CAN LEDS BE SEEN IN FOG AS WELL AS INCANDESCENT LAMPS?

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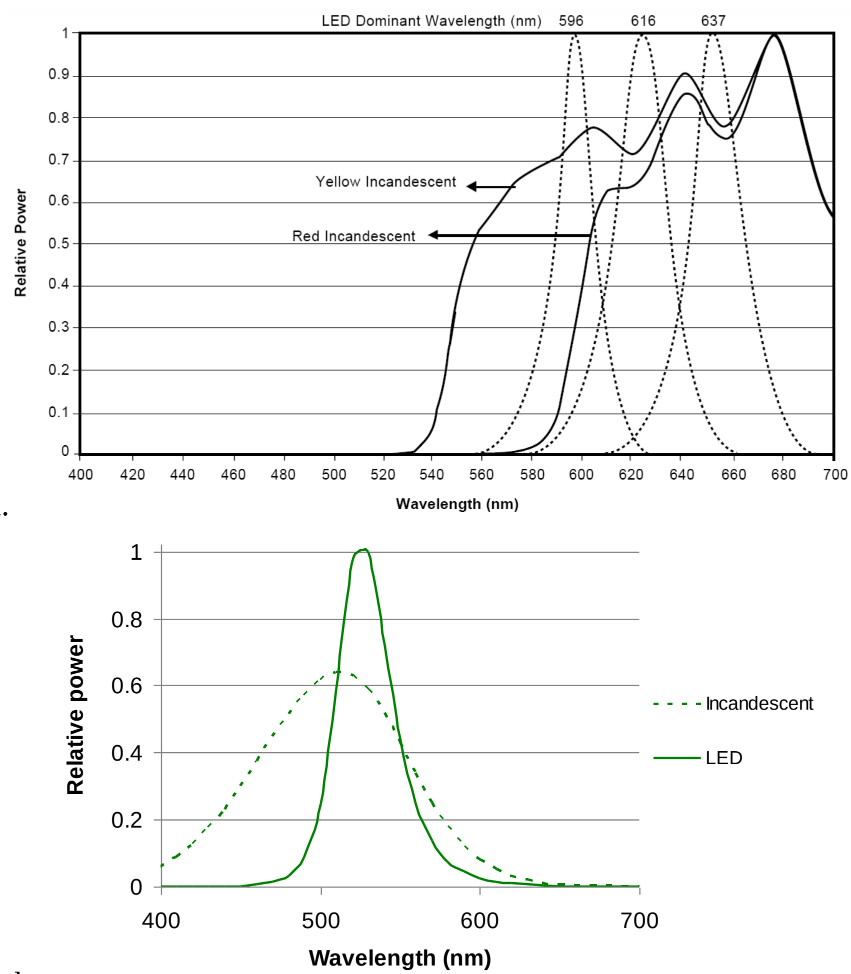
INTRODUCTION

Light emitting diode (LED) light sources are increasingly being used for airfield lighting because of their potential advantages in terms of energy savings and increased reliability [1]. They also may have some benefits for visibility such as increased accuracy of color identification compared to incandescent airfield lighting [2] and rapid onset and offset times that may increase their conspicuity in flashing-light applications such as runway guard lights (RGLs) [3]. Because of the narrower spectral distribution of colored LED signal lights compared to incandescent lights (Figure 1), they tend to produce more saturated colors and as a consequence, sometimes appear brighter than their incandescent counterparts [4].



a.

b.

Figure 1. Spectral power distributions of incandescent and LED signal lights: a) yellow and red; b) green.

The present paper reviews research findings and technical information on the perception by human observers of LED aviation lighting in inclement weather such as fog, compare to that of incandescent signal lighting. Three types of visual responses are described: color identification, brightness perception, and detection of flashing lights.

COLOR IDENTIFICATION

As stated above, colored LED signal lights tend to have advantages for color identification because of the more saturated colors they produce relative to incandescent signal lights; this benefit is most pronounced for green LED signals [2]. Additionally, white LED signal lights, which have higher correlated color temperatures (CCTs) than white incandescent lights, are less likely than incandescent lights to be incorrectly identified as yellow [2]. These advantages are applicable both to color-normal and color-deficient observers. The presence of fog and haze can have two impacts on chromaticity, related to the ambient condition and to size of the particles making up the fog and haze. In daytime, the apparent chromaticity of the light will move toward the chromaticity of the ambient daylight, generally reducing saturation. In fog or haze, sources with chromaticities nearer to the spectrum locus will maintain greater saturation as the density of fog or the distance between the signal light and the observer increases, which would be expected to be beneficial for color identification [2]. For most fog conditions [5], the attenuation of a signal light's intensity at night is unaffected by the wavelength of the light, so lights of different spectral composition will not be differentially impacted [6]. For detection of the signal light without regard to its apparent color, the impact of fog on lights of equal luminous intensity can be considered to be independent of the spectral distribution [7].

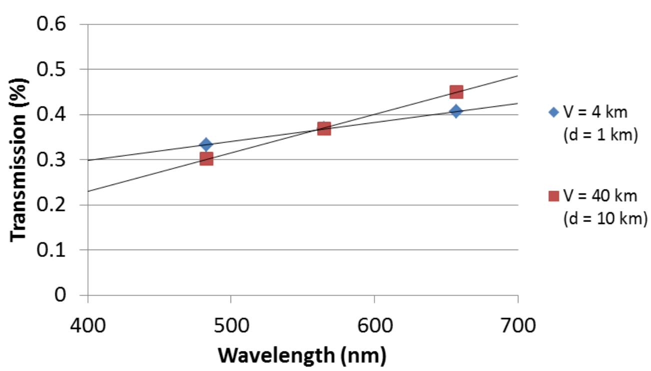


Figure 2. Spectral transmission of two haze conditions: a haze with visibility (V) = 4 km, viewed through a distance of 1 km, and a haze with V = 40 km, viewed through a distance of 10 km [6,9].

For hazes, which have greater visibility (V) distances than fog [5] but are generally made of smaller particles in the atmosphere, and certain rare fogs with small droplet sizes, there is some spectrally dependent scattering of light. In general, shorter visible wavelengths will be scattered and thereby attenuated more in haze (Figure 2), so that at night (i.e., setting aside desaturation from haze during the daytime), a green light will begin to appear more yellowish, and a yellow light will begin to appear more reddish [8]. For white signal lights, haze can serve to reduce CCT, so white LED signal lights will tend to be more likely to continue to be identified as white over longer distances through haze than white incandescent lights, which will appear yellow sooner [6]. For the green signal lights shown in Figure 1b and the haze conditions shown in Figure 2 [6,9], the chromaticity of each light would shift as illustrated in Figure 3. It can be seen that because of its narrower spectral distribution, the LED signal shifts relatively little in comparison to the incandescent signal, with chromaticity shifts about one-fourth in magnitude.

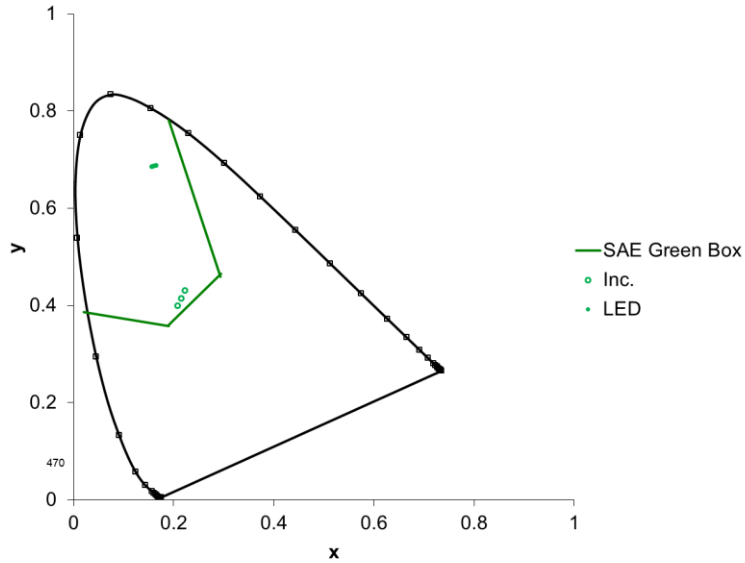


Figure 3. Chromaticity shifts of the incandescent and LED green signal lights under the two haze viewing conditions shown in Figure 2. The leftmost points indicate the chromaticity without haze. The central points indicate chromaticities viewed through haze with V = 4 km from a distance of 1 km. The rightmost points indicate chromaticities viewed through haze with V = 40 km from a distance of 10 km. In both hazes the apparent intensity of the light is reduced by about 63% relative to perfectly clear conditions.

It should be noted that although the LED exhibits a much smaller shift in chromaticity than the incandescent signal, in neither case is the chromaticity shift especially large, suggesting a slight relative benefit of narrow spectral distributions like those of LEDs with respect to spectrally selective scattering of light by atmospheric haze. This is the same conclusion drawn by the International Association of Lighthouse Authorities (IALA) in its recommendations for marine signal light colors [10].

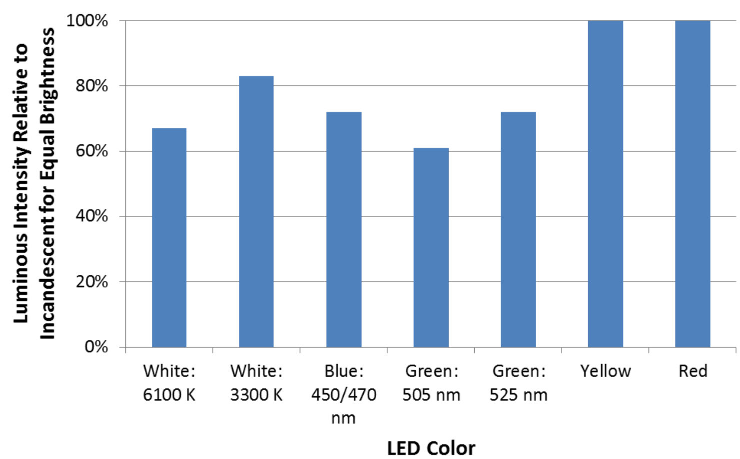


Figure 4. Relative luminous intensity needed by LED signals of various colors to match incandescent signal brightness, under clear viewing conditions.

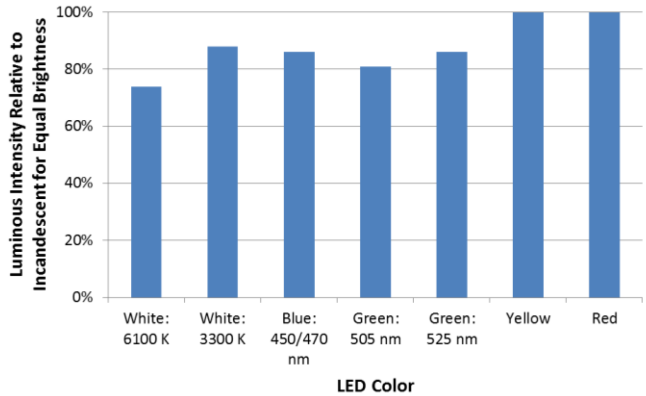


Figure 5. Relative luminous intensity needed by LED signals of various colors to match incandescent signal brightness under the fog conditions used by Bullough et al. [4].

BRIGHTNESS APPEARANCE

It has been shown that for certain colors (e.g., white, blue and green) [4], aviation signal lights using LEDs are judged as brighter than incandescent versions of the same colors, even when they produce the same intensity, so the LED luminous intensity could be reduced for these colors to achieve equivalent brightness as their incandescent counterparts (Figure 4). This does not generally apply to red and yellow signals, which produce similar chromaticities for LED and incandescent versions. This effect is moderated by fog, which tends to reduce chromaticity differences among signal lights. Bullough et al. [4] showed that in fog, white, blue and green LED signal intensities could not be reduced as much in order to achieve the same brightness of corresponding incandescent colors (Figure 5). The magnitude of the impact of fog on the relative brightness LED signal lights will depend upon the specific characteristics of fog and the ambient environment, and cannot be predicted easily. Nonetheless, LED signals with spectral compositions representative of today's available products are not likely ever to be judged as *less* bright than an incandescent signal of the same luminous intensity.

FLASHING LIGHT DETECTION

Radetsky et al. [3] compared simulated RGLs mimicking temporal on-off characteristics of incandescent lamps and LEDs, and found that in clear conditions, the maximum intensity of each RGL signal face to achieve equivalent response times and equivalent noticeability ratings needed to be more than four times higher for the incandescent signal than for the LED signals. The incandescent RGL in that study had gradual onset and offset times, producing a smooth transitions in intensity from "off" to "on" and vice versa. In comparison, the LED RGL had very immediate onset and offset times, and these may have enhanced their detectability and noticeability.

In the same study, a simulated daytime fog condition was created using the same simulated RGLs, and although the overall luminous intensities needed to achieve reliable detection increased by about a factor of ten relative to the clear conditions [3], the ratio in luminous intensity between the incandescent and LED intensities needed to achieve high levels of detection and noticeability was again, more than four times higher, similar to the simulated clear viewing conditions. These data suggest that any relative advantage of the more rapid onset and offset times of LEDs in terms of detection and noticeability is not diminished by the presence of fog [3].

SUMMARY

The data and research reviewed in the present paper suggest that LED light signals can have some advantages over incandescent signals in terms of color identification, brightness perception and detection of light onset by human observers. The presence of fog and haze may diminish the relative advantage of LEDs for color identification (particularly during the daytime) and brightness perception, but does not appear to reverse it. The narrowband spectral distribution of colored LEDs may be advantages for color changes caused by scatter in haze. Finally, fog does not seem to differentially impact observers' ability to detect the onset of a flashing light. In short, the answer to the question "Can LEDs be seen in fog as well as incandescent lamps?" seems to be "Yes."

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