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TECHNICAL NOTE

Reduce Risk of Inducing Spatial Disorientation Using Physiologically Compatible Ground Lighting

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Spatial disorientation that occurs while landing aircraft during night operation may result in accidents and fatalities which are often classified as secondary to "pilot error." It has now been determined that the use of "expedient" lights, which include flares, flashlights, automobile headlights, etc. can induce spatial disorientation in pilots. The element that contributes to induction of spatial disorientation is the "point source of light" provided by these lights. Impingement on the retina of concentrated photon emissions, as supplied by incandescent (filament) lamps, flares, etc. Produces and "after image," such as occurs when one briefly looks into the sun. The "After image" is caused by the time lag required for reconstitution of the neurohumoral transmitter substances in the retinal rods and cones. Pilots who develop "after images" during the final stage of landing a helicopter at night are predisposed to experiencing spatial disorientation, leading to aircraft mishaps. In contrast to flares and incandescent light sources, cold cathode lamps lack a "point source" of light emission, do not create a "after image", and are ideal to use in night landing operations. Cold cathode lights operating in the range of 512nm (blue-green) are thought to be the most physiologically efficient color to use for night landing operation. Light sources in the nanometer range provide maximum visibility and safety for the pilot during landing operations under all environmental conditions.

Keywords: spatial disorientation, cold cathode, aircraft landing lights, helicopter landing lights, after-image.

SPATIAL DISORIENTATION (SD) has long been a significant aero medical factor contributing to both military and civilian aviation mishaps (7,8). With increased research devoted to SD over the past 10-15 years, some definitive statements regarding the cause(s) of SD can now be made. SD contributes to, or is causative of approximately 5% of military mishaps and about 5-15% of civilian mishaps. Accurate figures are difficult to determine due to differences in definitions of SD mishaps and, because initially, many incidents are attributed to pilot error (14).

This paper focuses on the rectification of one newly identified causes for SD in helicopter pilots who attempt to land at night or in inclement weather-faulty visual cues supplied by inappropriate ground lighting, which can induce SD.

Key attributed of physiologically compatible landing lights includes: 1) constant candlepower (steady burn); 2) candela (uniform brightness); 3) chromaticity (uniform color in the nanometer range of 512 nm); and 4) cold cathode lamp. Attributes one and two are stipulated in the U.S. Federal Aviation Administration's Draft Air Circular 150/5345-50, Specification for Portable Runaway Lights, December 7, 1994. Attributes three and four are the subjects to this paper.

Use of specially designed ground lighting provides the helicopter pilot with adequate central visual cues, allows identification of micro texture, does not induce SD, and enables the pilot to concentrate on obtaining the required peripheral visual cue information to consistently land the aircraft safety.

Aircraft Landing Lights

Currently landing practices: For commercial airports or helicopter, there is an FAA Advisory Circular, Heliport Design, AC 150/5390-2A, January 20, 1994, which addresses helicopter operations for commercial precision and non-precision approach operations. Although helicopter lighting is discussed, specifications for a light source are not discussed. It is possible to induce SD in the pilot through the use of various types of light sources. In a recent research publication, the FAA referred the light sources, which are not certified as meeting FAA specifications to land aircraft as "expedient" lights (9). Such lights include "flares, vehicle lights, and other light sources" (9). Use of these light sources, which also include strobes and flashlights, have an elevated probability of inducing SD in the pilot. These light sources provide "point sources" of light, which can cause serious mishaps and fatalities. This statement is made on the basis of discussions with multiple civilian and military helicopter pilots, coupled with research done at the University of Tennessee's Space Institute (Kimberlin R. Personal communication. September, 995), as well as by the Maryland State Police (22). Critical research on this topic remains to be designed and completed. Expedient lights lack standardization with respect to steady burning (constant candlepower), brightness (candela), and chromaticity (color).

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Point source of light create after-images and can induce spatial disorientation: A point origin of light, such as a flare or an incandescent light, which employs a filament to provide illumination, is interpreted by the eye as a "point source" of light. Such light sources emit high concentrations of light rays (radiant energy or photons) which impinge on the retina of the eye in a relatively small area, resulting in the development of an after image. This phenomenon is created by the recovery of the retinal neurons (rods and cones) following their exposure to a concentrated light source. An after image occurs when the retina is slow to recover or to remove the retinal image, even though the actual visual field has changed. This result is due to the time delay it takes for the retina neurons (rods and cones) to "recover" (reconstitute their neurohumoral transmitter substance) from the light stimulus.

An example of these phenomena is seen when one looks into a bright light, such as the sun or a flashlight, and then looks away. The light image of the sun or flashlight appears to remain, even though the person is looking away from the light source. A natural reaction to receiving this type of stimulus is for the individual to squint, thus narrowing the visual field in an effort to block out the intense light. This phenomenon is a primary contributor to the induction of SD when the helicopter pilot is focusing on such intense light sources while simultaneously approaching "touch down." The "after-images" created by such light sources can cause pilots to misinterpret their spatial orientation at the helispot.

In order to avoid the occurrence of this phenomenon, dimming of airport runway lights and lighting at many helipads is routinely done during night landing operations. This phenomenon is not experienced by pilots using cathode lights for night operations and dimming of the lights is not required in order to avoid it. Comparison of cold cathode landing lights with cold cathode advertising signs is not a proper comparison. The light emitted by cold cathode neon signs, for example. Is far in excess of the light produced by a cold cathode landing light. This is due to the large diameter glass tubing used in the neon sign, which provides a much larger light source, spread out over many feet, coupled with the fact that neon sign uses four to five times more electrical energy that the landing light, providing a much brighter light source. Comparing such lighting sources is not unlike comparing the light emitted from a flashlight to that emitted by a floodlight.

Spatial Disorientation: A Significant Causative Factor in Aircraft Mishaps

The problem of spatial disorientation is a continuing one for all aviation. **Table I** summarizes some of the more significant studies bearing on this subject. Investigators continue to have difficulty studying this problem For the following reasons: 1) a lack of clear definition of the problem; 2) the complexity of pursuing large numbers of accidents involved with this problem; and 3) the lack of credible witnesses from whom to obtain accurate histories. A significant number of these incidents result in fatalities. The research sighted in the paper does not represent the number of fixed-wing vs. rotary-wing aircraft involved. After reviewing the pattern of accident, it is clear that SD is a significant problem in aviation safety.

TABLE I. SPATIAL DISORIENTATION AS A SIGNIFICANT/CAUSATIVE FACTOR IN AIRCRAFT MISHAPS.

Authors (Ref. No.)	% Aircraft Mishaps	% Fatal Aircraft Mishaps
Nuttall and Sanford (one major USAF Air Command 1954-1956) (19)	4%	14%
Moser (one major USAF Air Command 1964-1967) (18)	9%	26%
Barnum and Bonner (USAF Mishap Data 1958-1968 [4679 major mishaps] (1)	6%	15%
Barnum (USAF 1969-1971) (2)	6%	10%
Kellog (USAF 1969-1972) (13)	4.8%-6.2%	"High Proportion"
Gillingham and Page (unpublished data USAF 1979) (8)	9.6%	18.4%
U.S. Army (study year(s) unavailable) (8)	7.1%	N/A
U.S. Navy (study year(s) unavailable) (8)	6.75%	N/A
Kirkham (General Aviation 1970-1975, total of 4012 fatal cases) (14)	15.6%	14%
Kirkham (General Aviation 1978-all general aviation accidents) (14)	2.5%	The third most common cause
U.S. Navy Study 1980-1989 (3)	5.0%	N/A
U.S. Air Force Study 1989-1991 (17)	14.0%	N/A
Canadian Air Force Study 1982-1992 (4)	22.5%	N/A

A Physiologically Designed Light Source Which Minimizes Induction of Spatial Disorientation.

Cold cathode lamps lack a filament and produce and even light output, which are not interpreted by the eye as a "point source". One can look directly at the cold cathode landing light and, when averting the eyes, can immediately perceive that no after-image is created and than one's night vision is unaffected by looking directly at such lights (2). No after-image is created because the light energy is evenly distributed across the retinal; and, lacking a point of high concentration, the retina is able to recover quickly. Cold cathode lighting is not a new technology, however, it's application to landing is a new innovation that results in improved safety of night operations. Cold Cathode lamps produce a landing light that is comfortable to view and causes no after-image, and therefore, will not contribute to the induction of SD. Multiple example if this light source exists in the neon (cold cathode) advertising signs in most cities, world-wide.

The Optimum Color and Light Source for Rotorcraft Operations

Obsolete selection criteria: The FAA developed color (chromaticity) selection for airport light standard in the decade of the 1930's based only on subjective factors using the incandescent lamp as the light source (Bates R. Personal Communication. Washington, D.C.; Chief Visual Aids Standards Branch, Airport Service, Department of Transportation, FAA, April, 1990). Scientific studies of retinal physiology in low ambient lighting conditions are being considered, and the new knowledge gained will be used to re-examine these criteria. Many of the lighting codes sponsored by both the U.S. Federal Aviation Administration (FAA) and the International Civilian Aviation Organization (ICOA) are based on traditional and international agreements, and not on retinal physiology, which is of paramount important in preparing such standards. Use of cold cathode light for aircraft landing lights has only been possible for the past several years, and it's use has not been subjected to in-depth scientific studies, as has incandescent light technology.

The immerging significant for implications of research in this arena is emphasized by some of the subject matter, which was scheduled to be presented at the Illuminating Engineering Society of North America's 1998 Annual Meeting. Included in the meeting's program was a seminar entitled "The First Annual Great Debate: Measurement Vs. Perception- the Spectral Question," which, in part, discussed the scientific area wherein the effect of the spectral distribution of light on vision is now being researched. This puts into question the use of current standards of lighting measurement as a reliable predicator of human measurement, a point which underscores the significance of the content of this paper (12). (Brochure: Engineering Society of North America's 1998 Annual Meeting, San Antonio, TX, August 10-12, 1998).

Airports formerly were located away from the cities and sources of light pollution. As the cities have grown up around the runways and heliports, the importance of selecting the right color to enable the pilot to differentiate the runway or heliport from streetlights is paramount during night-landing operations.

Scientific selection of a light based on retinal physiology: Previous research on retinal physiology has identified the proper nanometer range of maximum retinal efficiency on the absence or near absence of light. A light source operating within the range of 520 nm was thought to stimulate the rods and cones to 85 % of their peak sensitivity, creating the optimal color blue-green, which can best be perceived by the eye in low ambient lighting conditions. Light source outside of this nanometer range where thought to be less efficient in regard to retinal reactivity. (**Fig. 1**) (6,11,16).

Extensive research over the last yr with a cold cathode lamp, designed to emit light in the range of 512 nm, operating through a clear aviation lens, has been identified to be close to a ideal, non-point-source of light, designed to maximize retinal efficiency for night landing operation. Incandescent light sources do not emit light at this frequency, and, thus, cannot be compared in scientific studies. This research has been conducted independently by members of the FAA's Vertical Flight Department and the U.S. Park Police (20). To date, none of their finds have been released or published. The spectral luminous efficiency curves for cones and rods as shown in Fig. 1, were developed by the Commission Interantionale de l'Eclaiarge, in 1924 for cones (photopic vision) and, in 1951 for the rods (scotopic vision). These assessments were made separately and may not reflect precisely the actual interaction between the rods and cones. In order to maximize retinal efficiency a light spectral encompassing a range over lapping these two curves is necessary. Additional research may clarify the physiological relationship between the neuroreceptors in the regard.

Over the past 3 yr repeated testing be multiple helicopter pilots, both military and civilian, reveals the eye apparently response the best to a light source operating in the range of 512 nm. From a distance, light form a cold cathode lamp in the range of 512 nm, using a clear aviation lens, appears green, but seems to be perceived by the eye with increased clarity as compared with an incandescent lamp in the range of 528 nm, the light emission range through a standard FAA Aviation green lens used for runaway approached lighting. A light operating in the range of 512 nm appears to be more easily identified in the surrounding "seas of lights" in an urban setting vs. an incandescent lamp filtered through a standard FAA Aviation green lens. Additional research and testing may demonstrate the usefulness of this light source for use as runway lights. The standard FAA blue taxi lights do not offer a source of light which can either be viewed at a distance for practical approach and landing sequences, nor do they provide the candla levels necessary for safe landing operations.

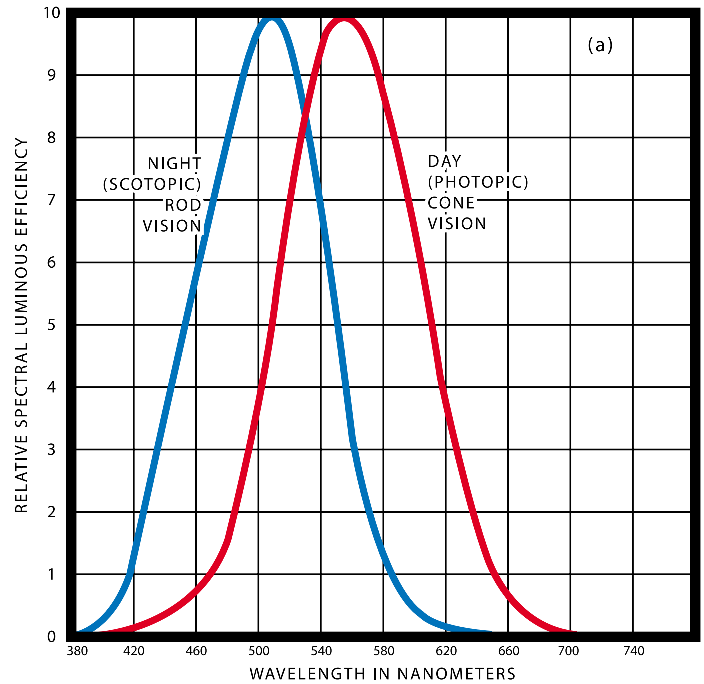

Fig.1. Realitive spectral luminous efficiency curves for photopic and scotopic vision, showing the Purkinje shift on the wavelength of maximum efficiency. (Reprinted with permission from: Kaufman JE, ed. Light and Vision. Baltimore: Waverly Press, 1966) (16).

As a result of this physiological phenomenon, during night landing operations the pilot is never subject to a bright source of light, but to a rather pleasant blue-green light when viewed on landing. At this time, no other light source has been identified which can produce this effect, in this respect, this is a unique light. As a result, no after-images on the retina are created. And the potential for induction of spatial disorientation form this source is minimized or absent. Standard, airport, and heliport, and runway lights use lens which are optically designed to support maximum light output for the pilot, using a special designed aviation light. However, the light source remains the incandescent light, which provides a point source of light.

New developments: Presently, there is no published body of research on this subject. The passage of an amendment to the FAA's programs on June 18,1998, authored by U.S. Representative James A. Traficant, Jr. promotes the use of enhanced vision technologies, which includes cold cathode lighting, to replace or enhance conventional landing light systems at U.S. airports. On June 18, 1998, the House of Transportation Subcommittee on Aviation approved legislation reauthorizing FAA's programs this year. According to the news release, the legislation 1) requires the FAA to conduct a study of the feasibility of requiring U.S. airports to install enhanced vision technologies to replace or enhance conventional landing light systems over the next 10 yr; 2) makes the installation of enhanced vision technologies eligible for AIP funding; and 3) requires the FAA to submit to Congress within 180 d of enactment of the bill a schedule for certification of two of the most promising enhanced vision technologies the FAA has been working with: laser guidance and cold cathode lighting. According to the news release, "The U.S. Navy has tested enhanced vision technologies, and plans to deploy these technologies on aircraft carriers. The U.S. Park Police has had great success with cold cathode lights at its helipad in Washington D.C. In addition, the FAA has been testing and analyzing enhanced vision technologies for the past several years" (20).

VFR Approaches at Night or During Inclement Weather Conditions Can Now Be Made with Confidence

When landing in a "black hole" situation, it is important for the pilot to have both central and peripheral visual cues. At night, peripheral visual cues are significantly reduced as that situation where a pilot is attempting to land his rotor craft with few, if any, visual cues, apart from the helicopter landing itself.

When a helicopter pilot attempts a landing without adequate central and peripheral visual cues, a dilemma is created for the pilot as to how to simultaneously identify the helispot (the center of the helicopter landing zone where the aircraft is to land) and to "clear" (ensure the lack of physical obstructions) the entire helicopter landing zone itself. As a result, the total workload of the pilot can easily exceed 1000% capability, a situation that signifantly increases the probability for a serious error (10).

While not all field operations require landing into a "black hole," nonetheless it is physiologically extremely difficult for pilots to repeatedly and safely land a helicopter into a "black hole" without using specially designed auxiliary ground lighting, due to the causative factors leading to the induction of SD.

Use of specially designed ground lighting provides the pilot with adequate control visual cues, and allows identification of microtexture. This significantly reduces the probability for induction of SD and enables the pilot to concentrate on obtaining the required peripheral and visual-cue information to safely land the aircraft.

Flight safety and Human Factors

Sheridan and young identify the importance of human performance enhancing system performance, in which "safety is intrinsic to system performance" (21). "the majority of aviation accidents are attributed to operator (pilot) error. Close examination may reveal that the root cause goes back to a system design in failing to account for human capacity or limitation," (21) something especially true in the case of SD. The majority of aircraft mishaps due directly or indirectly to SD are usually classified initially as "pilot error." It is only after intense investigation and studies that the true nature of the underlying cause for the accident is discovered to be SD.

According to Gillingham, "SD wastes hundreds of millions of dollars annually and kills aircrew members. SD results primarily form inadequacies in the flying environment. The U. S. Air Force is conducting a three-pronged research and development effort to solve the SD problem. They are attempting 1) to elucidate further the mechanisms of visual and vestibular orientation and disorientation, 2) to develop ground-based and in-flight training methods for demonstrating to pilots the potential for SD and the means of coping with it, and 3) to conceive and evaluate new ways to display flight control and performance information so that pilots can maintain accurate spatial orientation" (7).

The use of specially designed ground lighting, which includes the attributes of physiologically compatible landing lights discussed above, provides a "system" where "safety is intrinsic to system performance" and which conforms with Sheridan and Young's recommendations (21). In addition, the use of specially designed ground lighting reinforces the pilot's acquired skill of visual dominance, a factor which is critical in avoiding induction of SD (8). Placement of specially designed ground lighting, as contrasted to presently used lighting sources, provides the helicopter pilot with adequate central visual cues, allows the perception of translation cues required for the fine control of a helicopter; identification of micro texture; significantly reduces the risk of inducing SD; and, enables him to more easily obtain the required peripheral visual cue information for safe landing of the aircraft.

In the same manner, now that specially designed ground lights are available for landing aircraft, it is imperative appropriate standards be developed for the use of proper ground-lighting sources to prevent or minimize the occurrence of SD in pilots of rotary-wing aircraft engaged in landing at night or in inclement weather ("system design"), thereby acting to prevent accidents, injuries and fatalities.

Relationship Between the Global Positioning Satellite System and Spatial Disorientation

The Global Positioning Satellite System (GPS) is now in place and operational. Its use by helicopter pilots will rapidly increase over time. Basic standards for rotor-craft use of GPS have already been drafted by the FAA. It is now possible, using this technology for the helicopter pilot to fly directly to the HLZ via VFR (Visual Flight Rules), or IFR (Instrument Flight Rules).

When a helicopter pilot flying under adverse weather conditions via VFR or IFR, the "cornerstone" for induction of SD is created. Adverse weather conditions, in combination with the lack of adequate visual cues, is the "envelope" that leads to SD. The potential for induction of SD is increased when the pilot changes form IFR to VFR flight and begins final approach and landing maneuvers, especially when the environment at the proposed landing site is degraded or minimal; offers poor visual cues, and expedient or point source ground lighting is employed.

The phenomenon is documented by recent U.S. air Force studies with fixed-wing aircraft (5). It is reasonable to consider that this same phenomenon occurs with rotary-wing pilots over the past 8yr. As these discussions were informal, occurred with both active and retired civilian and military helicopter pilots, in both face-to-face and telephone conversations, this information is considered anecdotal. However, these discussions support the concept that the use of specially designed ground lights in these situations would greatly reduce the risk of induction of SD, and increase the safety of night landings.

Cost Efficiency of Cold Cathode Lighting

All lamps that produce light form electrical sources are glass (containers) filed with various gases surrounding a metal conductor, which provides a point for the transference of electrical energy that excites the gases, which in turn gives off light. The cold cathode lamp is not new technology, having been used for decades in neon sign advertising and for obstruction lights for airports and bridges.

Cold cathode lamps are significantly more cost efficient than the standard incandescent lamp in the following aspects:

- Power Consumption: 25 W
- Lamp Life: 20,000 + hours.
- Efficiency: 65% of energy is converted to light, 35% lost to heat for a typical incandescent lamp.
- Maintenance Requirements: Low
- Reliability: Excellent
- Initial Cost: Moderate.
- Life Cycle Cost: Approximately 20% of comparable incandescent light unit.

Light Efficiency of Cold Cathode Lighting

Laboratory tests reveal the cold cathode lamp differs significantly from an incandescent light with regard to light emission using FAA medium intensity runway lenses. Comparisons of 30 W and 45 W incandescent aviation lights, employing a standard omni directional medium intensity FAA green runway lens, with a light emission of 528nm, and a clod cathode lamp rate of 4 W, with alight emission of 512 nm, using a standard omni directional medium intensity FAA clear runway lens, are summarized in **Table II** (15). A significant drop in luminous intensity (Candela) levels in the incandescent light sources occurs at approximately 10°, dropping to 3-4 candela in the critical viewing range for the helicopter pilot. In the cold cathode; amp a small loss in candela is observed, beginning at 14°, but never drops below 5 candela up to 20°. The cold cathode lamp provides uniform light emission throughout the lens. No dimming of the cold cathode light is required on short final approach (1/4 –1/2 mi) and landing, as occurs with incandescent light sources. In addition, the cold cathode lamp provides excellent illumination of the helipad, virtually eliminating the necessity to use floodlights.

TABLE II. COMPARISON OF LUMINOUS INTENSITY BETWEEN INCANDESCENT AND COLD CATHODE AVIATION LIGHTS.

Vertical Angle	Luminous Intensity (Candela)		
(in Degrees)	30W	45W	Cold Cathode
20	3.0	4.7	35.5
19	3.2	4.5	36.9
18	2.9	4.4	38.0
17	2.8	4.4	39.3
16	2.9	4.5	40.6
15	2.9	4.9	41.8
14	3.1	5.3	42.8
13	3.3	5.6	43.6
12	3.6	6.1	44.2
11	3.8	6.8	44.6
10	4.1	7.5	45.0
9	4.6	8.7	45.3
8	5.2	10.5	45.5
7	6.2	12.9	45.7
6	7.7	16.1	45.9
5	9.7	20.4	46.2
4	12.3	25.5	45.8
3	15.2	32.6	45.3
2	18.9	43.4	44.6
1	25.3	56.9	44.2
0	34.6	68.9	43.9
1	43.4	74.7	43.4
2	47.0	72.1	43.1
3	45.5	63.9	42.6
4	40.1	52.3	NA
5	33.1	41.6	NA

Use of Cold Cathode Lamps for Heliport/runway/taxiway Lighting

Use of the cold cathode lamp presents a significant opportunity to decrease costs for airports and heliport lighting as GPS technology is implemented. With the systematic decommissioning of ILS, VOR and all other navigation systems currently in use, GPA will be the world standard for air navigation. One result is that pilots will have IFR access to hundreds of current VFR airports and heliports. Combining the use of GPS with emerging laser systems technologies, precision approaches will be available for al runways and heliports. It is imperative that the most cost effective means of providing lighting for these facilities be utilized. Taking into account both cost and safety factors, cold cathode lamps offer a new and promising direction in lighting for heliports and airports. In addition, low cost, portable, cold cathode lighting units are presently approved for temporary use for both runway and taxiway lights under FAA's AC 150/5345-50, Specification of Portable Runway Lights. These portable light units are available to support law enforcement and EMS helicopter operations at impromptu, temporary sites as well.

SUMMARY

Specially designed ground lights for rotary-wing aircraft are being manufactured and sold in the U.S. These cold cathode lights have the characteristics necessary for proper ground lighting and include: 1) constant candlepower (steady burn); 2) candela (uniform brightness); and 3) chromaticity (uniform color in the range of 512 nm). Further they provide no point source of light, thus minimizing the risk for induction of SD.

Improved quality of ground lighting will reduce pilot workload in a critical phase of flight, and minimized the chances for induction of SD during night landing operations for rotary-winged craft. The configuration of lights used, or, intense training, will not eliminate the risk of SD; however, provision of specially designed ground lights ill establish a preventative safety standard, and will not leave the possibility of the induction of SD "up to chance" or to "pilot error." With the introduction of cold cathode lamp designed to emit light around 512 nm, it is now possible to provide an ideal light source designed specially for maximum retinal efficiency. This is the first time in aviation history that a recommendation is made to employ a lamp which has been designed to be physiologically compatible with retinal physiology for use in landing aircraft. The use of specially designed ground lights provides a significant advance in aircraft for pilots, flight crews, passengers, and ground personnel.

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