PAVEMENT EDGE LIGHT SAFETY SYSTEM, PELSS: VISUAL ENHANCEMENT TO AIRFIELD LIGHTING

By:
Scott Stauffer and Warren Hyland
Luminaerospace, LLC
7788 Oxford Court, N Huntingdon, PA 15642
USA
Phone: (412) 613-2186
sstauffer@luminaerospace.com
whyland@luminaerospace.com

PRESENTED FOR THE
2014 FAA WORLDWIDE AIRPORT TECHNOLOGY TRANSFER CONFERENCE
Galloway, New Jersey, USA

August 2014

For over 60 years, boundary edge lighting has been limited to a single point of illumination. A taxiway Pavement Edge Light Safety System provides a much needed improvement to the traditional “nodes of light” by adding an illuminated horizontal linear bar that is aligned with the pavement edge. Individual nodes of light can become confusing at night, during reduced visibility periods or when approaching the lights from an angle out of alignment with the runway or taxiway. At larger airports, these lights may appear as a “sea” of random lights which may not provide adequate visual cues for pilots to safely navigate around the airport. The addition of a linear light source to existing taxiway light fixtures, or as a replacement, provides information related to both the location and the orientation of the pavement edge.

This paper should not be confused with the LED Linear Source project that is currently under way by the FAA Technical Center [1]. The FAA has been studying In-Pavement Linear Source for nearly a decade with the intent to determine if advantages exist and what the minimum length and spacing should be to provide an advantage over point light sources; however, their base line evaluation presented does not illustrate a differentiation between a single node of light and relatively short linear segments. An assumption appears to have been made due to the fact that a two foot linear bar appears as a single point source when viewed from a distance of a few thousand feet away; it is not discernable whether there is any improvement between a single point light source and a two foot linear segment in their study because the data has not been presented, to date. Pilots are regularly challenged on taxiways with interpretation of multiple point light sources, such as “hot spots” and runway exit locations in their immediate vicinity while moving at speeds of less than 20 knots; in other words, pilots have 60 seconds to discern the geometry of an intersection that is 2000 feet ahead. Rather than time, distance, length and spacing, this paper focuses on patterns that are created once the line segment shape is discernable by the human eye and progress related to a fixture that presents a purposeful illusion of a boundary using a combination of relatively short, elevated, linear light sources.

The National Transportation Safety Board has identified situational awareness of pilots about an airport as a main contributor to runway incursions around the world; in 2012, this issue topped the NTSB “Most Wanted” list. The number of incidents, accidents, incursions, and excursions that occur each year would be greatly reduced by improving the ability of pilots to quickly recognize safe runway exit locations and to better recognize the runway/taxiway intersections they are approaching.

Individual points of light have offered a foundation for situational awareness. In order for them to more effectively represent edge lines they could be placed much closer together, like the pixels on a video monitor. Research with regard to utilization of line segments, instead of continuous pixels on video displays [2] is in agreement with the feedback received from pilots and ground personnel who have viewed a demonstration of PELSS. The rudimentary test conducted in 2013/14 at Cleveland Hopkins International Airport involved 25 light-bars fitted to taxiway lights along the edge of the D Apron. Pilot reaction (46 responses to a survey) was 93.5% positive. The research has shown that short sequences of discontinuous lines allow the brain to efficiently interpolate line sequences and create a complete representation of an image without using a continuous line.

The Phenomenon of curved illusory boundaries is used to recreate the actual pavement edge boundary in the mind. The Gestalt Psychology central principle is that the mind forms a global

whole with self-organizing tendencies, ref. History of Psychology [3]. Airport lighting systems have been using Gestalt principles of symmetry, similarity and proximity since the dawn of aviation. In many cases, it is the expectation that these principles will exist that actually create problematic taxiway geometry. Consider the case of an airport with two parallel runways; the expectation is that each parallel runway also has a parallel taxiway. In figure 1, Parallel Runways, the expectation is not met and may result in a taxiway excursion.

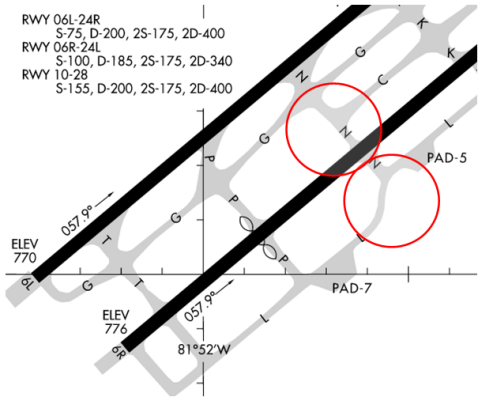

Figure 1. Parallel Runways

A linear marking oriented parallel to the pavement edge will prevent an excursion, Figure 2, Linear Marking. While it is possible to place individual taxiway lights at much closer spacing in this area, the semi-continuous line provides an improved visual cue and reduces ambiguity.

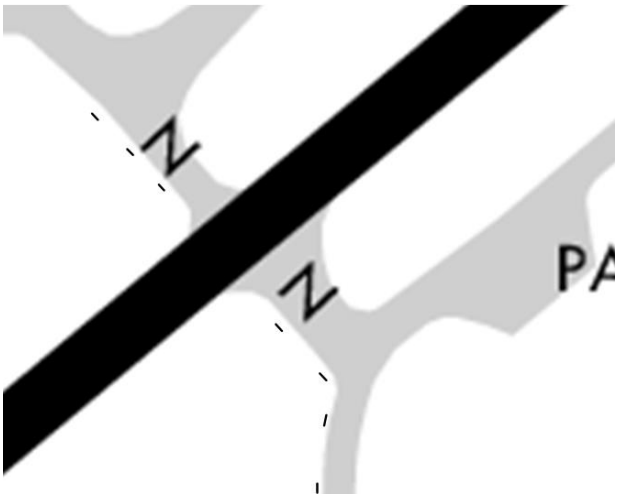

Figure 2. Linear Marking

In this particular case, symmetry and similarity are missing from the taxiway configuration which requires additional visual aids. In the past, nodes of light have made an effort to create illusory boundaries without the use of a continuous line segment. The linear marking presents a *step change improvement* over the node of light emanating from the traditional taxiway light

fixture. Recent taxiway geometry guidance from the FAA that emphasizes symmetry and similarity will reduce this problem in the future.

The solutions presented are not perfect. Viewing perspective and distance have a significant impact on the mental picture. The lack of foreground and background references at night prevents the formation of a three dimensional image in the mind. While viewing an illuminated linear marking that is perpendicular to the path of travel, an unquestionable barrier lays ahead; however, when you are traveling parallel to the illuminated marking, the perceived length of the marking appears to decrease as the parallel path of travel nears the actual path of the linear line segments. As with an aircraft on a taxiway, a slightly elevated viewing perspective allows the linear segment to be more visible, while light bars that are more distant will eventually appear as a single node as the angle decreases between the line of site and linear segment. This is actually the way our mind interprets reality. We know that the road is flat and the pavement edges are parallel, but our mind creates an internal image as shown in Figure 3, ref. The Dimensions of Visual Experience: A Quantitative Analysis as illustrated in research by Steven Lehar, Ph.D. [4]. For this reason, both off-center and elevated viewing perspectives will provide an enhanced overall representation at greater distances.

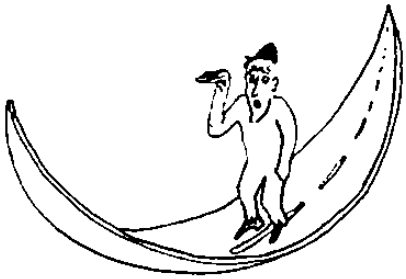

Figure 3. The Dimensions of Visual Experience: A Quantitative Analysis

In a 1956 study of shape and pattern perception for the Air Force, Fred Attneave and Malcolm Arnoult conclude that form perception involves a number of psychological mechanisms that function in a complementary, and in some degree overlapping, manner [5]. As such, an illuminated segment may also be in the form of a curve with points concurrently tangential to the boundary that it represents, Figure 4, Non-Linear Marking. In this case the curved boundaries in “hot spots” may be emphasized for near boundary perception while linear segments provide distant cues.

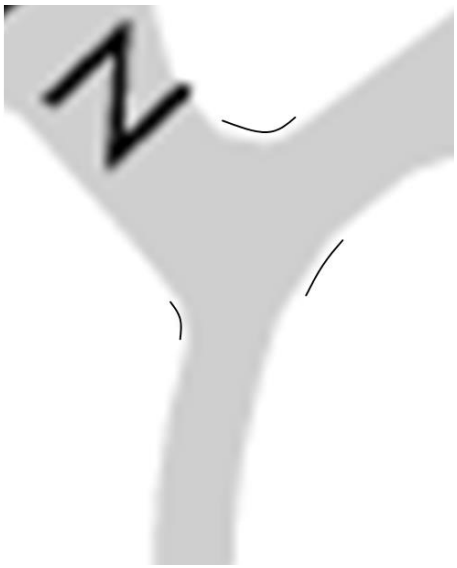

Figure 4. Non-Linear Marking

The geometry of the intersection is obvious in plan view; from a distance on the ground, this is not the case. As closure on the intersection approaches, the perspective improves with clear boundary delineation once in close proximity to the boundary edge.

Irving Biederman demonstrates Human Image Understanding in the following sequence on the left related to deletions of contour, vertex and midsection, Figure 5, Perception of Degraded Objects [6], while the image on the right illustrates an enlarged modification of the Biederman cup as individual points similar to traditional taxiway lighting.

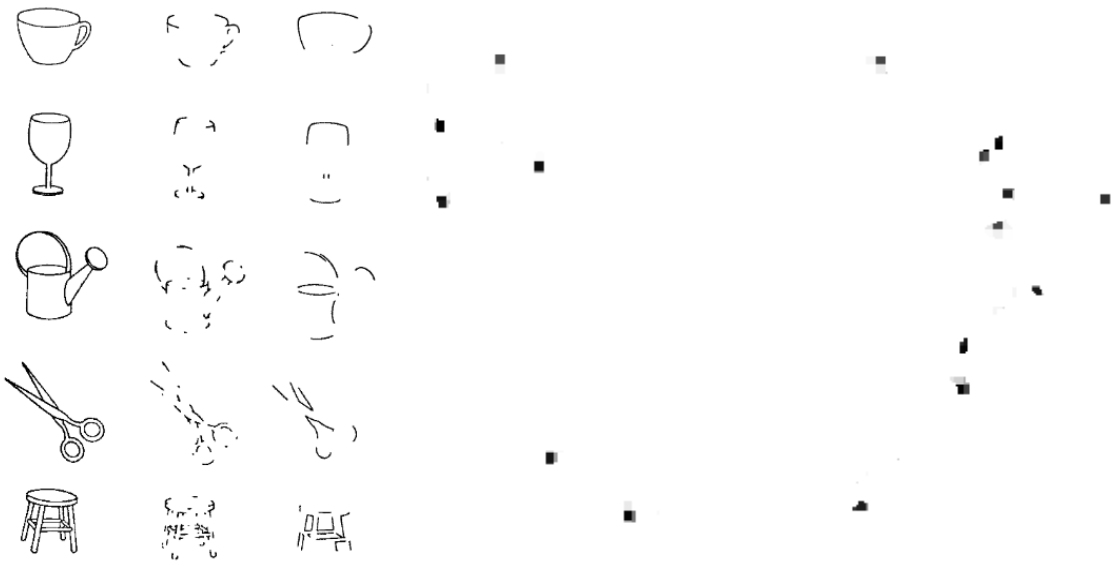

Figure 5. Perception of Degraded Objects

In 2005, Jacob Feldman and Manish Singh conclude that "the contribution of the geometrical structure of a shape to its mental representation does not depend on scale (as curvature proper does); information is a function of "shape only"" [7]. While the recent FAA study has evaluated linear segment length, size is a factor only for the eye to detect the shape of the illuminated segment. As the segments appear smaller in the distance, they will eventually appear so small that the eye cannot perceive its shape and it will appear as if it occupies a single point; this fact is of little consequence since the aircraft must only have sufficient maneuverability to remain on the taxiway prior to reaching a distal node. Furthermore, should the FAA study conclude that a 2 foot linear bar should be eliminated from evaluation since only 57 seconds remain prior to arrival at an intersection, instead of 58, then it would be an inappropriate use of otherwise valid response time data that provides a quantification of benefits.

Linear lighting segments provide an additional visual cue related to the orientation of the boundary or pavement edge. Overall situational awareness is improved by allowing the pavement boundaries to be recognized quickly and easily. Although subtle, from a distance the human brain interpolates the actual boundary edge from this additional visual cue.

Luminaerospace, LLC began testing this new lighting system at Ohio's Cleveland Hopkins Airport (CLE) in February of 2013. The enhanced design provides more than just single blue lights at the edge of taxiways. Instead, PELSS incorporates a pair of illuminated arms extending from both sides of the existing blue light that are aligned with the direction of the taxiway. This allows pilots to intuitively recognize the actual pavement edges at night and/or in inclement weather. The new lights improve pilot situational awareness even in good weather.

Airport Operations staff at Cleveland Hopkins International Airport has been working with Luminaerospace, LLC to quantify the benefits of this new linear lighting concept for taxiways.

Figure 6. Traditional Lighting

Figure 7. PELSS Lighting Enhancement

Design has evolved based upon logistics, form and function. Initially, the light was designed based upon incandescence while incorporating the existing approved node of light and adding the horizontal bar below. The logic behind the design was that by incorporating the traditional single node of light above the illuminated bar, the fixture would be in compliance with the existing specification thus only requiring approval of the additional visual cue, as in Figure 8, Incandescent Fixture with Traditional Node.

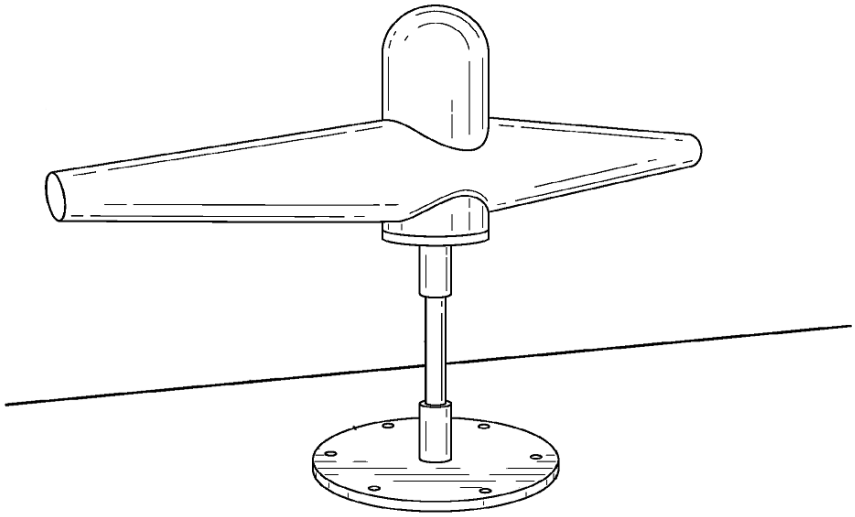

Figure 8. Incandescent Fixture with Traditional Node

An additional option is presented for a horizontal marker attached to the existing taxiway light post with a retro reflective coating as seen in Figure 9, Reflector.

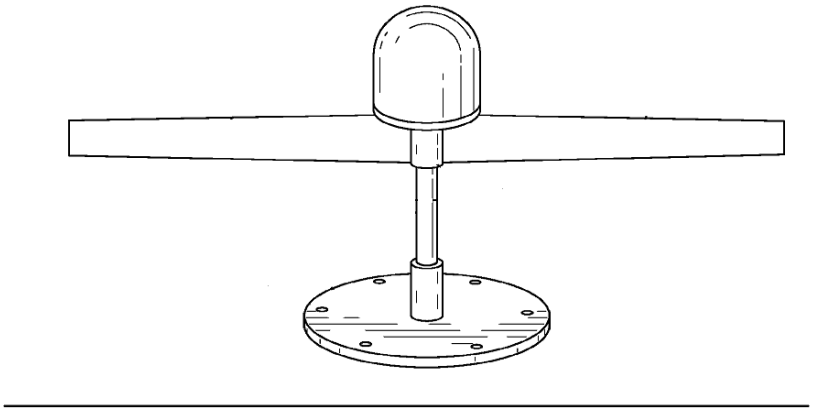

Figure 9. Reflector

The industry was clearly moving in the direction of LED lighting and the shear mass required of the incandescent version proved to be problematic. Retrofit would also have required raising the existing incandescent bulb which would have been time consuming. To incorporate LED lighting, a string of 13 blue LED's was incorporated into 2 hollow plastic 12 inch tubes and fitted inside 2 metallic tubes with elongated slots to allow the light to emanate directionally. This design allowed retrofit of existing taxiway lights and was presented to the airport operations personnel at Cleveland Hopkins International Airport; the design was immediately accepted and applauded, Figure 10, LED Retrofit. Pilots could see the blue light-bars from afar and well within the range required to avoid missing an intersection or misinterpreting a series of point sources as an extension of a pathway.

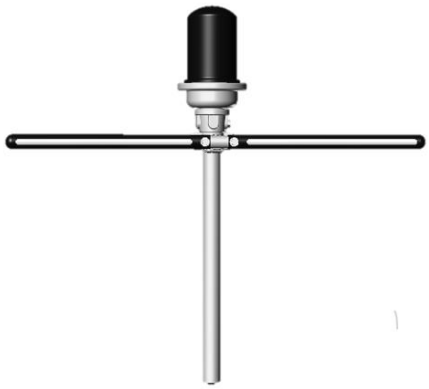

Figure 10. LED Retrofit

The illuminated LED bar also uses significantly less energy than the traditional incandescent light. Due to operational needs, illuminated segments have been relocated on a few occasions. This has enabled various geometries to be evaluated with more than a year of operational experience.

Energy efficiency continues to be a driving incentive across our airport infrastructure. According to feedback related to the Cleveland installation, the string of LED lights needed to be brighter. In order to accomplish both, the string of LED's was replaced with two, high intensity, directional LED lamps shining outward to illuminate a translucent tube. The result can be seen in Figure 11, Translucent LED Light Tube. This new version of the light-bar has recently been developed using only 2 LEDs and driven with a 12v source. The illuminated bar is a hollow tube within another translucent hollow tube, both supported by a metal casing with elongated side and top openings.

Figure 11. Translucent LED Light Tube

The improved design will incorporate end cap lenses that focus the excess LED light into a beam in line with the axis of the bar that adds to the visibility of the bar when viewed from a distance, Figure 12, Beam of Light. In addition, this *beam of light* illuminates fog or snow and virtually extends the length of the visible bar for enhanced pilot awareness.

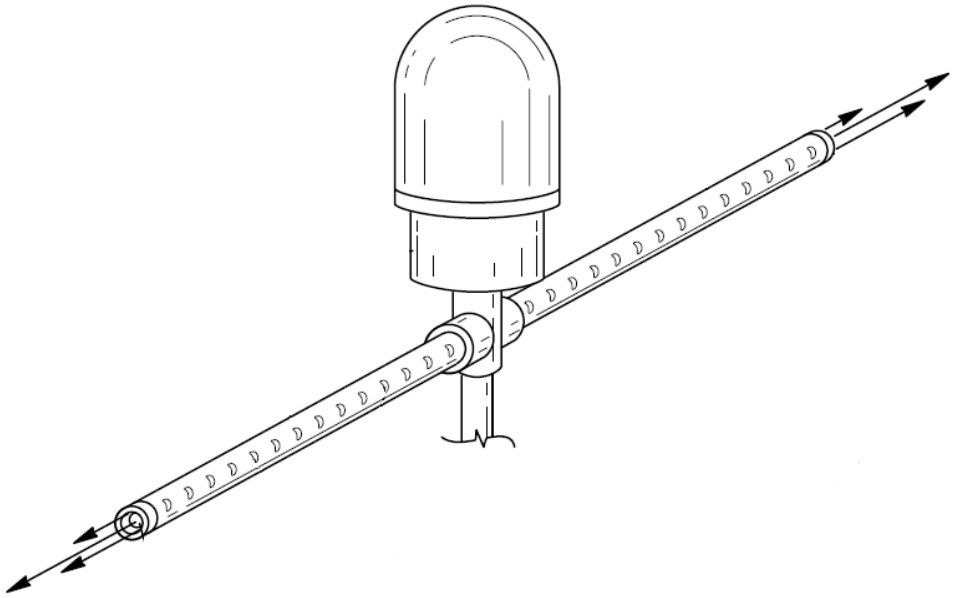

Figure 12. Beam of Light

The electronic module for the new version can be mounted below ground to reduce the cost of replacement in the likely event of damage by snow plows or mowers. Replacement with two elevated LEDs and two hollow tubes would be a fraction of the cost the entire system. The 12v system can be stepped in 3 or 5 increments of intensity and will draw only 1.4 amps at maximum brightness if 4 LEDs were installed in each fixture. Cost of the complete light-bar without a glass top module would be equivalent to today's LED taxiway lights.

Should an FAA Advisory Circular be written that requires the length of the bar to be longer than any of the former designs presented, an additional support post will be necessary in order for the light bar to maintain alignment. The second post does not have to be permanently fixed and may be a simple stake for insertion into a receptacle or the ground itself so that it may be lifted and rotated for mowing, maintenance or accessibility. A rendition of this proposed design can be seen in Figure 13, Dual Posts.

Figure 13. Dual Posts

Our industry is encouraged to continue providing their feedback through participation in the brief survey (http://surveymonkey.com/s/GQGHP9H). Your willingness to participate in this survey may influence regulatory approval and has the potential to improve operational safety in our industry.

Members of Luminaerospace, LLC are comprised of both aviation professionals and experienced passengers who recognized the need for improved boundary recognition. Luminaerospace, LLC was founded in 2010 as an intellectual property holding company for the patents related to elevated linear lighting segment technology. The original United States Patent with priority back to 2009 has been allowed with additional protection pending in Europe, Asia and the Americas. The need for an improved boundary edge light has been recognized by pilots, airport personnel and passengers. The enhancement of this Pavement Edge Light Safety System has been embraced by the aviation community.

This safety improvement is currently allowed on aprons (ramps), and boundaries areas not governed by FAA specifications. It is the mission of Luminaerospace, LLC to license this technology to existing airport lighting manufacturers and to pursue FAA approval of practical elevated linear lighting specifications.

REFERENCES

1. "Visual Guidance/Runway Incursion Prevention Research & Development Update", IESALC Fall Conference, October 22, 2013, Tucson, Arizona
2. Candice Brown Elliott: *No Illusions: Toward Brighter Flat Displays*, EE Times, (December 19, 2005)
3. David Hothersall: *History of Psychology*, chapter seven,(2004)
4. Steven Lehar, "The Dimensions of Visual Experience: A Quantitative Analysis", Toward a Science of Consciousness Conference (2006)
5. Attneave, F. and Arnoult, M. (1956). *The Quantitative Study of Shape and Pattern Perception*, 470.
6. Biederman, I, *Recognition-by-Components, A Theory of Human Image Understanding,* Psychological Review (1987), Vol. 94, No. 2, 135
7. Jacob Feldman and Manish Singh, Rutgers University—New Brunswick, *Information Along Contours and Object Boundaries,* Psychological Review (2005), Vol. 112, No. 1, 249