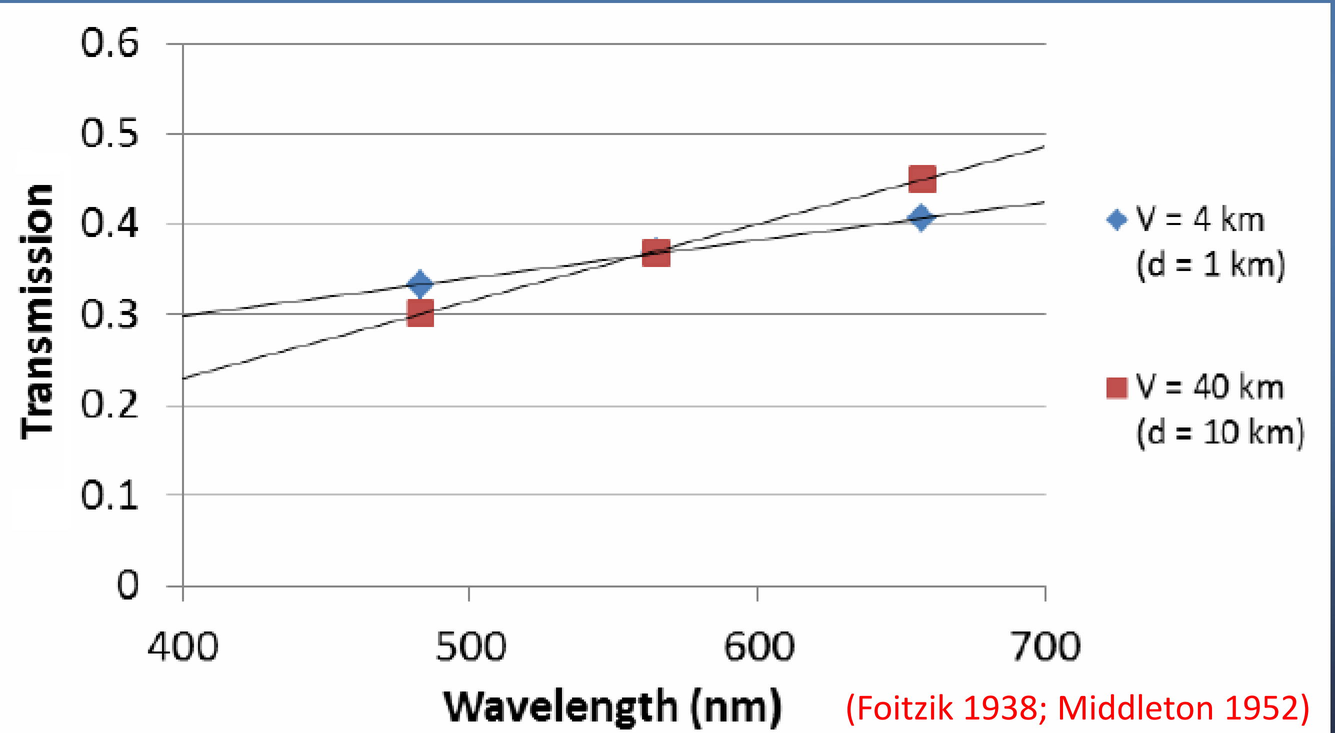
Color Identification in Haze

- Daytime issues similar to those of fog
- Haze selectively transmits light of different wavelengths
  - Smaller particle sizes (Arnulf et al. 1957)



(Foitzik 1938; Middleton 1952)

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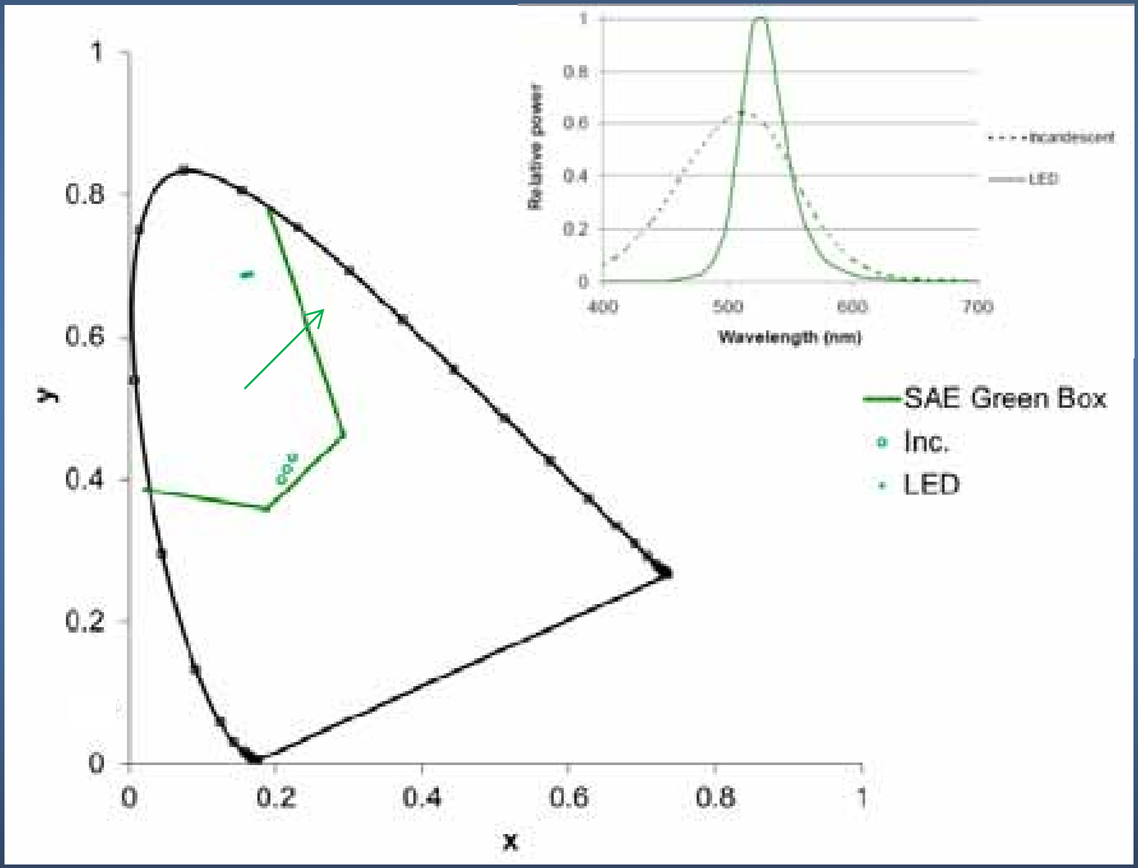
Color Identification in Haze (cont'd.)

- Shorter wavelengths are scattered more in haze
- Narrower spectral distribution is more "resistant" to chromaticity shifts



Flashing Light Detection

- To achieve equivalent response times and ratings of noticeability in clear conditions, simulated flashing incandescent runway guard lights (RGLs) needed to have about 3 times higher intensity than flashing LED RGLs (Radetsky et al. 2009)
- The presence of fog increased the necessary intensity by a factor of ten to achieve equivalent visibility, for both incandescent and LED RGLs
  - To achieve equivalent response times and ratings of noticeability under fog conditions, simulated flashing incandescent runway guard lights (RGLs) needed to have about 3 times higher intensity than flashing LED RGLs (Radetsky et al. 2009)
  - Fog did not seem to impact detection of LED signals with shorter onset times any more than incandescent sources, with longer onset times

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Summary

- "How do LED and incandescent light fixtures compare in good and bad visibility?"
  - LEDs will tend to appear brighter
    - Size of brightness difference is small relative to difference in brightness steps for airfield lighting systems
  - LEDs are resistant to color shifts from haze at night
  - Daytime fog and haze diminish, but do not reverse, advantages for LED color identification and increase in LED brightness
  - Fog does not affect relative conspicuity benefit of shorter onset times of LEDs in RGL applications

Thank you!

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