Task 12: Usability of Color-Coded Light-emitting Diodes (LEDs) by Pilots with Color Vision Waivers (Milburn)

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Requirements Statement
Operational Shortfall or Knowledge Gap The FAA's Lighting Systems Group (AJW-46) is considering a replacement of the current (incandescent) airport lighting system with a system using more energy-efficient light emitting diodes (LEDs). One issue related to this change with respect to pilots with anomalous color vision is the perceptual effect of LED's narrow spectrum (monochromatic) light compared to the broad visual spectrum of light produced by incandescent lamps.
Benefit in Closing the Shortfall or Gap Color vision deficiencies usually involve a loss of one of the three types of cone receptors (red, green, or blue). The deficiency can appear as a shifting of the perceptual range of the cone's pigments. Therefore, research is needed to determine whether perception of the narrower band presented by the LEDs is still usable by the pilot population who possess color vision waivers.
Description of the Desired Product Determine the optimal wavelength for the Precision Approach Path Indicator (PAPI) red lights, the optimal correlated color temperature (CCT) for the white of the PAPI system, optimal wavelengths for the Medium Intensity Approach Lighting System with Runway Alignment Indicator Lights (MALSR) threshold lights, and (CCT) for the MALSR white steady burning lights.
Schedule Identify and procure hardware for the research Design and Develop the LED and Incandescent Lamp mock-up Prepare laboratory apparatus and stimuli, obtain Institutional Review Board (IRB) approval, collect performance data, plot and analyze data Determine the color perceptual effect of replacing incandescent lights with LEDs

Research Objective
Examine whether the previous standards that were established for incandescent lights are suitable for LEDs. Identify any implications of changing to the new LED technology on color coding interpretation. Identify the optimal wavelengths for the Medium Intensity Approach Lighting System with Runway Alignment Indicator

Lights (MALSR) threshold lights, the optimal CCT for the white of the MALSR system, and the optimal wavelength for the Precision Approach Path Indicator (PAPI) red lights.

Background

The FAA has maintained a color vision standard for pilots for many years because of the need to interpret the non-redundant color coding used to communicate glide-slope information from the PAPI lights system to the pilots; and, because of the non-redundant color coded signal lights that air traffic controllers use to communicate with pilots who are experiencing radio failure. Color coding is used in many areas of the airport such as green runway threshold lights, red end of runway lights, blue taxiway lights, and white runway edge lights. In addition, the glass cockpit of modern aircraft relies heavily on color coding to display vast amounts of information that must be quickly interpreted.

About 8 to 10 percent of all males and about ½ of 1 percent of females have a color vision deficiency. Those color vision deficiencies are primarily genetic and involve the loss of one of the three cone pigments or a shift in the perception of one of the cone's pigments. An analysis of a possible percentage of licensed pilots with color vision deficiencies revealed approximately 5,200 pilots may be expected to have anomalous color vision. The color vision deficiency does not allow the individual to see colors in the same way as individuals with normal color vision. For example, an individual with a color vision deficiency may not see a color difference between red and white lights but has learned to refer to the dimmer one as red and the brighter one as white.

In the case of the color coding used in the PAPI light system that uses 4 lights composed of red and white lights to indicate the proper glide path (2 red and 2 white lights), the individual may perceive a brightness difference if at least 1 of the lights is a different color (e.g., 1 red and 3 white lights); however, if all 4 lights are red (meaning that the plane is coming in too low) the color deficient individual could misinterpret the lights as all white (meaning that the plane is too high). For these reasons, the FAA has maintained a color vision medical standard for pilots.

Previous Activity on this Task

The FAA and ICAO established chromaticity polygons outlining the boundaries for the aviation colors in CIE color space; however, LEDs are a new technology that presents colored lights with very different spectral characteristics (such as the narrow band vs. the broad band difference previously discussed) from those of the incandescent lamps with colored filters that were used to establish the chromaticity polygons. Furthermore, other aspects of the LED technology are potentially problematic for pilots with color vision deficiencies of the deutan type (those who are green weak). The chromaticity polygons for the color green were intentionally selected to fall within the bluish-green region of CIE color space to perceptually separate green from white for deutan individuals, the group that comprises the largest number of color deficient individuals. That decision (selection of the bluish-green color as "aviation green") was based on incandescent light technology. Incandescent white lights appear yellowish; therefore, to increase the difference between the colors white and green, a bluish-green was selected instead of a yellow-green. However, that "fix" for incandescent lights may be a liability in the LED system because LEDs produce white light by shining blue light through a yellow phosphor.

Proposed or Planned Research

A cooperative study with Rensselaer Polytechnic Institute (RPI) Lighting Research Laboratory is planned to begin in mid-February. The participants will receive 22 additional color vision tests (either screening or diagnostic). Test performance will be compared to a generic, computer-based test containing pilot relevant colors and the FAA's current secondary screening test for pilots, called the Signal Light Gun Test. That test presents red, green, and white lights from a distance of 1,000 and 1,500 feet. It is the same instrument that tower air traffic controllers use to signal/communicate with pilots who are experiencing radio failure.

Research Question(s)

Are the previous standards that were established for incandescent lights suitable for LEDs?
What are the implications of changing to the new LED technology on color coding interpretation?
What are the optimal wavelengths for the Medium Intensity Approach Lighting System with Runway Alignment Indicator Lights (MALSR) threshold lights?
What is the optimal CCT for the white of the MALSR system?
What is the optimal wavelength for the Precision Approach Path Indicator (PAPI) red lights?
What is the optimal CCT for the white of the PAPI system?

Technical Approach

Current Year

CAMI personnel will work with RPI to design and develop the LED and Incandescent Lamp mock-up. The mock-up shall simulate the airport environment lighting conditions. The mock-up shall have the light sources subtend similar angular resolution of a MALSR lighting field and a PAPI system.

In addition, CAMI and RPI will develop drive circuits for the LEDs and power supplies for the incandescent lamps. CAMI and RPI personnel will measure the photometrics of all light sources and the chromaticities of all light sources. CAMI and RPI will provide a task report on the mock-up including pictures, schematics, photometric and chromaticity measurements.

CAMI has awarded a contract to Companies of JJ Young of Albany, NY to recruit and pay research subjects. CAMI and RPI personnel will screen and test research subjects. Participants of varying degrees of color vision deficiency will be recruited with an emphasis on those most likely to possess/obtain a color vision waiver. A group of participants with normal color vision will serve as the control group. The research participants will complete all FAA-approved color vision screening tests, several proposed color vision screening tests (such as the CAD, the Cone Contrast Test and others), the Signal Light Gun Test that is administered to pilots requesting a color vision waiver or SODA (statement of demonstrated ability) and the Oculus anomaloscope will be administered to classify participants by color vision diagnoses. All research results will be reported as a function of anomaloscope classification and screening test pass/fail determination will be based on the current criteria published in the Guide for Aviation Medical Examiners.

Research subjects will be asked to identify the color of a variety of lights using various wavelength or CCT LEDs and incandescent lamps with filters. In some tests, various intensities of the light sources may be used for additional information. The subject's task shall be analogous to a pilot's workload on approach to a runway in that the lights will be presented for a limited time (~ 5 sec.) The various wavelengths and CCTs of the LEDs shall be compared and reported based on the subject's performance (by color vision diagnoses) as a function of (limited) simulated exterior lighting conditions.

An IRB application has been submitted, the study design has been finalized, test materials have been assembled, test proctors have been trained, and color vision equipment (including all currently FAA-approved tests and several new tests seeking FAA-approval) have been shipped to RPI in Troy, NY. RPI has completed the construction of an apparatus that presents colored LED lights and colored incandescent lights. The lights are presented in pairs and the subject is asked to mark (on the electronic response pad) the name of the target color.

Out-Years

Provide a task report on the mock-up including pictures, schematics, photometric and chromaticity measurements. Determine the optimal wavelengths for the Medium Intensity Approach Lighting System with Runway Alignment Indicator Lights (MALSR) threshold lights, and optimal correlated color temperature (CCT) for the MALSR white steady burning lights.

Air Traffic Resources Required

None

Information Technology Resources Required

Back-up data on non-networked computer. Calibration of Viewsonic monitor for the Cone Contrast test

Calibration

The PI will ensure that the Photo Research 650, the LMT Luminance Meter, the Minolta CS-100/CS-200, the CAD test and any CRT monitors used for data collection are calibrated prior to beginning data collection

FY10 Milestone Schedule		
Description	Proposed Start Date	Proposed Completion Date
Establish collaborative relationship with RPI	FY09 Q3	FY09 Q3
Identify and procure hardware for the research	FY09 Q3	FY10 Q1
Procure subject contract for PAPI	FY09 Q3	FY10 Q2
Design and Develop the LED and Incandescent Lamp PAPI mock-up	FY09 Q3	FY10 Q2
Identify and test research subjects' color vision	FY09 Q4	FY10 Q3
Test the subjects using the research mock-up for the PAPI	FY10 Q1	FY10 Q3
Procure subject contract for MALSR	FY10 Q2	FY10 Q3
Design and Develop the LED and Incandescent Lamp MALSR mock-up	FY10 Q2	FY10 Q3
Identify and test research subjects' color vision	FY10 Q4	FY10 Q4
Test the subjects using the research mock-up for the MALSR	FY10 Q4	FY11 Q1

FY10 Deliverables		
Description	Proposed completion date	Actual completion date
Report on the mock-up including pictures, schematics, photometric and chromaticity measurements	FY10 Q2	
Report detailing the number of subjects as a function of color vision classification	FY10 Q4	
Draft Report on findings of mock-up study for the PAPI	FY11 Q1	
Draft Report on findings of mock-up study for the MALSR	FY11 Q1	