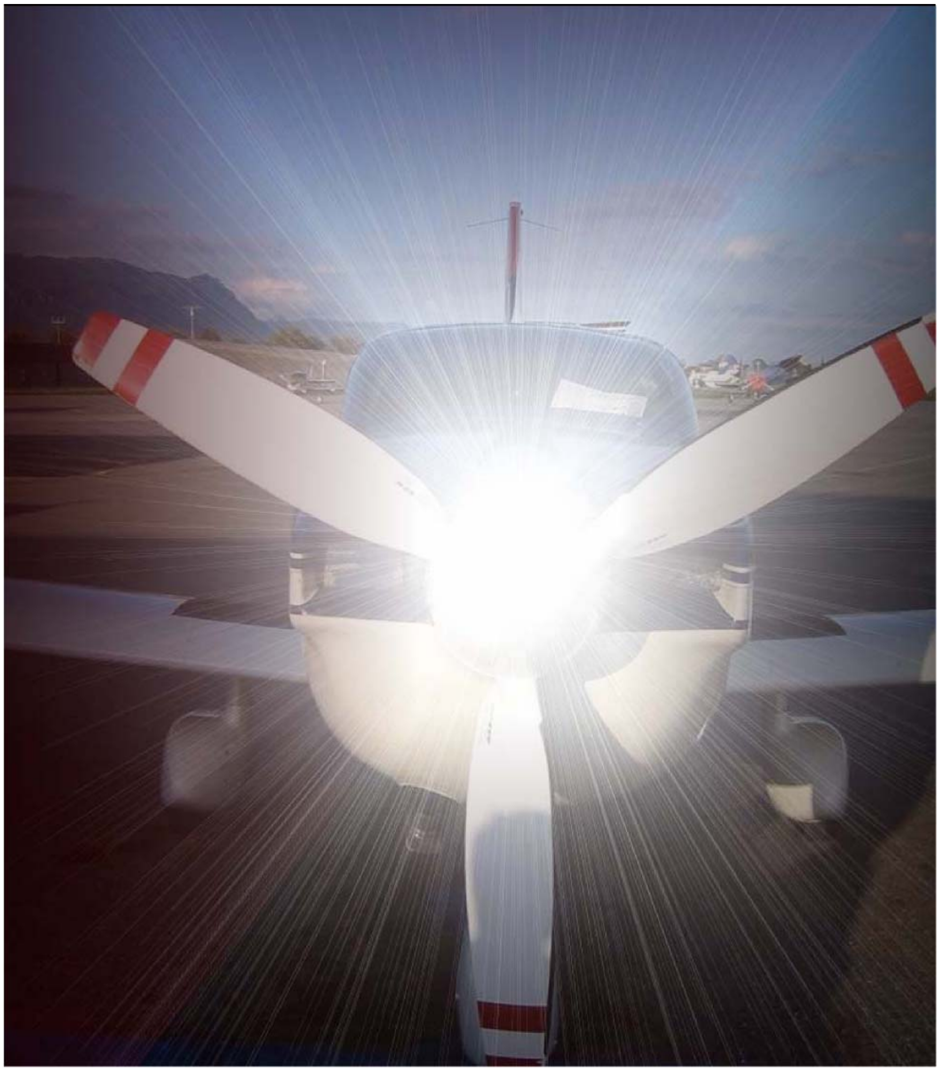
COMMUNITY SERVICE AIRPORTS
VISUAL AIDS HANDBOOK



Acknowledgments

The content of this handbook is the consolidated effort of the Illuminating Engineering Society Airfield Lighting Committee (IESALC), the Center of Excellence for General Aviation Research (CGAR) and the Federal Aviation Administration (FAA) Airport Safety Technology Research and Development's Visual Guidance Program.

Contents

FOREWORD

This document is being offered for use by the segment of airports termed "Community Service Airports". In the context of this guideline, Community Service Airports are non-Part 139 facilities. They typically serve General Aviation (GA) aircraft of ten seats or less, however a seat arrangement is more likely to be four to six people. These airports are not recipients of federal, state, or even local government funding in most cases. They are quite often funded only by the direct contributions of the users, either monetarily or through "sweat equity." They are either private or public. It is in the interest of Community Service Airports to adopt a standardization that is applied to their visual guidance systems. This should be offered by any of the visual aids installed at such a facility. Standardization is critical for a safe operating environment. This leads to the reason for the guidelines that we hope to establish with this document.

The content of this handbook is the consolidated effort of the Illumination Engineering Society (IES) Subcommittee on General Aviation Lighting, the Center of Excellence for General Aviation Research (CGAR) and the Federal Aviation Administration (FAA) Airport Safety Technology Research and Development Visual Guidance Program personnel. The purpose of the content is to generate awareness of an alternative line of products. This alternative line of products represent the visual lighting presentation of the more expensive, fully FAA-approved lighting systems at a reduced cost while still maintaining needed visual cues.

The rationale for the FAA certification is to guarantee that when an airport procures visual aids, the visual aids will perform successfully in all environmental conditions that may occur at major airports. In order to meet this guarantee, extensive testing is required as per the FAA's Advisory Circulars (AC) which raises the cost to the manufacturers. In many cases, the cost can be substantially reduced at airports that do not conduct operations in extreme environmental conditions. An example might be the fabrication of a runway/taxiway light fixture base can. Since Community Service Airports will not use base cans in extreme environmental conditions, they can save on the costs of manufacturing to such demanding requirements. The manufacturer has the opportunity to use good quality material, but the overall cost is reduced. The treatment for longevity can be eliminated or reduced at a substantial savings in the retail cost of the final product. Although longevity is compromised, the base can final functionality as a support for a runway/taxiway light fixture is not compromised. The final assembly provides a visual presentation that is consistent with applicable FAA requirements.

Alternatively, the construction of these products may be so basic, specialized, or refined that little or no further reduction in cost can be achieved without affecting the visual presentation. An example exists with the modern day runway/taxiway light fixture, to include its lens. The base is typically aluminum, cast or stamped. In some cases, even plastic composites have been utilized. Each of these methods of producing light fixture housings have resulted in increasingly inexpensive products, narrowing the chance of significantly reducing production costs. The lens is essential to the optical characteristics and visual presentation of the assembly, and would be difficult to produce more economically even at the expense of longevity of service. This is primarily due to the Fresnel pattern of the lens existing on all modern runway/taxiway lights. It is needed to properly focus the light emitted by the internal lamp within the fixture. The lamp offers some opportunity for minor cost-reduction. It is recognized that the next real opportunity for significant cost-savings in light fixture design could result from future generations of light emitting diode (LED) products. At first glance, it becomes immediately obvious that not all system elements can be significantly redesigned to offer "Standardization of Presentation" at a much-reduced cost. In such instances, the product will not be offered at the expense of safety or visual presentation. Some system elements are not practical at the Community Service class of airports and as such will not appear as a significant consideration in this guideline.

An additional objective of these guidelines is to stimulate the interest of lighting manufacturers to the degree that they will produce the products at an attractive savings to the Community Service Airports that serve a critical role in meeting the air travel needs of our communities. In many small communities throughout the United States, it is the only access to air travel and the quick transport needs that can occur there, particularly with respect to medical emergencies.

The initial guidelines were directed at the non-technical users, and offered a blend of basic information and technical specifications regarding individual visual aids. This was done to attract the interest of manufacturers to produce a low cost version of the FAA approved counterpart visual aids also referred to as system elements. However, the overall and overriding objective was to encourage the installation of products by Community Service airport owners that is visually true to the system elements at larger airports but priced to be substantially more affordable. Low cost is not meant to be inconsistent with the FAA standards for visual presentation. However, the compromise could affect longevity in service. It is believed that the compromise is acceptable for the advantages realized since Community Service airports are not FAA Part 139 service facilities which have stringent criteria for system availability and reliability.

Although some of the most stringent of FAA specifications are compromised to reduce cost, the visual presentation is maintained for the pilot that expects to see an airfield with a standardized lighting configuration. We believe that the resulting effect is a safer operating environment even though the equipment may not have the long-term life expectancy of its more expensive counterpart. "Standardization of Presentation" is the desirable outcome.

To summarize, this guideline is neither designed to nor does establish lighting standards, but rather it encourages uniform, consistent, and high-quality airport lighting. The information and guidelines published herein are not intended to be a substitute for professional expertise, sound judgment, or technical knowledge. It does not seek to replace the requirements for maintenance, operation, inspection, and licensing of airports which are included in the FAA National Plan of Integrated Airport Systems (NPIAS).

These guidelines are intended for the many smaller non-Part 139 airports with only a local and/or state interest who do not qualify for federal grant-in-aid assistance, and many that would qualify cannot afford the required "local" share. Over the years, individual airport operators and state aviation agencies have devised "affordable" equipment and systems to meet the needs of airports in these situations.

These guidelines serve to document recommendations which have proven successful in the field. Several have been in use for many years. Others might be considered experimental or tentative pending the test of time. Exhibits are provided at the end of this document, which identify several states, and a segment of airports within each of these states that have earnestly attempted to practice the philosophies outlined in this guideline. Feedback to date has been positive and we have every reason to believe that other states should share in their success.

This document is comprised of three different sections:

Section 1 — Community Service Airport Lighting System Elements, offers a brief introduction to the different types of lighting systems available for the small community airport.

Section 2 — describes the lighting elements in more detail including some performance guidelines.

Section 3 — covers information on each lighting element so an airport manager can take the necessary steps to outfit a small community airport.

The appendices include a brief history of the committee, studies performed for the Remote Airfield Lighting Systems (RALS), Alignment tables for Precision Approach Path Indicator (PAPI) lights, and Visual Aids.

SECTION 1 - COMMUNITY SERVICE AIRPORT LIGHTING SYSTEM ELEMENTS

The lighting fixtures, also referred to as system elements, described in this section comprise the most basic and arguably the least sophisticated of visual aid devices that might be utilized to assemble an airport lighting system for use by pilots under Visual Flight Rules (VFR). FAA Part 139 airports build upon these basic system elements by adding a variety of additional lighting products carefully selected to further enhance the visual presentation available to pilots. The degree of complexity and sophistication associated with its final design is completely dependent upon the unique purpose of the airport. This fact explains why there exists such a varied configuration of systems between airports of seemingly the same size and purpose. There are many ways to achieve the final result of a standardized visual environment for pilots.

The object of this document is to construct a visual presentation that pilots can rely upon. Depending on ancillary attributes of the landing facility, the family of visual aids can vary significantly to achieve an adequate visual presentation. It is suggested the following system elements should at least be considered, if not deployed, at the basic general aviation facility that we refer to as a Community Service Airport (CSA).

1. RUNWAY AND TAXIWAY LIGHTS AND MARKINGS

Runway and taxiway lights and markings are installed on the edge of runways to be used during nighttime operations or periods of limited visibility. Runway lights are available to produce various levels of brightness and are typically classified as low, medium, or high intensity. There are three types of runway lights that are currently specified by the FAA: (1) Low Intensity Runway Lighting (LIRL), (2) Medium Intensity Runway Lighting (MIRL), and (3) High Intensity Runway Lighting (HIRL). It is expected that CSA will use products that have performance requirements consistent with LIRL specifications as this type of runway lighting system is used for VFR conditions.

Some GA airports, where few of these may be considered a CSA, have non-precision IFR approaches. These airports make use of MIRL systems with higher intensity requirements. HIRL is not expected to be used by CSA as it specified for large Part-135 certified facilities that conduct operations in extremely low visibility.

Low Intensity Runway Lights (LIRL) These types of lights are used at airports which conduct VFR operations. The light fixture should be supported by a base or a stake with a frangible coupling holding the fixture to that base. This means that the frangible coupling must break when the light is struck, but the base remains firmly affixed to the ground. The coupling can be wood, PVC, or another material suitable for support of the light. Typically, 30 inch stakes are used for base support, however, non-load bearing GA base cans may also be used.

Taxiway Lighting Community Service Airports frequently do not have full or even partial parallel taxiways. When adequate funds are available, any full-length taxiways and exit taxiways should be equipped with low intensity taxiway lighting system (LITL) that is blue in color. All taxiways are appropriately marked with centerline stripes and appropriate hold lines. Centerline stripes also exist on taxi lanes traversing apron areas.

Taxiway Reflectors A highly practical technique for marking taxiway edge and centerlines is the use of retro-reflective markers, which are passive devices and relatively inexpensive. They can be installed to provide centerline and pavement edge guidance.

General taxiway reflectors shall be a marker with reflective qualities of a color meeting FAA standard color configuration for airport lighting. Taxiway reflectors shall be reflective blue. Green taxiway centerline reflectors are acceptable, in non-snow areas, in lieu of taxiway edge reflectors. Reflectors shall meet the physical performance specification of visual markers. Reflector system layout shall meet FAA standard light-spacing criteria.

2. AIRPORT APPROACH LIGHTS FOR USE IN VMC

Airport Approach Lighting Systems are installed to provide visual guidance to the pilot on approach to an airport. There is currently one Approach Lighting System for use in Visual Meteorological Conditions (VMC), and that is the Omni-Directional Approach Lights (ODALS) Runway Alignment Indicator Lights. This system is composed of a variety of flashing or strobing lights configured to identify the extended centerline of the approach end of a runway. The pilot will use this information to align the aircraft on a direct path to the extended centerline of the runway for landing.

The minimum visibility where an ODALS may be used for non-precision runways is 1 statute mile provided the runway is 3,200 feet long with an MIRL system. This is not likely to be the case for most CSA's, and therefore will likely not be advised for use in most cases.

3. RUNWAY END IDENTIFIER LIGHTS (REIL)

REIL fixtures are flashing lights installed at airports to provide easy and positive identification of the approach end of the runway on which they are installed. The system consists of a pair of synchronized flashing lights located across from one another on each side of the runway threshold. REILs can be either omni-directional or unidirectional. Unidirectional units are positioned facing outward, towards approaching (landing) aircraft. They are particularly important for airports located in areas of low contrast. This could include areas surrounded by extraneous lights or a runway that blends in with surrounding terrain.

Low Intensity Runway End Identifier Lights (LREIL) The LREIL can be either unidirectional or omni-directional.

4. PRECISION APPROACH PATH INDICATOR (PAPI)

The precision approach path indicator (PAPI) uses light units installed in a single row perpendicular to the runway and consists of either two or four light units. These systems have an effective visual range of about 5 miles during the day and up to 20 miles at night. The system emits a white signal above the glidepath and a red signal below the glidepath. The PAPI unit must come equipped with a tilt circuit to prevent the unit from becoming inoperable when it is out of alignment. The PAPI units need to draw power from the runway lighting circuit or separate power.

5. AIRFIELD VISUAL MARKER

An Airfield Visual Marker is a marker contrasting from the background colors of the air operation areas and used for daytime, Visual Flight Rule (VFR) guidance. The marker shall be frangible to FAA requirements when located within runway or taxiway safety areas and must be visible from traffic pattern altitude. Typical markers are non-rigid cones, etc.

6. ROTATING BEACON

A Rotating Beacon is utilized for long distance, enroute visual acquisition of an airport. It is an extremely intense point source intended to guide the pilot to a position where he or she may acquire additional navigational aids once the pilot is in the vicinity of the airport. There are many types of beacons, and the flash rate, color, and intensity requirements are specific to the type of airport or seaport using the beacon. The requirements contained in this document are specific to CSAs.

7. PILOT RADIO CONTROL

A Pilot Radio Control allows the pilot to control several of the system elements from the aircraft cockpit via keystrokes on the aircraft communications radio. Control of lighting systems is often available at locations without specified hours for lighting and where there is no control tower or Flight Service Station (FSS), or when the tower or FSS is closed (locations with a part-time tower or FSS) or specified hours. All lighting systems that are radio controlled at an airport, whether on a single runway or multiple runways, operate on the same radio frequency. Usually, this includes runway lights, taxiway lights, and Runway End Identifier Lights (REILs). Operation is described in detail later in this document under the heading, "Radio Control of Airport Visual Aids." However, circuitry details shall be left to the discretion of the manufacturer.

Wind Cones (Also known as windsocks) Devices that are used to indicate wind direction. Some wind cones are constructed so that they can be used to roughly determine wind speed.

8. SELF-CONTAINED SOLAR-POWERED LED FIXTURES

Solar-powered LED airfield lighting systems provide an alternative lighting solution where power may be unavailable, unreliable, or economically unfeasible to acquire. Self-contained and designed to operate with little to no maintenance, solar LED airfield lighting solutions can eliminate the need for powered infrastructure including cabling, regulators, transformers, trenching, conduit, vaults and power controls. Airports will benefit from easy installation along with a reduction in the cost of contracted labor and outsourced engineering design.

For remote airports where maintenance and operating costs may be an economic or labor-intensive burden, minimal scheduled maintenance coupled with minimal- if any-energy costs can provide significant return on the capital investment. Solar lighting may require battery replacement every three to five years, and it is recommended that airports purchase units which have replaceable batteries. Otherwise, airports should expect to build into their cost comparison estimates the full initial cost of the solar-powered units to be expended every four to five years. Often, this cost comparison will be favorable when accounting for savings in initial installation, incandescent lamp replacement, and energy consumption. These factors are different for every installation, and should be examined prior to purchase.

Light emitting diodes (LEDs) will provide many thousands of hours of light output, also environment and operation dependent. In addition, solar is a safe, renewable energy source providing the required light, and is independent of power outages, grid failures, electrical hazards, line-loss, scheduled maintenance, cable replacement, cable failure, and increasing energy costs.

It is recommended that all solar LED airfield lighting solutions are equipped with power management systems capable of providing reliable airfield lighting independent of environment at the intensity level required for that visual cue. All solar LED lighting solutions should provide dusk till dawn light output when substituted for powered or retro-reflective lighting standards. If wireless control is required or sought after, each solar LED lighting application should provide this feature.

Solar airfield lights should meet the required chromaticity standards of FAA AC 150/5345-46. If necessary, the optical covering should require a UV and scratch-resistant coating for deployment in harsh environmental conditions and contingency airfields. The solar airfield lights should be ISO certified, able to withstand extreme weather, chemicals, sand-blasting, temperature extremes, and large temperature variations over short periods. It is recommended that solar airfield lights have other means beside the photovoltaic panel for recharging the batteries. Extreme hot or cold temperatures, cloud-cover or poor solar environments should not jeopardize reliability or required performance when operating solar LED airfield lighting in virtually all geographical locations.

The discussion on utilizing solar energy to power a lighting circuit connected together through wires will be discussed in the individual application sections' portion of this guide.

9. REMOTE AIRFIELD LIGHTING SYSTEMS

Lighting an airfield or airstrip located in a rural, remote area has unique challenges. Scarcity of power from an electrical grid, limited funding, and few technical personnel require a lighting system that uses little power, operates reliably and cost-effectively, and requires minimum training for installation and operation—all while meeting the needs of pilots.

Remote airfields serve local communities needing emergency medical service and provisional supplies. These communities are willing to take minimal responsibility for the airfield's operation and basic maintenance, but they do not have an economy that can support more than a very basic airfield infrastructure.

For the scope of this document, a remote airfield is defined as, "any airport that is not on the road system. A remote airport is one that is not paved, has no powered lighting nor reliable electric power supply, is not accessible by paved or otherwise well-developed roads, is not used by jet aircraft, has no or minimal glide-slope, runway, elevation or location markings useable from the air. A remote airport serves an identifiable community need for occasional emergency and provisional supply functions and has a constituency population that is willing to take minimal responsibility for its operation."

The lighting system consists of these components, at minimum:

Corner lights are mounted at each of the four corners of the usable area of the airstrip to help pilots locate the airfield and orient the plane for approach.

Edge-markers can be either retro-reflectors (i.e., self-luminous devices that reflect light from a plane's landing lights) or powered edge-lighting units similar to the corner lights. The edge markers are mounted along the edge of the usable area of the airstrip on each side between the corner lights to indicate the edge of the runway.

Retro-reflectors do not require power. The selection of edge lights will depend on the amount of power available at the site and budgetary concerns for both purchase and operation. Corner lights and edge markers are the minimum components necessary for an effective remote airfield lighting system. However, other visual cues may be advantageous and could be added as budget and power availability allows.

Recommended Airport Visual Aids Systems by Airport Classification

Airport Type	**Remote Airfield**		**Non-Paved Airfield**		**General Aviation Airfield**	
Level	*Minimum*	*Enhanced*	*Minimum*	*Enhanced*	*Minimum*	*Enhanced*
Wind Indicator	N/R	N/R	Standard	Standard	Lighted	Lighted
Corner Lights	Flashing	Flashing	N/R	N/R	N/R	N/R
Rotating Beacon	N/R	N/R	N/R	N/R	Standard	Standard
Runway Lighting/Markin	Reflective	Reflective	N/R	N/R	Low Intensity	Low Intensity
PAPI	N/R	N/R	N/R	N/R	N/R	Standard
REIL	N/R	N/R	N/R	N/R	N/R	Low Intensi
Radio Control	N/R	N/R	N/R	N/R	N/R	Pilot Activate
Taxiway Lighting/Markin	N/R	N/R	Daytime	Reflective	Reflective	Reflective

Options Described:
N/R: Not Required.

Wind Indicator:
Standard: Wind Indicator with segmented circle.
Lighted: Lighted Wind Indicator with segmented circle.

Rotating Beacon:
Standard: Airport beacon with green and white alternating pattern.

Corner Lights:
Standard: Four flashing green LED corner lights.

Taxiway/Runway Markings:
Daytime: Daytime Visual markers (nonelectrical) contrasting with the air operations area.

Reflective: Reflective visual aid for day or night use.

PAPI:
Standard: Precision Approach Path Indicator.

REIL:
Low Intensity: LREIL Low Intensity Runway End Identifier Lights.

Radio Control:
Pilot Activated: Pilot activated radio control of airport lighting.

Notes:
Remote Airfield: The designation of a rural unpaved airfield that serves the immediate community, but does not adhere to established guidelines or standards.

Non Paved Airfield: The designation of a minimum, turf runway airport developed to state established guidelines or standards.
*Any airport development may exceed the recommended minimum guidelines.

SECTION 2 – Specifications & Details of Lighting System Elements

Contained in this section are specification guidelines for the basic elements needed for a Community Service Airport. These systems include low-cost alternatives to those required at large Part 139 airports. The guidelines contained here will help manufacturers to design lighting elements that meet the needs of Community Service Airports.

1. LOW INTENSITY AIRPORT RUNWAY AND TAXIWAY LIGHTING

1.1 Scope

This guideline describes the requirement for two types of low intensity runway and taxiway edge lights to be used at small general aviation airports. There are guidelines set for two types of fixtures in this section:

- Type I — Preferred type for airports with paved runways.
- Type II — Acceptable for small airports which do not have high background lighting, i.e. the presence of many light fixtures on surrounding residences and streets

1.2 General Description

The light globe shall consist of a lens of a heat-resistant plastic or glass, a sturdy body with securely mounted lamp socket and a suitable means of fastening to a mounted lamp socket and a suitable means of fastening to a mounting column.

1.3 Requirements

1.3.1 Optical Performance

The filament (or light-emitting surface) and lens shall meet photometric light output guidelines listed in Table 1 after transmission through the lens. Table 1 is applicable for 360° angles in the azimuth and vertical angles 2° to 10°.

Table 1. Photometric Intensity Requirements for LIRL Runway Edge Light Fixtures

Type	Color	Minimum Intensity (candelas)	Minimum Average Intensity (candelas)
I	White	15	25
I	Green	10	15
I	Red	3	5
I	Blue	2	-*
II	White	2	5

For 360° angles in the azimuth and vertical angles 10° to 15°, the fixture shall conform to guidelines set in Table 2. Note that only minimum intensity (and not average intensity) is specified.

Table 2. Photometric Intensity Guidelines for LIRL Runway / Taxiway Edge Light Fixtures

*minimum average intensity not specified in AC

Type	Color	Minimum Intensity (candelas)
I	White	10
I	Green	5
I	Red	1
I	Blue	-
II	White	2

1.3.2 Colored Lens

The colored lenses for threshold or taxiway application shall have a transmission factor as follows when using incandescent lights. Please note that LED systems should not have lenses affixed which are not recommended by the manufacturer. Using colored lenses with LED systems can severely reduce light output below the guidelines set in the 1.3.1.

Table 3. Transmission Factor Guidelines for LIRL Runway Edge Light Lenses

Color	Factor
Green	0.15
Red	0.10
Blue	0.02

1.3.3 Lamp

Incandescent lamps shall have a minimum-rated life of 3,000 hours.

1.3.4 Socket

The socket for incandescent sources shall be the intermediate base type-rated for the application. The socket shall be rigidly mounted in the body of the light fixture.

1.3.5 Construction Features

The body of the light fixture shall support the globe and a gasket shall be provided for seating the lens to prevent water entrance. Suitable means shall be provided for holding the globe securely in place. The globe shall be easily removable without the use of special tools. The light body shall be provided with a slip fitting to receive a 1 inch frangible column as a mounting column. A stainless steel set screw shall be provided to secure the light to the column.

Corrosion Resistance

The light fixture shall be constructed of material specifically selected and/or treated to resist corrosive atmosphere, such as salt, fog, heat and humidity.

Frangibility

The mounting column shall be constructed to break at or near ground level. The breaking range shall not be less than 100 foot-pounds and no more than 400 foot-pounds.

Body

The light fixture body shall have wire openings to allow the wire to be run either down into the column or on the exterior of the mounting column. If the wires are to be run on the exterior of the column, the access holes must be fitted with a water-tight fitting.

Anti-Tampering Hardware

If specified, the fixture may be supplied with anti-tamper hardware.

Leads

The light fixture shall be provided with 36 inch leads. The leads shall consist of single conductor, #16 AWG (min.) standard wire. The insulation shall be such that it will not become brittle and can be bent at -45C. Each lead shall be supplied in two parts: one part to be attached to the fixture's socket, and the second part for attachment to the supply wires. An easy, quick disconnect shall join the two parts.

Fixture Color

The exterior of the light body shall be aviation yellow. The yellow may be painted on or molded-in, as required. The finish shall be of high-quality, suitable for the application.

2. TEST DOCUMENTATION

The manufacturer shall make available to the purchaser copies of Certified Test Reports from a third party source to prove that the light meets the photometric requirements specified herein.

2.1 Instruction Book

The manufacturer shall supply a complete parts list and installation instructions with each order of lights. Sufficient drawings or illustrations shall be provided to indicate clearly the methods of maintenance and installation.

3. LOW INTENSITY RUNWAY END IDENTIFIER LIGHT (LREIL) AND SIMPLIFIED OMNI-DIRECTIONAL APPROACH LIGHT SYSTEM (SODALS)

3.1 SCOPE

This guideline describes the requirements for low and medium-intensity discharge lights to be used at small general aviation airports during VFR operations.

3.2 GENERAL DESCRIPTION

The flashing lights shall consist of a sturdy body, heat resistant lens (es), means for frangible mounting in the following configurations:

A. SODALS:

See FigureF 1. Lights that flash in sequence toward the runway and two lights located at the runway end flashing simultaneously, ending the sequence. The flashing lights in the SODALS system shall have two intensity steps that can be actuated by a radio control unit. See paragraph 3.2.1.

B. LREILS: The runway end identifier light units shall be similar to the SODALS units.

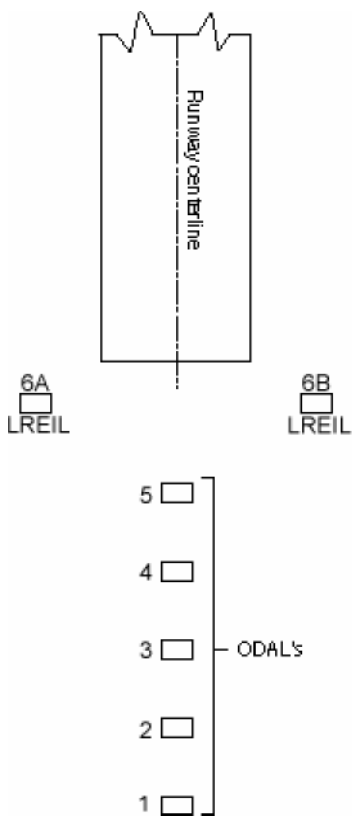


Figure 1. Simplified Omni-directional Approach Light System with LREIL

NOTES:

1. Spacing of 300 feet between the five lead-in lights is standard. Approaches with restricted land areas may reduce the number of lead-in lights to 4 or may reduce spacing between lights to 200 feet or 100 feet.

2. LREIL lights number 6A and 6B should be spaced no less than 40 feet and no more than 75 feet from and perpendicular to the runway edge. When a Visual Approach Slope Indicator (VASI) is present, locate the LREIL at 75 feet.

3. Should it be necessary to deviate from the standard 300-foot spacing between the lead-in lights, it may be desirable to increase the flash interval between consecutive flashers and maintain a constant flash movement speed.

3.3 REQUIREMENTS

3.3.1 Optical Requirements

All intensity units and measurements shall be in effective intensity as defined in the IES Lighting Handbook published by the Illuminating Engineering Society, General Aviation Subcommittee.

3.3.2 Intensity Requirements

The effective intensity of the omni-directional flashing lights shall be listed in Table 4:
Flashrate of the LREILS shall be as indicated in Table 5.

3.3.3 SODALS Timing

The flashing lights shall flash as shown in Figure 1, starting with the light located farthest from the runway threshold. The flashes shall move toward the threshold. The interval between the last (number 5) centerline flasher light and the simultaneous flashes of the two lights (6A and 6B) in the REIL configuration shall be as listed in Table 5. The time interval between the flash of the REIL lights and the start of a new cycle shall be the longest. All flash intervals may vary ±10%.

Table 4. Performance Guidelines for SODALS Effective Intensity

Minimum Effective Candela

Vertical Angle	Step 1 (Low)	Step 2 (Medium)
1°	230	500
2°	320	700
3°	420	900
4°	510	1100
5°	600	1300
6°	700	1500
7°	560	1200
8°	460	1000
9°	370	800
10°	320	700
11°	280	600
12°	230	500

For SODALS with a 60 flashes per minute rate, a number of different flash sequences are specified in Table 5.

Table 5. Flash Sequence by Light Number and Time (seconds) between Flashes

System	Light Number (Time Interval)
(60 flashes per minute)	
SODALS-7	#1(1/15); #2(1/15); #3(1/15); #4(1/15); #5(4/15); #6A with #6B(7/1 5)
SODALS-6	#2(1/15); #3(1/15); #4(1/15);
SODALS-5	#3(1/15); #4(1/15); #5(1/15);
(60-90 flashes per minute)	
LREIL #6A with #6B(l to 43/64)	

3.3.4 Control System

The SODALS/LREILS shall be designed and be capable of being controlled manually or remotely by pilot radio control, photocell, astronomic timer or through application of power through a control circuit. The remote control equipment is not included as part of this specification.

3.3.5 Input Voltage

The SODALS and LREILS shall be wired so that they can operate from either 240 VAC or 120 VAC (±10%).

3.3.6 Power

Total power draw shall not exceed 1500 watts for the SODALS or 500 watts for the LREILS.

3.3.7 Terminal Boards

The master timer for the SODALS shall have clearly marked terminal boards for input power, remote control inputs, and outputs control wiring from the master timer.

3.3.8 Life

The flash tube shall have an average life of at least 2000 hours at the highest intensity. Lamp life is defined as 70% average relative light output degradation (compared to intensity at installation) in the envelope described in Table 4.

3.3.9 Lightning Protection

The control systems shall have lightning and transient protection as near as possible to points of entry. The arrestor's spark over voltage shall be less than the unit's dielectric withstanding rating.

3.3.10 Construction Features

All materials used in the fabrication of the flashing lights and their control systems shall be suitable for the intended purpose and adequately protected against corrosion. All wiring and electrical components shall have adequate capacity and shall not be operated in excess of the component manufacturer's recommended rating.

3.3.11 Marking

All components shall be properly assembled and marked for future identification. Marking on parts and subassemblies shall match the numbers included with the Instruction Book.

3.4 TEST DOCUMENTATION

The manufacturer shall certify to the purchaser that the lights meet the photometric requirements specified herein.

3.4.1 Instruction Book

The manufacturer shall supply a complete parts list and installation instructions with each order. Sufficient drawings or illustrations shall be provided to indicate clearly the method of operation, maintenance and installation. A trouble-shooting table and schematic diagram shall be included in the instruction book.

4. PRECISION APPROACH PATH INDICATOR SYSTEMS (PAPI)

4.1 Scope

This guideline describes the requirements for the Precision Approach Path Indicator to be used at small general aviation airports during VFR operations.

4.2 General Description

The Precision Approach Path Indicator (PAPI) system provides vertical descent guidance for approach to a runway. Until 1985, VASI systems were the national standard for providing this guidance. In 1985, the FAA determined that PAPI was more beneficial than VASI for several reasons:

1. PAPI provides a relative indication of how much: too high or too low from the established glide path an approaching aircraft is.
2. Transition of the PAPI signal from white to red or from red to white is much sharper and quicker than in a VASI system.
3. The PAPI requires the pilot to follow a light signal from only one area adjacent to the runway, rather than watching two separate light signals.
4. The PAPI system is less costly to install.
5. PAPI is an established standard in most other areas of the world.

The PAPI light boxes are able to individually change from red to white or vice versa as a pilot goes above or below the glide path by each light being aimed 0 20' less than the adjacent box to its left. The box closest to the runway edge is aimed the highest, the next box out is 0 20' less and so on.

In 4-box PAPI system, the effective glide path is the angle midway between the aiming angles of the second and third light boxes. In a 2-box PAPI, the effective glide path is the angle midway between the aiming angles of the two light boxes. A PAPI lamp box will also perform in the same manner.

4.3 Requirements

The PAPI location design is based on providing an on-course signal that clears all approach objects by a safe margin. The PAPI system operates as a four-box or two-box system as shown in the diagrams below.

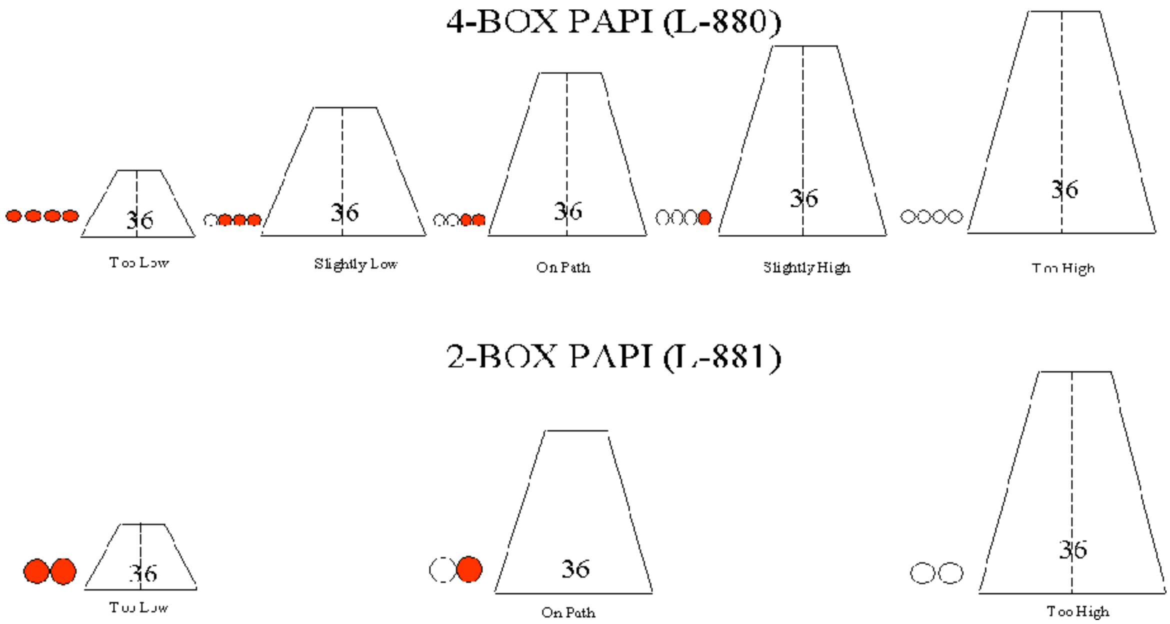


Figure 2. Indications of Two and Four Box PAPI Systems

4.3.1 Site Considerations

The PAPI must be sited and aimed so that it defines an approach path with adequate clearance over obstacles and a minimum threshold crossing height. The PAPI system glide path angle described in 4.3.4 refers to Figure 3 for the basic system layout for installation on a non-precision instrument or VFR runway.

For most small CSA's, placement of the PAPI systems may occur at a distance from the runway edge of 30 ft (+10 ft, -0ft) measured from the runway edge to the closest side of the inboard PAPI unit. In certain circumstances, the CSA may have a large runway surface (3,500 feet long by 100 feet wide or more), in which case a 50 foot (+10 foot, -0 foot) will be acceptable.

The separation between each PAPI unit from each other will be 20 feet ±1 foot measured center to center of each PAPI unit. If the CSA has a large runway surface as described above, then a distance of 30 feet ±1 foot center to center will be used.

Each PAPI unit shall be aimed outward into the approach zone on a line parallel to the runway centerline within a tolerance of ± 1/2°.

The height of the PAPI units measured at the center of the units will be within ±1 inch of each other, and shall be within ±1 foot of the elevation of the runway centerline at the intercept point of the visual glide path with the runway, which is termed the runway reference point (RRP). At locations where snow is likely to obscure the light beams, the PAPI units may be installed so the top of the unit is a maximum of 6 feet above ground level.

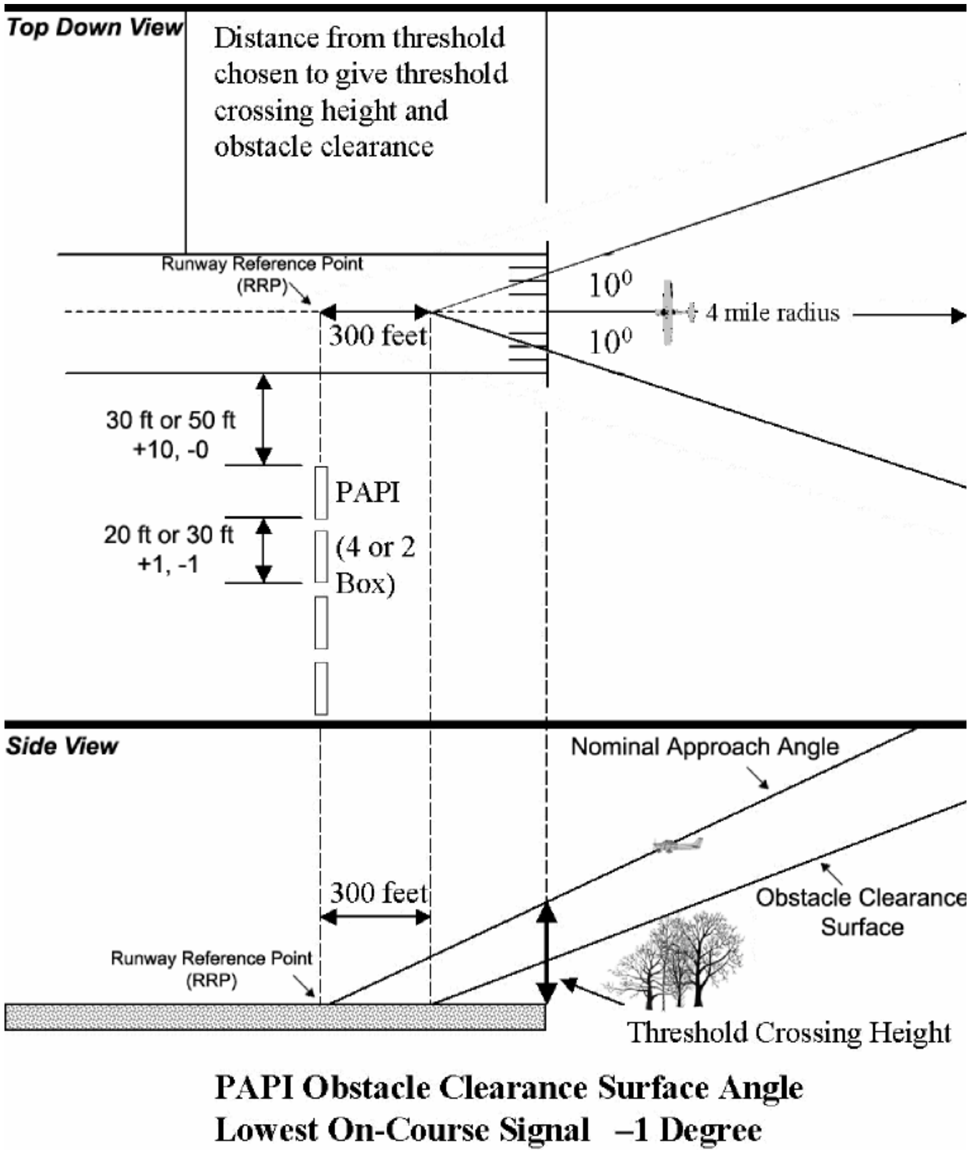


Figure 3. PAPI Obstacle Clearance Surface, RRP and Threshold Crossing Height

4.3.2 Threshold Crossing Height

The Threshold Crossing Height (TCH) is the height at which an aircraft on the glide path will be when crossing the threshold. TCH for a Community Service Airport is between 20 feet and 45 feet, and is normally 40 feet. The TCH can be varied depending on length of runway. If the runway is shorter, then an airport owner or manager will choose a lower TCH. The choice of TCH is also dependent on the type of aircraft using the runway as smaller aircraft will be able to cross at lower TCH. Determining if a choice of TCH is acceptable or not depends on the Obstacle Clearance Surface (OCS) described in 4.3.3. If the TCH or glide slope is to be adjusted after the PAPI is installed, then the OCS must be determined again to assure adequate obstacle clearance of aircraft with obstructions.

4.3.3 Obstacle Clearance Surface

The obstacle clearance surface (OCS) is established to provide clearance over obstacles during final approach. The OCS starts on the runway surface 300 feet from the PAPI units toward the threshold, and continues at ±10° in the azimuth of that surface for 4 nautical nmiles. The slope of the OCS will be:

1. For 4-box PAPI System: one degree less than the aiming angle of the third light box outboard from the runway.

2. For 2-box PAPI system: one degree less than the aiming angle of the outboard light box.

The two box system is the most used at Community Service Airports. No objects may penetrate the OCS, and a method for determining this is described in Section 3-5.1.

4.3.4 Glide Path Angle

The visual glide path angle (VGPA) is normally three degrees, but may be as high as four degrees if necessary to provide obstacle clearance. Aiming angles of the light units for three and four degree VGPAs are as follows:

Table 6. PAPI Unit Aiming Angles for a 3° Glide Slope (Listed Inboard to Outboard)

Three Degree VGPA	**4-Box**	**2-Box**
Box 1	3 3	3 1
Box 2	3 1	2 4
Box 3	2 5	
Box 4	2 3	

Table 7. PAPI Unit Aiming Angles for a 4° Glide Slope (Listed Inboard to Outboard)

Four Degree VGPA	**4-Box**	**2-Box**
Box 1	4 3	4 1
Box 2	4 1	3 4
Box 3	3 5	
Box 4	3 3	

4.4 Test Documentation

The manufacturer shall certify to the purchaser that the lights meet the photometric requirements specified in Table 8. This shall be for ±10° in the horizontal and ±5° in the vertical.

Table 8. Minimum Photometric Performance Guidelines for PAPIs at CSAs

Color	Intensity (cd)
White	15,000
Red	10,000

4.4.1 Instruction Book

The light units should be installed in accordance with manufacturer's instructions. Some basic installation criteria are:

1. Depth of footing should be at least four feet (for stability) but should also be at least two feet below the frost line to avoid frost-heave, which could lead to an erroneous light signal.
2. The area around the light should be finished with a gravel pad (lined with 3-mil screen) to eliminate the need to mow between light units.
3. The aiming angle should be put on each light unit by stenciling or attaching a laminated plastic label.

If a PAPI control unit is used (as in a 1 20/240v PAPI), the control unit should be located by the outermost light unit to minimize equipment being located near the runway.

5. RADIO CONTROL OF AIRPORT VISUAL AIDS

Sequence Operation – The following methods of radio control operation are recommended. This control sequence is for runway lighting systems with three light intensity levels. The second sequence provides for the option of using the highest intensity setting of the runway edge lights while having the single intensity LREIL off.

Frequencies Available for Use with Radio Control – air-to-ground radio control systems operate within the frequency range of 118 MHz to 136 MHz.

Uncontrolled Airports – Airports without an air traffic control tower utilize the UNICOM or MULTICOM frequency for the radio-controlled operation of airfield lighting. The following frequencies have been identified for UNICOM or MULTICOM use by the Federal Aviation Administration.

Airports	Heliports
122.700 MHz	123.050 MHz
122.725 MHz	123.075 MHz
122.800 MHz	
122.900 MHz	
122.975 MHz	
123.000 MHz	

Controlled Airports – Airports with Air Traffic Control Towers operate on the local air traffic control tower frequency or MULTICOM frequency as assigned.

Coordination – Frequency should be chosen which minimizes interference with neighboring airports.

Avoiding Inadvertent Radio Control Operation – One of the disadvantages of the proliferation radio-controlled airport lighting systems is that when one system is activated, lighting systems at other airports within 20 miles operating on the same frequency are also activated. Additionally, particularly during daytime hours, whenever a radio control unit receives three pulses, whether from one aircraft or from several aircraft all communicating on the same frequency, the radio controller reads those pulses as a signal to operate the lighting and consequently intiates an unintentional and unneeded operation.

There are several methods by which the number of inadvertent radio control operations can be eliminated or reduced during daytime . Table 8 shows some of the methods of radio control operation.

Table 8. Methods of Radio Control Operation

Radio Control Runway	Dormant Off/10%	3 Click 10%	5 Click 30%	7 Click 100	3 Click 10%	5 Click 100%	7 Click 100%
LREILS:	Off	Off	Off	Off	Off	Off	On
Single-Intensity Multi-Intensity	Off	Off	Low	Hi	Off	Low	Hi
Approach Lights	Off	Low	Med	Hi	Low	Med	Hi
PAPI/VASI	Off/On	On	On	On	On	On	On

The 3x control circuit can be eliminated during daytime hours through the use of two pole relay (1 NO, 1 NC) and a photocell. Proper connection of the relay/photocell combination will provide access to the radio control system through the use of the 5X and 7X circuits. This method eliminates the majority of inadvertent radio control operations caused by congestion on UNICOM frequencies, while still enabling use of the radio controls system.

The radio control system can be deactivated during selected periods through the use of a single pole relay and manually operated switch photocell or astronomic time switch. This method eliminates any use of the radio control system unless specifically energized.

Frequencies should be checked against uses at other airports within a forty (40) mile radius. Sensitivity of radio control can be adjusted downward to limit the range of radio control system (normally a factory adjustment).

6. WIND CONE

6.1 Scope

This specification covers fabric wind cones and their supporting structures used at general aviation airports and heliports to indicate surface wind conditions.

6.2 Classification

6.2.1 Type

WC-R: Those mounted on rigid supporting structures.

6.2.2 Styles

Styles I - lighted

Styles II - unlighted

6.2.3 Sizes

Size 1: 8 feet long by 18 inches in diameter

Size 2: 12 feet long by 36 inches in diameter

6.3 Requirements

6.3.1 Environmental Conditions

The wind cone assemblies shall be designed to operate under the following environmental conditions:

<u>Temperature</u>

Any ambient temperature between -30 degrees C. and +55 degrees C.

<u>Wind</u>

WC-R - Wind speed up to 75 knots (138 km/hr).

Ice and snow

One-half inch ice or snow accumulation

6.3.2 Fabrications

The windsock shall be made so that it takes the shape of a truncated cone when filled with air; be reinforced at all points that are subject to abrasion or flexing against the wind cone framework and be designed to allow removal and replacement without the use of special tools or stitching. In addition, provisions to facilitate the drainage of water from the supported section of the sockwindsock are required.

6.3.3 Fabric

Fabric for the windsock may be made of cotton, a synthetic material, or a blend of the two. If the fabric is not naturally immune to water absorption, it shall be treated or coated to become water-repellent.

6.3.4 Color

Windsock fabric may be natural (white) or orange. Any coloration should be resistant to fading. The customer will specify windsock color.

6.3.5 Dimensions

The recommended length and throat opening of the windsocks are as follows:

Size 1 - (8) feet in length and 18 inches in throat diameter.

Size 2 - Twelve (12) feet in length and 36 inches in throat diameter.

The taper of the sockwindsock from the throat to the trailing end shall be designed to cause the windsock to fully extend when exposed to a wind of 15 to 20 knots.

6.3.6 Integrity

Design integrity of the windsock and its method of attachment must be such as to pass the performance demonstrations of Paragraph 2.6.

6.4 Wind cone Framework

6.4.1 Design

The wind cone framework shall be designed to hold the throat of the windsock fully open under no wind conditions, support the windsock in a rigid open position for three-eighths the sock length, and deter the accumulation of water in the sock.windsock. The wind cone framework must interface to a support structure, and the combination of wind cone and windsock perform as a wind vane.

6.4.2 Materials

The wind cone framework may be made of metallic or non-metallic materials, provided the selected material will serve well and maintain its shape under the environmental condition specified.

6.4.3 Wind cone Movement

The wind cone with windsock attached shall wind vane freely when subjected to a wind of 3 knots or more, and indicate the true wind direction within +/- 10 degrees.

6.4.4 Supporting Structures

Typical supporting structures are shown in Airport Guideline 10.02.05.00. Although the illustrations are typical, the dimensions shown should be complied with.

WC-R

The type WC-R (Rigid) support should be designed to allow lowering of the basket and lighting assembly, so that servicing can be conducted at ground level. When the support is mounted in place, it shall withstand, without damage, a wind velocity of 75 kph . When equipped with the manufacturer's recommended wind cone framework and windsock, the force is applied parallel to a point 16 feet above the surface to which the support is attached.

6.5 Illumination

Style I wind cone assemblies shall be illuminated from above, or from within, such as to provide 2 foot-candles or more illumination at all points on the top viewing surface of the wind cone in its fully-extended position, throughout the full 360 degrees of rotation. There should be no exposed wiring above ground. Electrical cable shall be of proper type and size for this application. Lamps shall be suited to available power.

6.6 Obstruction Light

Optionally, an obstruction light may be supplied. The obstruction light is to be mounted at the highest point of the wind cone assembly to avoid being obscured by any other part when viewed from above or from the side. The obstruction light should be wired in parallel, and operate in conjunction with the illumination lighting.

6.7 Lubricated Parts

Bearings, bushings, or like devices shall be either permanently lubricated or provided with fittings to allow periodic lubrication. Additionally, they shall be suitably protected so that reasonable ice and snow shall not impede their operation.

6.8 Finish and Protective Coatings.

6.8.1 Painting

All exposed metal parts, excluding reflective surfaces of light fixtures shall be given a minimum of one prime, one body, and one finish coat of paint. Primer coat shall be appropriate for the particular metal being painted. The finish coat shall consist of non-fading orange color paint, reference Federal Standard 595, and Orange number 12197.

6.8.2 Plating

The shaft of the wind cone framework and other non-external parts may be galvanized, or zinc-plated for protection.

6.8.3 Fasteners

All fasteners, excluding anchor bolts should be corrosion-resistant.

6.9 Instructional Manual

A manual shall be supplied with each wind cone assembly containing, as a minimum, the following information:

a. Complete wiring diagram for lighted wind cones.

b. Complete parts list with the name and part number of the original manufacturer.

c. Assembly and installation instructions, including mounting foundation and anchor bolt requirements.

d. Maintenance instructions.

6.10 Recommended Demonstrated Performance

6.10.1 General

Each type, style, and size of wind cone assembly should withstand the following tests without failure.

6.10.2 Windsock Attachment

Test the attachment of the windsock to the wind cone framework by applying the following loads parallel to the length of the windsock to the free end of the windsock when in a vertical position:

Size 1 - 45 pounds

Size 2 - 100 pounds

No distress should be noted.

6.10.3 Support Rigidity

Mount the support on a surface to simulate its normal field installation and apply the forces to the support. The force shall be applied parallel to and at the specified distance from the surface.

6.10.4 Cone Movement

The cone should move freely and align with a 3-knot wind.

6.10.5 Illumination

The illumination shall be of the upper surface of the extended fabric wind cone, and shall not be less than the 2 foot-candles.

6.10.6 Cone Extension

Test the wind cone to assure that it extends fully when subjected to a wind of 15 to 20 knots.

7. GUIDELINE FOR GENERAL AVIATION INSET LIGHTS

7.1 Scope

This guideline describes the requirements for inset light to be used at general aviation airports during VFR operations when runway configurations require other than the standard elevated fixtures.

7.2 General Description

The inset light shall be fabricated from aluminum and heat-treated. It shall mount on an IESGA inset light base and provide a standard visual presentation. This light shall allow for 180 degree rotation of the filters to accommodate split signals for threshold, end of runway, taxiway, and edge lights.

7.3 Requirements

The lights shall provide the minimum intensity guidelines as specified in Table 9, for a profile that includes 1° to 10° in the vertical and ±5° in the horizontal.

Table 9. GA Inset Lights Minimum Photometric Light Output Guidelines

Color	Light Output (cd)
Green	45
Red Intensity	30
White	25
Blue	2

7.3.1 Lamp

The lamp life shall have a minimum 1000 hours rated life. Lamp life is defined as 70% average relative light output degradation (compared to intensity at installation) in the envelope described in 7.3.

7.3.2 Construction

The fixture shall be provided with four (4) mounting holes so that it can interface with the base.

7.3.3 Leads

The fixture shall be provided with leads consisting of single conductor #16 AWG standard wire . The leads shall be suitable for wet locations.

7.3.4 Painting

The exterior of the fixture shall be aviation yellow. The finish shall be high quality, aviation yellow color No. 13538 Tables of federal standard 595B suitable for this application.

7.4 Test Documentation

The manufacturer shall make available data showing that the light meets the photometric requirements in Table 1.1

7.4.1 Instruction Manual

The manufacturer shall provide instruction details and a spare parts list for each order.

7.4.2 Warranty

The manufacturers shall warrant that the light will perform to and meet the requirements set forth herein for a period of one year from date of installation or 2 years after purchase, whichever occurs first.

8. SOLAR POWERED LIGHTING

8.1 Scope

This guideline describes the requirement for all types of solar-powered lighting systems, either off-grid stand alone systems or grid-tie back solar system solutions. Scalable solar power systems are designed for easy installation on commercial buildings or earth-based locations with connection to the electrical grid for supply of the complete power generation requirements or a portion of required power.

8.2 General Description

Each lighting element shall consist of the light fixture photovoltaic panel and a battery with a charge management system.

8.3 Requirements

8.3.1 Optical Performance

Each type of light fixture shall meet at a minimum those performance values set forth for their electrical grid-powered counterparts as defined in this handbook.

8.3.2 Battery

Battery shall be replaceable and rechargeable by means other than photovoltaic power.

8.3.3 Construction Features

The body of each type of light fixture shall meet at a minimum those construction features set forth for their electrical grid-powered counterparts as defined in this handbook.

Corrosion Resistance

The light fixture shall be constructed of material specifically selected and or treated to resist corrosive atmosphere, such as salt, fog, heat, and humidity.

Frangibility

The mounting column shall be constructed to break at or near ground level . The breaking range shall not be less than 100 foot-pounds (feet. lbs.) nor more than 400 feet. pounds.

Anti-Tampering Hardware

If specified, the fixture may be supplied with anti-tamper hardware.

Fixture Color

The exterior of the light body shall be aviation yellow . The yellow may be painted on or molded-in, as required. The finish shall be high-quality, suitable for the application.

8.4 Test Documentation

The manufacturer shall make available to the purchaser copies of Certified Test Reports to prove that the light meets the photometric requirements specified herein.

8.4.1 Instruction Book

The manufacturer shall supply a complete parts list and installation instructions with each order of lights. Sufficient drawings or illustration shall be provided to indicate clearly the methods of maintenance and installation.

8.4.2 Documented Battery Health Methods

A method for determining the state of charge of the solar-powered system shall be provided with the solar-powered unit. This may be accomplished through the use of a radio controller where electronics monitor and report the unit's state of charge, i.e. 0 through 100% remaining state of charge . Alternatively, a voltage-based state of charge estimation may be recommended by the manufacturer.

In the voltage-based method, the airport operator may manually check the open voltage of the battery across its terminals via a voltmeter. This will be provided that the battery potential is rated 25 Volts or less when fully charged for safety concerns . Voltmeters are available cheaply (~$10 - $20) at local electronic hobbyists locations. These and any other methods for estimating the state of charge of the solar-powered system shall be well-documented in the operating manual.

A performance graph or matrix shall be provided by the manufacturer in the instruction book or separate addendum which correlates state of charge reading (reported percentage, voltage reading, or otherwise) and ambient temperature to remaining hours of operation. This should be provided for the intensity settings recommended by the manufacturer, and minimally should be reported for the 50% and 100% intensity settings . An example of how such a matrix may appear is shown in Table 10.

Table 10. Voltage and Temperature vs. Hours Autonomy (50% Setting)

Temperature / Voltage	0°F	10°F	32°F	60°F	70°F	80°F	90°F	110°F
4.0 V	7	9	9.5	9.2	8	7.2	6	5.9
3.9 V	6.7	8.7	9.1	8.5	7.5	6.5	5.9	5.8
3.8 V	6.5	8.5	8.2	8	7.2	6	5.8	5.7
3.7 V	6.2	8.2	8	7.2	6	5.8	5.7	5.6
3.6 V	6.1	8	7.2	6	5.8	5.7	5.6	5
3.5 V	6	7.2	6	5.8	5.7	5.6	5	4
3.4 V	4	6	5.8	5.7	5.6	5	4	2
3.3 V	2	5.8	5.7	5.6	5	4	2	1
3.2 V	1	4	4.1	5	4	3	1	-
3.1 V	-	2	2.1	4	3	2	-	-

This will be similar to a percentile reading of the state of charge (SOC), shown in Table 11.

Table 11. Percentile SOC and Temperature vs. Autonomy (50% Setting)

Temperature / % SOC	0°F	10°F	32°F	60°F	70°F	80°F	90°F	110°F
100%	7	9	9.5	9.2	8	7.2	6	5.9
90%	6.7	8.7	9.1	8.5	7.5	6.5	5.9	5.8
80%	6.5	8.5	8.2	8	7.2	6	5.8	5.7
70%	6.2	8.2	8	7.2	6	5.8	5.7	5.6
60%	6.1	8	7.2	6	5.8	5.7	5.6	5
50%	6	7.2	6	5.8	5.7	5.6	5	4
40%	4	6	5.8	5.7	5.6	5	4	2
30%	2	5.8	5.7	5.6	5	4	2	1
20%	1	4	4.1	5	4	3	1	-
10%	-	2	2.1	4	3	2	-	-

Manufacturers shall oblige requests from airport owners or managers for another issuance of these battery performance graphs or matrices in a separate addendum based on the age of their system in one year increments. Minimally, these graphs or matrices should assume a past performance of the solar-powered system which remains in operation during the night at 100% intensity operation in a temperate climate zone. Airport owners and operators may request these performance graphs or matrices customized for the geographic location of their airport (latitude).

9. REMOTE AIRFIELD LIGHTING SYSTEMS

9.1 Scope

This guideline describes the requirement for remote airfield lighting systems. In particular, this guideline describes the four corner lights and the runway edge markers that constitute the minimum system.

9.2 General Description

The two essential components of a remote airfield lighting system shall be composed of the following:

9.2.1 Corner Lights

These shall be mounted at each of the four corners of the usable area of the airstrip to help pilots locate the airfield and orient the plane for approach.

9.2.2 Edge Markers

These shall be either retro-reflectors (i.e., self-luminous devices that reflect light from a plane's landing lights) or powered steady-burning edge lighting units. The edge markers/units are mounted along the edge of the usable area of the airstrip on each side between the corner lights to indicate the edge of the runway.

9.3 Requirements

The corner lights shall have an intensity distribution and flashing characteristics described in Table 12, for the vertical viewing angles put forth in those figures and 360° in the azimuth. Currently, it is recommended that only aviation green LEDs with a peak wavelength of 505 nanometers be used. The intensity of the system should be at least 5 time-averaged candela which is equivalent to 10 Photopic candela with a maximum 50% duty cycle flashing at 2 to 4 Hz. Other LED peak wavelengths in and around 505 nanometers, but still considered aviation green in color, shall have an equivalent presentation as calculated by the material presented in Table 12 and Appendix F.

Table 12. Photometric Guidelines for RALS Corner Lights

Parameter	Condition*	Value		Symbol	Units
		minimum	*maximum*		
intensity distribution	0° < θ ≤ 10°	20	NA	I_e	time-averaged mesopic candela (X = 0.12)**
	10° < θ ≤ 90°	0.6/sin²(θ)			
flash frequency		2	4	f	Hz
flash duty cycle		8f	50	D	%
flash phase	relative to other units in system	–10	10	φ	degrees
continuous operating duration	no external power sources, 112-hour maximum recovery/charging time	4	NA	t_{op}	hours
color		cannot be within the emergency vehicle, traffic signal, or FAA red or blue color boundaries			

* All conditions include meeting specified values throughout an ambient temperature range from –40°C to +55°C.
** See "Background and Justification of Requirements" herein for definitions of units.

These guidelines are given in Mesopic candela. This means that the equivalent Photopic intensity, or standard candela, is dependent on the wavelength (color) of the light emitted . See Appendix F for background describing these units, as noted also in the footnotes of Table 12.

Provided that the edge markers are steady-burning fixed lights, then these shall have a nominal light output intensity distribution of 10 candela through 10° in the vertical and 360° in the azimuth. Provided that retro-reflective markers are used, then the markers should have characteristics compliant with Table 13 which provides guidelines for a single face surface area. Markers should be double-faced for each direction of the runway. A metallic mounting surface and adhesive agent should be rated for the environmental conditions at the target site, and not be prone to warping or wrinkling. A form of UV protection should be employed. Both lights and retro-reflective markers should employ a mounting device attached to the ground and resistant to wind forces typical at the target site. Frangibility requirements should be assessed by the airport owner or operator.

Table 13. Retro-reflective Guidelines for Edge Markers

Minimum Surface Height (ft)	Minimum Surface Width (ft)	Minimum Surface Area (sq. ft)	Retro-reflectivity	Orientation
3	2	6	Type IX*	Perpendicular to Approach**

* Retro-reflectivity should be minimally 300 cd/lx/m^2 at 0.5° observation angle when within a 4° light entrance angle, and preferably the material should be compliant with all Type IX ratings as specified in ATSM D 4956, "Specifications for Retro-reflective Sheeting for Traffic Control," or material equivalent to 3M Diamond Grade™ retro-reflective sheets

** i.e. If a standard 3 degree approach is utilized, the panels should be oriented 3 degrees in the vertical so the surface is perpendicular to the pilot's line of sight.

9.3.1 Battery

Battery shall be replaceable and rechargeable. The battery shall have means of indicating charge level. The battery recharging system shall have a 112 hour maximum recovery / charging time. The battery shall provide for a minimum of 4 hours continuous operation.

9.3.2 Construction Features

The body of each type of light fixture shall be constructed.

Corrosion Resistance

The light fixture shall be constructed of material specifically selected and or treated to resist corrosive atmosphere, such as salt fog, heat and humidity.

Frangibility

The mounting column shall be constructed to break at or near ground level. The breaking range shall not be less than 100 foot-pounds or more than 400 foot pounds.

Anti-Tampering Hardware

If specified, the fixture may be supplied with anti-tamper hardware.

Fixture Color

The exterior of the light body shall be aviation yellow. The yellow may be painted on or molded-in, as required. The finish shall be of high-quality, suitable for the application.

9.4 Test Documentation

The manufacturer shall make available to the purchaser copies of Certified Test Reports to prove that the light meets the photometric requirements specified herein.

9.4.1 Instruction Book

The manufacturer shall supply a complete parts list and installation instructions with each order of lights. Sufficient drawings or illustrations shall be provided to indicate clearly the methods of maintenance and installation

10. GUIDELINE FOR USE OF PHOTOCONTROLLERS

Photo controllers are used to turn on/off or reduce intensity levels of visual lighting aids. Standard photocells will turn lights off when ambient lighting is three (3) times the operating light intensity levels.

Table 14. Basic Photocell Characteristics

Style	O	Off	Delay	VA	Temp(f)	Switch
FAA	35	58	15	3000	-	SPST
Utility	1-	3X	15	1800	-	SPST
Utility	1-	3X	15	3000	-	SPST
Simple	1-	3 -10	15	1800	-	SPST
Simple	1-	3 - 10	15	3000	-	SPST

On/Off/ Values are expressed as candelas (foot-candles). Switch types as abbreviated are: SPST: single pole single throw, and SPDT: single pole double throw.

Table 15. Recommended Photo Controller Use per Lighting System:

Visual Lighting Aid	Recommended Style
Runway Edge Lights	Utility/Simple
VASI of PAPI	FAA
ODALS	Utility/Simple
Wind Cone	Utility/Simple
Beacon	Utility/Simple
Floodlights	Utility/Simple

An FAA-specified photo controller can be used in any instance in lieu of a utility or simple style photo controller.

Warning, Cautions and Notes

WARNING

You are required to obtain permits from the local municipal government prior to attempting an installation of electrical systems. All licensing requirements, inspections, and authorization to activate any electrical system must be adhered to.

Exercise caution while working on active circuits. Failure to comply with this warning may result in death or serious injury.

All components used in an electrical installation must be UL approved.

SECTION 3 – USER'S MANUAL

This section of the handbook contains the necessary information to guide airport managers in acquiring and monitoring the installation of lighting systems at their airfields. These guidelines also detail how to obtain replacement parts for the different lighting systems. A maintenance guide is also included to aid in the continuous operation of each system. It is strongly suggested that the airport manager contact licensed contractors to perform the installation.

1. RUNWAY EDGE LIGHT CONFIGURATIONS

A runway edge lighting system is a configuration of lights which define the lateral and longitudinal limits of the usable landing area. Two straight lines of lights, which are parallel to and equidistant from the runway centerline, define the lateral limits. The longitudinal limits of usable landing area are defined at each end of the area by straight lines of lights installed perpendicular to the lines of runway edge lights and are called threshold/runway end lights. It is essential that the layout (spacing and offset) follow the FAA published dimensions. See "Location & Spacing".

1.1 Selection Considerations

The selection of a particular edge light should be based on the operational needs in accordance with the following guidelines:

LIRL: Termed Type I fixtures in this document, these are for use on runways under Visual Flight Rule (VFR) at airports having no planned approach procedures whose performance guidelines are specified

MIRL: These are fixtures for use on runways having a circling or straight in non-precision instrument flight rule (TFR) procedure. Most CSAs do not have these, and as such, the performance guidelines are not stated in this document.

LITL: Termed Type II fixtures which are blue in color for use on taxiways and aprons where LIRL is used on the runways

Runways:

LIRL: low intensity runway lights

Taxiway:

LITL: low intensity taxiway lights

1.2 Color of Lights

The runway edge lights emit white (clear) light. The threshold lights emit green light toward the approach area, while the runway end lights emit red light toward the runway. These lights are usually combined into one fixture and special lens or filters are used to give the desired light coverage.

1.3 Location and Spacing

The runway edge lights are located on a line not more than 10 feet from the edge on the full strength pavement, which is designated for runway use. For runways used by jet aircraft, it is usually advisable to install the lights at the maximum distance to avoid possible damage by jet blasts. For smaller airports, a distance of approximately 2 feet is recommended. The longitudinal spacing of the lights should not exceed 200 feet and be located such that a line between light units on opposite sides of the runway is perpendicular to the runway centerline. The lights should be spaced as uniformly as possible with the threshold/runway end lights used as the starting reference points. Where a runway is intersected by other runways or taxiways, a single elevated edge light should be installed on the runway side opposite the intersection to avoid gaps in excess of 400 feet where the matching of lights on opposite sides of the runway cannot be maintained.

1.3.1 Threshold and Runway End Lights

The combination threshold and runway end lights are located on a line perpendicular to the extended runway centerline not less than 2 feet or more than 10 feet outboard from the designated threshold of the runway. The designated threshold is the end of the pavement surface useful for aircraft operations. The lights are installed in two group located symmetrically near the extended runway centerline. For instrument runways, each group of lights contains not less than 4 lights: for other runways, not less than 3 lights. In either case, the outermost light in each group is located in line with the runway edge lights. The other lights in each group are located on 10 foot centers toward the extended runway centerline.

1.3.2 Displaced Threshold

When the threshold is displaced from the extremity of the runway, the threshold and runway end lights are located outboard from the runway. The innermost light of each group is located in line with the line of runway edge lights, and the remaining lights are located outward, away from the runway, on 10 foot centers on a line perpendicular to the runway centerline. As the displaced runway area is usable for specific operations (takeoff, rollout, taxiing), runway edge lights are installed to delineate the outline of this area as shown in Figure 3.

1.3.3 Relocated Threshold

When the threshold is relocated from the extremity of the runway, the threshold and runway end lights may be installed either outboard from the runway, or across the abandoned runway area.

2. TAXIWAY EDGE LIGHT CONFIGURATIONS

All taxiway edge light figures emit blue light. The light fixtures are located not more than 10 feet from the edge of the full strength pavement on each side of the taxiway and spaced longitudinally not more than 200 feet apart to define the lateral limits of the taxiing paths. On a straight section the lights on opposite sides of the taxiways are located on a line perpendicular to the taxiway centerline. The longitudinal spacing of the lights is influenced by the physical layout of the taxiways. Closer spacing of the lights should be provided on short taxiway sections, curves, and entrances to taxiways from runways or aprons. In lieu of shorter spacing of the lights, the lights may be supplemented by elevated reflectors. For CSAs, elevated reflectors may be used in lieu of edge lights for outlining taxiing area. When used, the reflectors should be spaced the same as taxiway edge lights.

2.1 General Design Considerations

It is obviously best to be able to do some planning for a lighting system before pavement is laid on a runway. When this is possible, crossing conduits can be put in place prior to the paving operation. Where this is not possible, such as lighting an existing paved runway, other methods of accomplishing runway crossings with conduits are required although more expensive. Location of primary power, routing of the lighting cable, location of the beacon and wind cone, and control systems are other factors to consider because their locations have a direct effect on total system cost.

When elevated lights are used, it is recommended that a low cost frangible aluminum column with a predictable “break away” (frangible) point be used.

Design Specifics, Runway Lighting

2.2 Layout

The runway edge lights and threshold lights are positioned along the runway at a perpendicular distance between 2 – 10 feet from the edge of pavement. Remember, for an instrument runway, you need four (4) threshold lights on each side of the centerline on each end of the runway. Space the runway edge lights 200 feet apart, making up any irregular interval between the threshold and the first runway light. Divide this irregularity equally on each end. As an option, if the irregularity is minor, runway light spacing may be changed slightly to make spacing equal over the full length of the runway.

Example: A 2,550-foot runway could be arranged with:

1. 11 spaces at 200 feet each with 2 spaces of 175 feet each, or

2. 13 spaces of 196.15 feet each.

Arrange the threshold lights across each end of the runway. If the runway is VFR only, three (3) lights on each side at each end is adequate. If the runway will serve Instrument Flight Rules (IFR) traffic, install four (4) lights on each side at each end. The out on each side should be in line with the runway lights.

Runway and threshold lights should be installed 2 - 10 feet off the end of the load-bearing surface of the runway.

2.3 Cabling

As you approach this phase for the installation of an airport lighting package, with proper planning and layout, it is imperative that contact is made with a local licensed and bonded electrical contractor. In addition to the license and bonding, it is preferable to select a contractor that has had prior airport lighting experience.

While it may appear to be a relatively simple and straight-forward electrical process, it is complex and requires the knowledge of professional and experienced electrical contractors preferably with specific airport knowledge.

In the review process of the contract proposal, it is essential that the local, county, state and National Electrical Codes (NEC) codes are met. The best way to ensure these codes are met for your project is to have the project manager contact each authority and determine what they require for the installation of the airport lighting package. If any questions remain, excellent contact points are the state aviation authority or the FAA field inspector for your area.

Due to the complexity of proper electrical service, **never attempt the electrical service hookup yourself.** Even though the airport is classified as a non-public access area, liability for self hookup is extremely high. It is not worth it to jeopardize the installation of a lighting package to improve the safety and utilization of an airport and have a hazard exist in the electrical service.

Check all codes that apply and adhere to them.

Plan properly and professionally for the installation.

Seek guidance from state aviation offices and the FAA field inspectors.

Review your contractors' experience and past work.

Oversee the installation process to ensure you have reduced liability and improved safety by using professional contractors.

3. WIND CONES, WIND TEES

3.1 General Considerations

The wind cone and wind tee are wind direction-indicating devices to assist pilots in determining the most favorable runway on which to land or take off.

At uncontrolled airports, heavy dependence is placed upon the wind cone or wind tee for wind direction. If a runway is a distance of 3000 - 4000 feet, the wind can be blowing in two different directions at the same time, resulting in the need for a wind cone at each runway end. For this reason, the wind cone must be located such that it is visible, not only from the air, but also by aircraft departing the terminal area or ramp area. For airborne aircraft, the most conspicuous location is to the left side of the approach runway and 200 - 500 feet off the runway centerline. However, this may not be a good location as far as taxiing aircraft are concerned. Therefore, begin the location selection by starting at the center point of the runway location, and then compromising that location only as much as is necessary to satisfy the visibility for taxiing aircraft.

Install the wind cone in the most conspicuous location possible so as to be effective for both airborne and taxiing aircraft. Parallel taxiways, buildings, other structures or surface irregularities may necessitate the need to place the wind cone in a secondary choice location.

A wind cone is a very light, rapidly responding indicator that indicates instantaneous wind direction, and to some degree gives an indication of wind velocity.

A wind tee is a very heavy, slowly responding indictor that averages wind direction. It provides no information with regard to the wind velocity.

A wind tee is the most conspicuous or easily spotted wind indicator from the air. It is followed by the 36-inch wind cone, and lastly, the least visible indicator, the 18-inch wind cone.

Wind tees have lost their popularity, and are being used less frequently today.

Placing a segmented circle around the indicator enhances the visibility or conspicuousness of a wind indicator. The segments take many forms, from poured concrete slabs (usually 3 feet x 10 feet) to 55 gallon barrels. The diameter of the circle should be 50 to l00 feet, and the segments should be alternately painted white and international orange.

3.2 Electrical considerations

The electrical power required for wind indicators is as follows:

Wind Tee 120VAC 750 watts

Wind Cone 120VAC 916 watts (36" x 12')

Wind Cone 120VAC 735 Watts (18" x 8')

There are two or three situations to appraise when designing the power system for a wind indicator. These are:

- You are going to replace an existing wind cone, and you wish to use the existing cable for powering the new wind indicator,
- You have a certain size wire available and you want your electrical contractor to determine if it can be used to power the wind indicator,
- Everything is new, and you want the contractor to design a power system for the proper operation of the lighting.

In the first two situations above, the contractor will simply be calculating the line loss with a given size and the loads upon it. In the last situation above, the contractor will be designing the electrical system to best fit the need and what is needed to deliver a particular voltage to the lighting system.

At this point of the project, it is of utmost importance to refer to page 24 of this manual. The installation of the wind indicator is a safety classed item and requires the knowledge of an experienced electrical contractor with the proper license and bonding.

The need of a professional electrician cannot be overstressed.

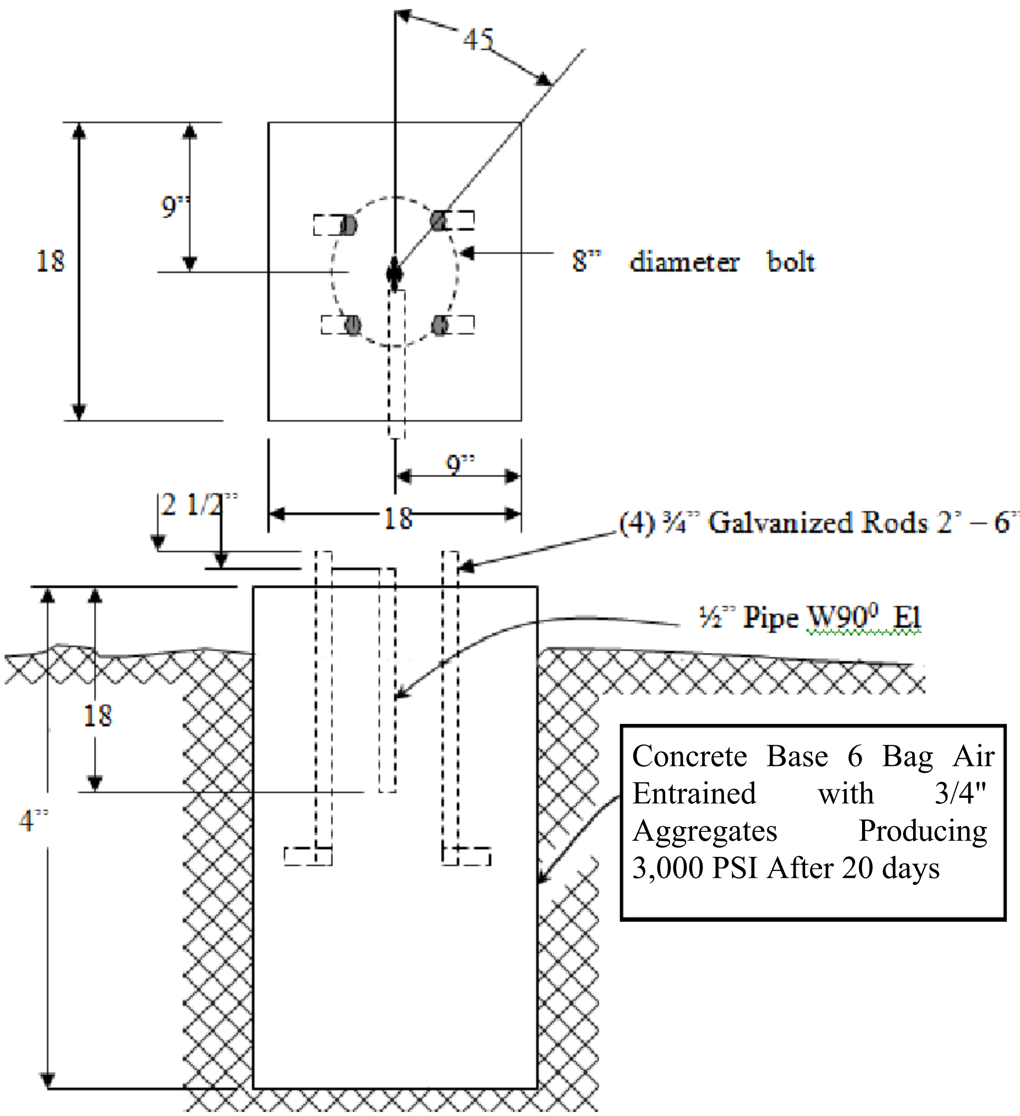


Figure 4. Typical Wind Cone Anchor Assembly

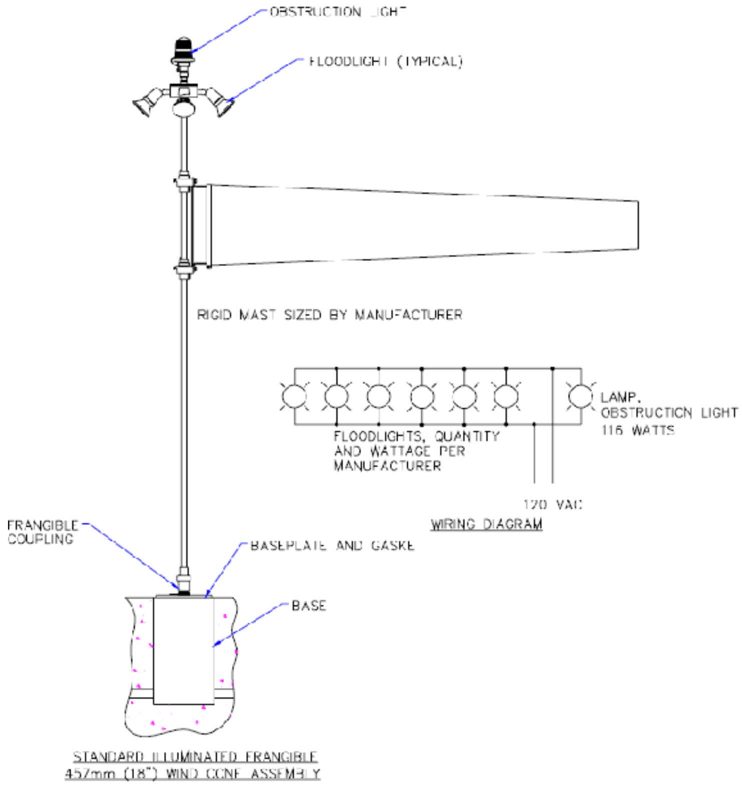


Figure 5. Typical Externally Lit Wind cone Assembly with Frangible Coupling

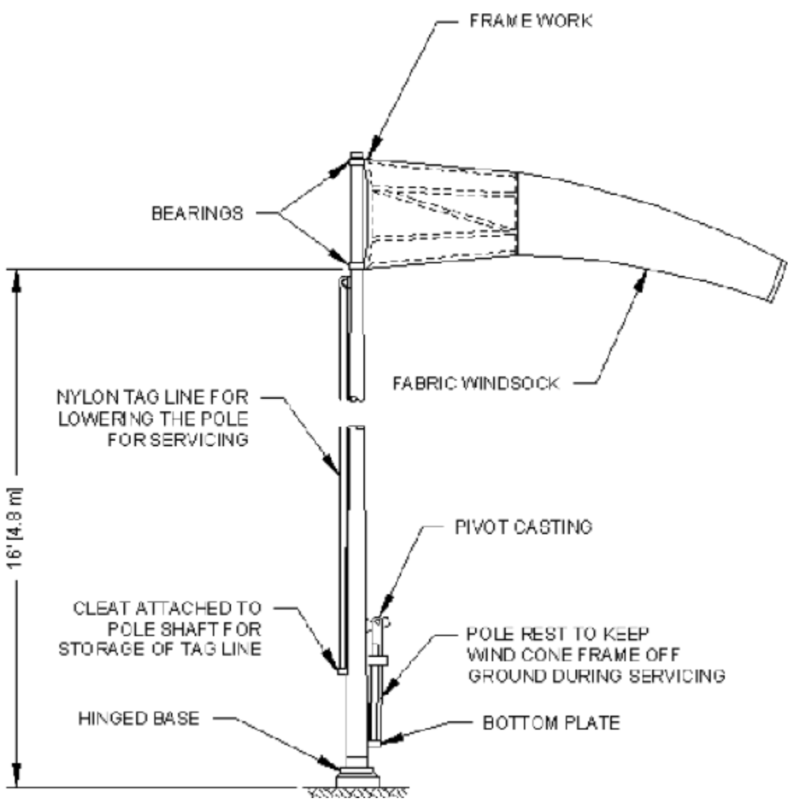


Figure 6. Hinged Base Wind Cone Assembly

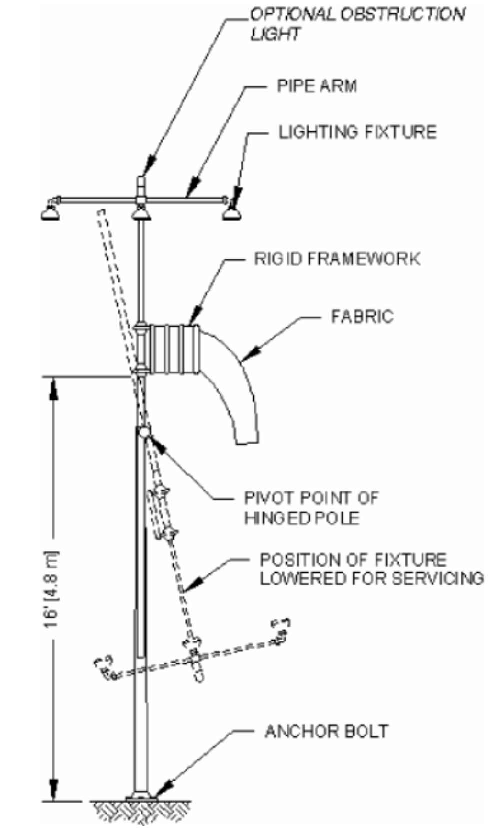


Figure 7. Wind Cone in a Tipdown Pole Configuration

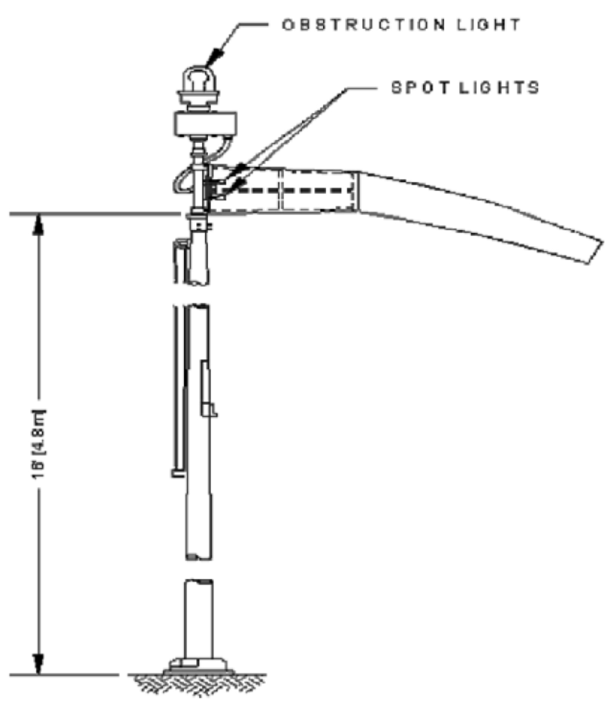
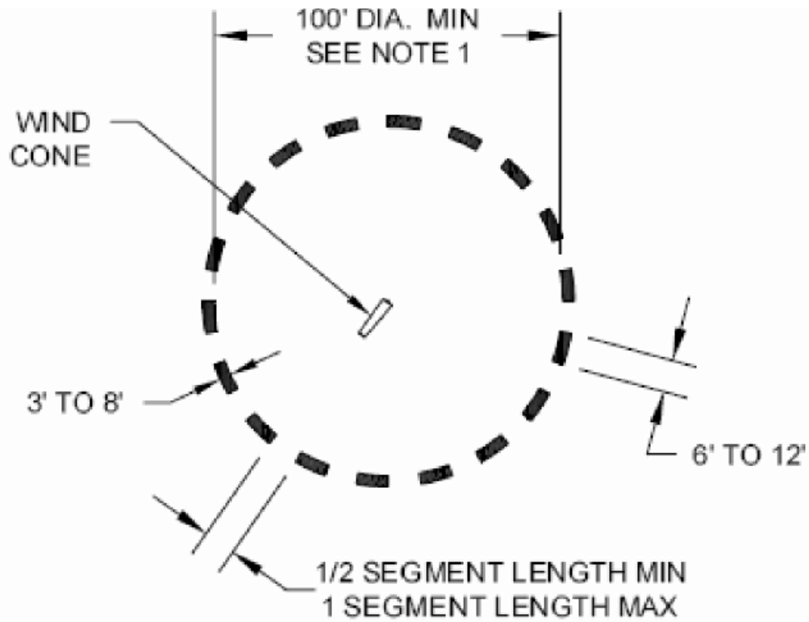
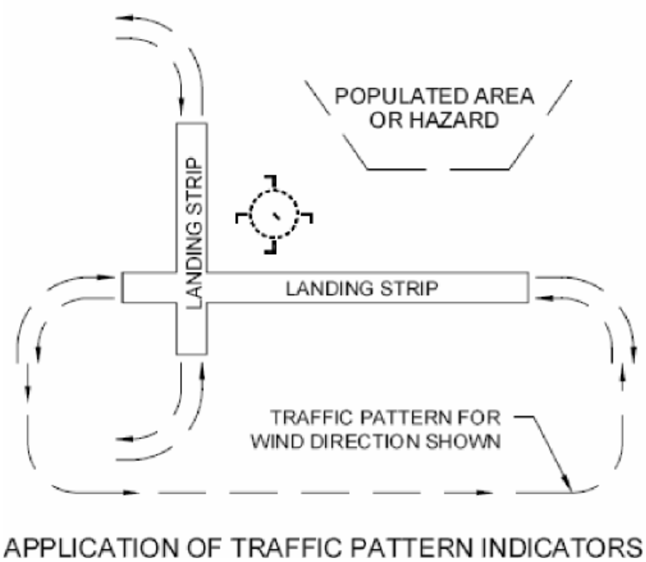


Figure 8. Internally illuminated Wind cone



GENERAL NOTES:

1. WHEN THE DISTANCE BETWEEN THE RUNWAY SAFETY AREA AND THE BUILDING OR PROPERTY LINE DOES NOT PERMIT A 100' SEGMENTED CIRCLE, A 75' DIAMETER CIRCLE MAY BE USED.
2. ALL ITEMS SHALL BE CONSTRUCTED OF DURABLE WEATHER PROOF MATERIAL.
3. COLOR OF MATERIAL (NATURAL OR APPLIED) SHALL PROVIDE AN EFFICIENT CONTRAST WITH AREA.
4. VARIOUS ELEMENTS (EXCEPT THE WIND CONE) MAY BE OF ANY PRACTICAL MATERIAL THAT WILL MATCH THE DESIGN SHOWN. THEY MAY BE FLAT OR A TYPE THAT WILL SHED SNOW. INSTALLATION SHOULD BE SUCH THAT THEY WILL NOT BE OBSCURED BY VEGETATION, FLOWING MUDDY WATER, SAND, ETC.



APPLICATION OF TRAFFIC PATTERN INDICATORS

Figure 9. Typical Applications for Segmented Circles

4. ROTATING BEACONS

4.1 General Considerations

The FAA currently specifies two types of airport identification beacons. These are the (1) L-810 medium intensity, and (2) L-802 a high intensity beacons. Required light output of the L-802 is only 50% greater than the light output of the L-810.

Airport beacons should be located in a central location to the airport, and within one mile of the runway. They should be located away from and above all structures and terrain that would impede their beams. This is sometimes impossible or impractical; therefore, compromises may be required. When location must be compromised, locate the beacon such that the beams are visible for the maximum azimuth coverage possible.

Common supporting structures for a beacon are:

1. *Roof of hangar, roof of control tower, or other structure.* Figure 10 shows a typical adaptor plate for mounting a beacon on a roof. This mounting is made from angle iron and 1/4" steel plate. Such an adaptor can be fabricated to interface to most any surface. When such a mounting is fabricated, it should be phosphate or coated galvanized to prevent rusting.

2. *35 - 50 foot utility pole.* A typical pole-mounting adaptor may be used for mounting a beacon on top of a utility pole. These adaptors have adjustments so that the beacon can be leveled after it is necessary because it is highly unlikely that the side of the pole will be exactly vertical.

3. *Beacon Tower.* Several commercial towers are available for holding a beacon.

4.2 Power Requirements and Wire Size

The performance of the rotating beacon is highly dependent upon the proper power being supplied to it. Due to this factor, it is essential that your electrical contractor determine the proper wire size and power being supplied to it. Please refer to page 24 of this manual for proper electrical installation.

As the installation of a beacon is a major factor in the safety and utilization of your airport, it is important to reduce the level of liability by having the beacon installed by a licensed and bonded electrical contractor with airport lighting system knowledge.

Be aware of and adhere to the placement of the beacon as per FAA requirements.

As in the addition of any item to your airport, seek guidance through the appropriate Advisory Circular (AC) of the FAA or seek information from the FAA field inspector near you.

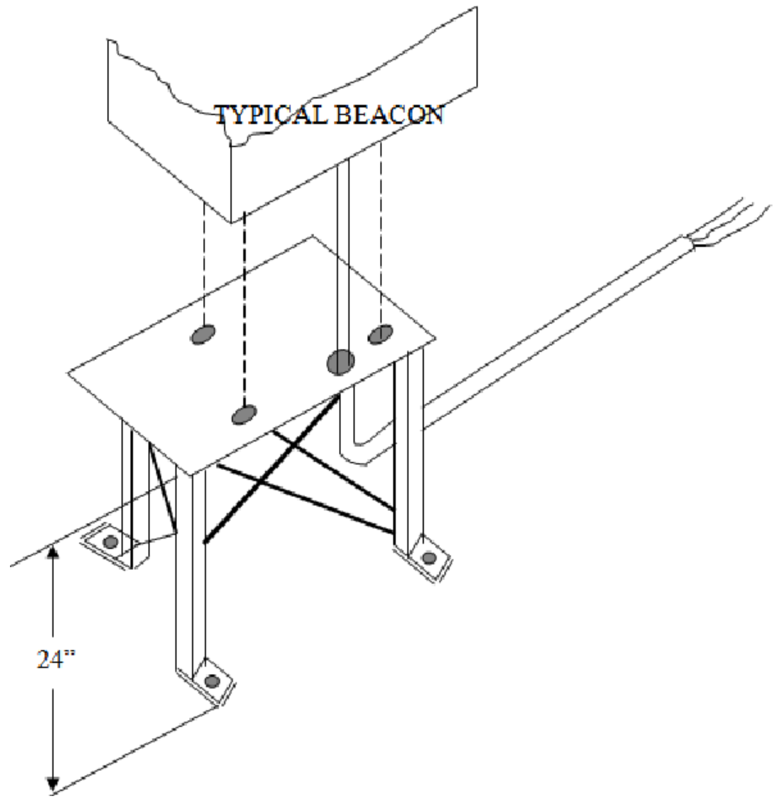


Figure 10. Typical Roof Mount for Airport Beacons

Precision Approach Path Indicator (PAPI)

4.3 General Considerations

It is recommended that a consultation with the local FAA field office, DOT State Aviation Authority, or National Oceanic and Atmospheric Administration (NOAA) be performed prior to the installation of PAPI to ensure compliance with local and federal laws and regulations. These agencies may accommodate site surveys or provide valuable information to airport owners and managers.

The installation of the two (2) box PAPI system requires several steps to ensure proper installation and maximum performance. These steps should not be bypassed.

1. Determination of proper location of the light boxes.
2. Installation of the footers and mounting pads.
3. Interconnect wiring and home run wiring.
4. Alignment of the light box assemblies.
5. Electrical adjustments.
6. Flight check.

7. Determination of Proper Light Box Location.

To obtain an optimal approach system, several factors must be considered. These are:

1. What is distance between the pilot's eyes and the wheels of the largest aircraft to use the runway?
2. What is the desired threshold crossing height?
3. What is the desired glide-scope angle?
4. Will the selection of the above parameters satisfy the required obstacle clearance requirements?

For general aviation, small commuters and corporate turbojets, the wheel-to-eye distance in landing configurations is 10 feet or less. The required threshold crossing height (TCH) is in the range between 20 feet minimum and 45 feet maximum. It must be selected high enough that adequate clearance is available to aircraft when crossing the threshold. However, as the TCH is raised, the runway reference point (RRP) also moves down the runway, meaning that the touchdown point moves further down the runway away from the threshold. Additionally, as the glide-slope angle is increased, the RRP moves back towards the threshold. Therefore, you must select the desired TCH and the desired glide-slope, locate these points on the runway, and then check whether or not they satisfy the obstacle clearance requirements.

A surveyor should be contacted to conduct a site survey of the OCS for the desired TCH and glide-slope. The surveyor should assume that the TCH is 40 feet above the midpoint (usually the runway crown) of the threshold, or at the height requested by the airport owner or manager. The surveyor will then calculate the RRP and placement of the PAPI units as shown in Figure 3 of section 2-4.3.1.

Appendix B specifies alignment angles and placement settings for different PAPI system configurations, and may be provided as reference to the surveyor. In areas where there is a significant runway longitudinal gradient, then the procedure described in Appendix B shall be followed.

After the RRP is determined, the PAPI light box location indicated on the tabulation will be satisfactory provided the mounted height of the PAPI units will be at an elevation equal to the elevation of the crown of the runway at the RRP ±1 foot as stated in section 2-4.3.1.

If not, then the planned location of the PAPI units should be moved up or down the runway according to the tabulation presented in Table B-2 in Appendix B. If the terrain is high at RRP point, then the PAPI units shall be moved toward the threshold. If the terrain is low, the PAPI units will be moved away from the threshold. The location of the PAPI Units should be moved while maintaining the same RRP, TCH, and glide-slope settings of the PAPI system.

After the RRP is calculated, the surveyor will position himself inside the OCS which starts 300 feet in front of the RRP on the runway surface toward the threshold. Observing ±10° in the azimuth, the surveyor will determine if any obstacles penetrate the slope specified in the numbered list in section 2-4.3.1. Recall this slope is different for 2 and 4 unit systems. If an object is at a height that intercepts this slope, then the surveyor must determine if that object is within 4 Nautical Miles of the start of the OCS.

If a site survey determines that there is an obstacle which penetrates the OCS, and the obstacle cannot be removed, then the glide-path angle must be changed or the PAPI system moved further from the threshold. By moving or re-aiming the PAPI, the OCS is repositioned such that no obstacle will penetrate it.

The repositioning or changing of the PAPI system glide-slope will result in the TCH being moved up or down. Recall that the TCH should not exceed 45 feet or be lower than 20 feet for CSAs. The surveyor will recommend the adequate placement point of the PAPI such that obstacle clearance requirements are maintained. This will ensure that pilots utilizing the PAPI will have adequate clearance between aircraft and obstacles along the approach path.

In addition to providing OCS and RRP determination, the surveyor can accurately describe footers and mounting pad placement parameters to the installers of the PAPI system. This is described in the next section.

4.4 Installation of Footers and Mounting Pads

Once the elevation and exact physical location of the PAPI units have been determined, footers should be prepared for the PAPI units and power supply as recommended by the equipment manufacturers. If the installation is in an area subject to freezing, then the footers should be at a depth of 6 to 18 inches below the frost line. When cutting the 2 inch Electrical Metallic Tubing (EMT) legs, the minimum height should be accounted for per equipment manufacturer's instructions in the center of the PAPI unit lens, which will be above the mounting surface.

Mount the PAPI units and power supply on the pads as recommended by the equipment manufacturers.

Interconnect Wiring and Home Runs.

The home run wiring size should be carefully selected to ensure optimum performance of the systems. Select the size as follows:
In order to keep line-loss within reasonable limits, the following table provides the suggested minimum wire size for various distances between the power source and the PAPI system for units utilizing two (2) – 200 watt lamps and systems utilizing four (4) - 200 watt lamps.

	Two 200 watt Lamps	Four 200 watt lamps
0-2000 feet	#12 AWG	#8 AWG
2000-4000 feet	#10 AWG	#6 AWG
4000-6000 feet	#8 AWG	#4 AWG
6000-8000 feet	#6 AWG	#2 AWG

If the power unit is located within 30 feet of the light box, #10 wire is adequate for the lamp circuit, and #16 wire is adequate for the tilt switch circuit.

To protect the wiring between the light box assembly and the point at which it goes underground 1/2" watertight flex duct is a good selection. It can be terminated in a 1/2" conduit (pipe) sweep to interface to the trench.

4.5 Wiring Connections

Install the interconnect wiring according to the manufacturer's instructions.

Adjustment of the Light Box Assemblies

The light box assembly nearest the runway should be adjusted to the glide-slope angle + 1/4°.

The light box farthest from the runway should be adjusted to the glide-slope angle - 1/4°.

When the boxes are in place, make sure both boxes are adjusted with the adjustment jacks so that the centers of the lens of each box are at the same elevation.

Lastly, adjust the tilt switch per the manufacturer's instructions.

4.6 Electrical Adjustments

After each light box assembly has been properly aligned and the tilt switches properly set, the system is ready to be turned on.

Apply power to the system and turn on the power switch in the power supply. The lamps on both light boxes should now be "ON".

CAUTION: Do not look directly into the front of the light box because the light beam is very intense at that point.

Assuming it is daytime, the power supply should be adjusted to produce 120 V (± 10%) to the lamp circuit. If the current is outside its tolerance, make the appropriate adjustments to bring it to within tolerance.

Cover the photocell on top of the power supply. After a time delay, the lamps should dim, and the currents should drop to between 4.0 and 5.0 amperes.

Be sure that both light boxes and the power supply are connected to a ground rod.

4.7 Flight Check

Before placing in service, the system should be thoroughly flight-checked. The flight check should include flying over any and all obstructions in the approach area to be sure that all PAPI units are either not visible or emit red light whenever you are close to the obstruction.

Several normal approaches should be made to ensure a good signal at all points in the approach path.

5. HELIPORT LIGHTING GUIDE

This is a place holder to be completed after the corresponding AC is revised.

6. SOLAR POWER SYSTEMS

Solar-powered lighting systems offer airport operators an alternative to conventionally-powered electrical systems for remote airports. Airports can install solar-powered lighting systems and operate equipment or airfield lighting at isolated locations where power may be inaccessible, cost prohibitive, or unreliable.

Solar-powered systems shall be compliant with all of the guidelines listed in Section 2-8. Further, all solar-powered systems must meet the same performance guidelines stated in Section 2 for the application. For example, a solar-powered taxiway light must meet the same performance criteria as a taxiway light powered by conventional means. This section specifically addresses guidelines for airport owners, airport operators, or end users as it relates to the performance of the solar power system, and not the photometric performance of the fixture.

Solar power systems shall provide adequate power to fixtures relying on self-contained internal batteries. These power systems shall recharge the internal batteries, and cycle on during the night and off at dawn unless operated by radio control for daytime and nighttime use. The lights shall additionally allow the health of the battery to be determined as specified in section 2-8.4.1. They shall include mechanisms for preventing damage to the battery from over or under-charging. The solar-powered system shall enter a failure mode before the light output diminishes below the performance guidelines. This means that when battery depletion becomes significant, the light shall be extinguished as opposed to simply degrading with the charge of the battery.

6.1 Battery Health

Rechargeable, thin-plate lead acid or nickel metal hydride (NiMH) batteries are currently used in solar-powered light fixtures. In order to provide consistent charging performance coupled with efficient light output, solar LED airfield lighting should operate batteries in float mode, disallowing the deep cycling of the battery system. This will allow for longer battery life providing the airport with an average of 3-5 years operating profile before the battery needs to be replaced. Recyclable batteries should be chosen in order so airport operators can easily dispose of used batteries at minimal cost.

Battery health measurements should be conducted according to procedures outlined in the instruction book which shall be compliant with guidelines described in section 2-8.4.3 of this document.

6.2 Mounting Systems

Solar LED aviation lights should be installed using a frangible stake or concrete-mounted plate and coupling system with hex screw. It is important that any mounting system used with the solar-powered light be approved by the manufacturer. The reason for this is that some solar-powered lights have battery venting systems. If the venting system is blocked by the mounting apparatus, it may be detrimental to system operation; for example, a light may be mounted to a plate which covers a vent hole. Minimally, the plate should be drilled to allow proper exposure of this hole to the open air.

7. REMOTE AIRFIELD LIGHTING SYSTEMS

7.1 General Considerations

Lighting an airfield or airstrip located in a rural, remote area has unique challenges. Scarcity of power from an electrical grid, limited funding and few technical personnel require a lighting system that uses little power, operates reliably and cost-effectively, and requires minimum training for installation and operation.

This minimum system is designed so that pilots can locate the field, determine the orientation of the airstrip, land and stop. The components for a Remote Airfield Lighting System consist of the following: Corner Lights and Retro-Reflective Edge Markers. This minimum system can be augmented by using powered light for the runway edge demarcation.

7.2 Installation

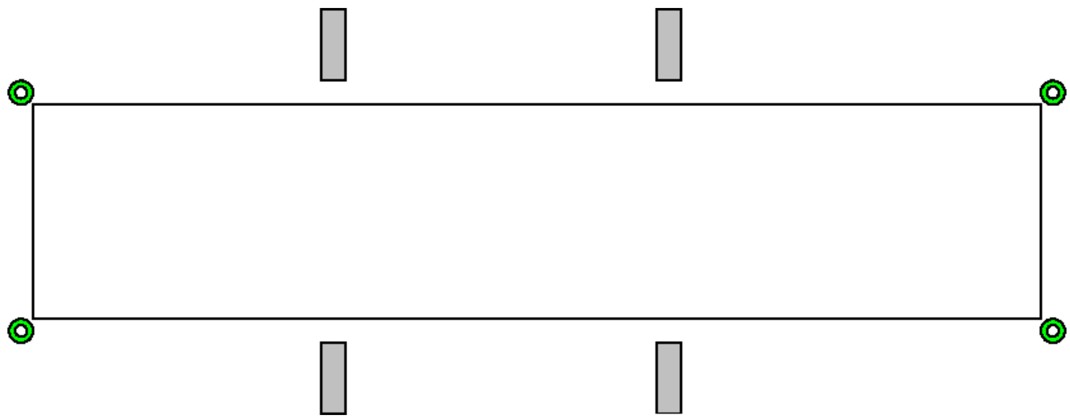
7.2.1 Corner Lights

Four lights are mounted at each corner of the useable area of the airstrip to help the pilots locate the airfield and orient the plane for approach. Operators should ensure that these lights flash in a synchronous pattern.

7.2.2 Edge Markers

Two pairs of edge markers are the minimum requirement for runway edge demarcation. Edge markers should be installed along the edge of the useable area of the airstrip on opposing sides.

With two pairs of edge markers, the runway needs to be divided into thirds. For example, a runway of 3000 feet would have markers at 1000 feet and 2000 feet from the threshold. See the diagram below for a graphical depiction of the system. More edge markers can be added as needed.



Edge Markers

Figure 11. Remote Airfield Lighting System Runway View

8. MAINTENANCE OF COMMUNITY SERVICE AIRPORT LIGHTING

Maintenance for this category of airport lighting equipment is really very straightforward and easy. All of the lighting fixtures were designed and developed with ease of maintenance in mind.

While the maintaining this lighting system can be accomplished by one who knows little about airport lighting, the value to the user cannot be measured as simply. The lighting system is designed to be as photometrically and cosmetically equal to the FAA-approved MIRL lighting system as possible but at a much lower cost.

It is essential that the airport manager or supervisor create a maintenance/inspection schedule and sign-off sheet for each item of the lighting system. As the various items are inspected, they should be signed off with a name and a date showing that the item was in good working order.

If for any reason the item needed repair, it should be noted what was repaired, by whom, and the date it was accomplished.

Closely following a good maintenance plan can and will be very beneficial to the airport and can prevent problems in the future.

It is essential that the nearest FAA facility be notified if any portion of the lighting system is inoperative and will remain that way overnight. Every effort should be made to repair/replace the component that is not operating properly immediately. A report to the FAA should include what element of the lighting system is out and when it will be back in service.

8.1 Runway Edge, Threshold and Taxiway Fixtures

In consideration of safety and efficient maintenance, the installation of a General Aviation airport lighting base can is essential. The base can will provide a clean and dry environment for all electrical connections. While a light fixture mounting stake appears to be the quickest and easiest installation, it is not.

The major problem with a stake-mounted fixture is that all electrical connections will be buried in the dirt and will eventually be accessible to anyone that happens by. The stake mount is also recognized as a safety hazard in times that an aircraft might strike a fixture with any wiring connections exposed. The GA base can will eliminate this problem.

With several years of study, it has been proven that the 40 watt traffic signal bulb is the most efficient bulb for this system. Considering the fact that all municipalities can purchase the traffic bulbs at a reduced cost, this heavy duty bulb is the best choice.

Any supplier of the GA lighting equipment will be happy to provide information and tips on maintaining this hybrid, yet very efficient, system

Efforts should be made to keep any vegetation from growing around the base cover and the fixture which may block the output of the fixture. You may find cases when the globe of the fixture is taken, especially the split green-red threshold globes. If this does become a problem at your airport, a good solution is to safety wire the band clamp so they are more tamper proof.

A scheduled maintenance check should be accomplished daily. Any broken or damaged globes or glassware, frangible columns or any other problems noted during this inspection must be repaired as soon as possible.

8.2 Taxiway Markers: (Retro-Reflective Markers)

The installation of reflective markers on the taxiway is a good choice for any community service airport. They have no maintenance costs after installation whatsoever.

It is vital, however, that the color signal that is transmitted to the pilot be uniform with FAA guidelines.

Any vegetation growing around the marker should be cleared so the device will function properly.

A scheduled inspection of the markers should be made and if necessary, cleaning of the reflective face should be accomplished.

Visual inspection of the mounting should be accomplished on a scheduled basis. Anything noted as out of the ordinary should be repaired.

Suppliers of these devices have pledged support and maintenance information to any airport installing the retro-reflective markers. While the retro-reflective markers are the most economical for general aviation, the installation of a taxiway lighting system is also an option.

8.3 Rotating Beacon:

The professionalism in the production of today's airport rotating beacon will require very little maintenance.

A daily scheduled check of the beacon lamps, lenses, and mechanism should be accomplished. It is an excellent idea to have at least one extra lamp/bulb of the proper wattage as supplied by the beacon manufacturer. If any portion of the beacon is below standards, it must be replaced.

A periodic inspection of the beacon mechanism should include opening the housing and lubricating the gears and bearings.

8.4 Wind Cone:

A part of the daily inspection will include the wind cone or wind direction indicator.

A scheduled inspection of the sock for tears or damage should be made. In addition, the mounting framework and sock support should be inspected. Any discoloration or fading of the sock would be a reason for replacement. If the wind indicator is lighted, a test of the electrical system should also be done at this time

A periodic inspection and lubrication of the mechanism should be accomplished.

8.5 Precision Approach Path Indicator (PAPI):

As the PAPI is an essential item of safety in the lighting package, it requires very specific care and maintenance.

A frequent inspection and check must be made of the alignment of the PAPI boxes. To conduct this inspection, the use of the manufacturer's precision alignment equipment supplied with the PAPI must be used. If for any reason, the PAPI units are outside limits, the unit must be shut down and the FAA notified. Every effort should be made to properly align and aim the boxes to the proper settings and put back into service.

The PAPI will greatly enhance the safety and efficiency of the airport.

A periodic inspection of the bases should be made and any vegetation should be removed that would block or distort the output of the units.

A periodic inspection and cleaning of the interior of the PAPI control boxes should be made and noted. In addition, the lenses should be cleaned to ensure the highest output possible.

8.6 Solar-Powered Fixtures:

Solar-powered fixtures used on the runway or taxiway require very little maintenance. However, they should be added to the scheduled maintenance program and inspected for proper operation.

Any vegetation should be removed from around the fixture to ensure that the fixture is not blocked.

The fixture mounting should be inspected to ensure proper alignment.

8.6.1 Cleaning of Solar Panels

During snowfall or heavy sandblasting, it is recommended to keep the solar panels as clean as possible. If the panels are not kept clean or covered during heavy snowfall or grit build up, the power management capabilities within each light will result in slightly decreased light output over time as a result of decreased voltage, inefficient charging or reduced solar. Therefore, it is imperative for airport operators to keep solar panels as clean as possible for best possible light output and high efficiency charging.

8.7 Runway end identifiers & Alignment Lighting (REILS & RAILS)

If an airport is fortunate enough to have the REILS & RAILS installed, a simple operational inspection should be made daily. The inspection should include a cycling of the lighting to ensure that it is working properly.

Any vegetation should be removed from around the fixtures.

8.8 Pilot-controlled Lighting (Radio Control):

The lighting inspection schedule should include a system check using the radio control. Cycling the lighting system on the proper radio frequency should be accomplished each day to ensure the system is available to pilots.

While today's radio controls are very reliable, items such as fuses and backup crystals should be kept on hand so the system is not down for a period of time while waiting for parts to be shipped.

8.9 Airport Informational Signage: (IS)

It has been proven through many years of use that retro-reflective signs are a very economical way to improve safety and efficiency at the general aviation airport. These signs require little or no maintenance.

The scheduled operational inspection should include checking the mounting system and that any vegetation is not blocking the legend of the sign. It may be necessary to clean the face of the sign on a rare occasion.

8.10 Suggested Maintenance Inspection Forms:

For the purpose of safety and liability the inspection of airport lighting systems should include:

- A date and time inspection block.
- A signature block.
- A section to note any deficiency and the recommended repair, with a signature block. The date and time of repair and what was done, with signature.
- If a repair is not made, the date and time the nearest FAA facility was notified and by whom.
- If the repair was not made, a notation of when the parts will arrive and the company that the order was placed with.

APPENDIX A

Brief History
IES Subcommittee on Aviation Lighting's
Guidelines for Airport and Airfield Lighting Systems at
Community Service Airports

This document defines airfield lighting guidelines for Community Service Airports. These guidelines were recommended jointly by the National Association of State Aviation Officials Center for Aviation Research and Education (NASAO/CARE) and the Illuminating Engineering Society Airfield Lighting Committee (IESALC). It offered and suggested alternative design considerations for a line of products true to the visual function of conventional visual navigational aids existing on airports nationwide. It provided an introduction and discussion of the types of systems that could successfully be utilized at Community Service Airports as defined previously. Installation criteria are also included for some of the lighting products and corresponding specifications were included for guidance by anyone who might consider manufacturing an economical version of the product. The information and guidelines published herein were not intended to be a substitute for professional expertise, sound judgment, technical knowledge, and the consideration of unique local factors.

States have been, and continue to be involved in the planning, development, maintenance, operation, inspection and/or licensing of airports which are included on the Federal Aviation Administration's (FAA) National Plan of Integrated Airport Systems (NPIAS), as well as smaller airports with only a local and/or state interest. Many of these do not qualify for federal grant-in-aid assistance, and many that would qualify cannot afford the required "local" share. Over the years, individual airport operators and state aviation agencies have devised "affordable" equipment and systems to meet the needs of airports in these situations.

Thus the NASAO/IES Joint Subcommittee on Visual Aids originally addressed the need for a set of "Lighting Guidelines" in 1981. The Subcommittee recommendation included a provision for the drafting of other airport design and development guidelines. Additional areas not covered by a national standard, or only partially covered, could be included in a NASAO/CARE Airport Guideline if the NASAO member agencies or local airport sponsors express the need.

The information provided in these guidelines was the collective product of a dedicated group of individuals that comprise the Illumination Engineering Society (IES) Airfield Lighting Committee (ALC) subcommittee for General Aviation Lighting as authorized in 1981 by specific action of the parent organization known as the Illumination Engineering Society. This organization reacted/acted to address a concern shared by committee members and the public interested in General Aviation safety by creating the IES Subcommittee for General Aviation Lighting. Several attempts have been made by the subcommittee to distribute the product of its efforts to the aviation community. Unfortunately only one distribution effort met with any degree of success. That was with the support of National Association of State Aviation Officials/Illumination Engineering Society (NASAO/IES) Joint Committee on Visual Aids when the NASAO briefly offered an earlier version of the guidelines for national distribution. Unfortunately it was made available for a fee to an Aviation Community that was already "strapped" for funds for other basic airport needs. It met with limited success and to the best of our knowledge is no longer available from NASAO. Currently the IES Subcommittee for General Aviation Lighting continues to provide updates to the guidelines under the auspices of the IES Joint Committee on Visual Aids. These guidelines served to document recommendations, which have proven successful in the field. Several have been in use for many years. Others might be considered experimental or tentative pending the test of time.

Approval and Dissemination Procedures

This modern adaptation of airport lighting guidelines was prepared by the IES General Aviation Lighting Committee in accordance with approval procedures established by the NASAO Board of Directors at the September 27, 1981 meeting. The representatives that have contributed are:

IES GA Lighting Committee

Mac McIver	Billy Schai	Mel Haywood
Joe Levraea	Allister Wilmott	Allan Taylor

Thus the NASAO/IES Joint Subcommittee on Visual Aids originally addressed the need for a set of "Lighting Guidelines" in consideration of unique local factors . States have been, and continue to be involved in the planning since 1981. The Subcommittee recommendation included a provision for the drafting of other airport design and development guidelines. Additional areas not covered by a national standard, or only partially covered, could be included in a NASAO/CARE Airport Guideline if the NASAO member agencies or local airport sponsors express the need.

The Lighting Guidelines were submitted on June 22, 1987 and discussed by the Board during its meeting on August 3, 1987. At that time, the Board referred, with a positive disposition, the guidelines to the Standards Council headed by Ms. Gloria Holmes of Louisiana. Following the Council's review, final Board acceptance was granted on October 21, 1987.

APPENDIX B – PAPI System Information for Surveyors

On runways where there is a difference in elevation between the runway threshold and the runway elevation at the PAPI, the location of the PAPI units may need to be adjusted with respect to the threshold in order to meet the required obstacle clearance and TCH. Where such a condition exists, the following steps (shown in Figures B-1 and B-2 on the next page) are taken to compute the change in the distance from the threshold required to preserve the proper geometry.

(1) Obtain the runway longitudinal gradient.

(2) Determine the ideal (zero gradient) distance from the threshold in accordance with the instructions above.

(3) Assume a level reference plane at the runway threshold elevation. Plot the location determined in Step (2).

(4) Plot the runway longitudinal gradient (RWY).

(5) Project the visual glide-path angle to its intersection with the runway longitudinal gradient (RWY). Then solve for the adjusted distance from threshold (dimension *d* on Figures B-1 and B-2).

(6) Double check to see that the calculated location gives the desired threshold crossing height.

Other Siting Considerations

Where the terrain drops off rapidly near the approach threshold and severe turbulence is experienced, the PAPI should be located farther from the threshold to keep aircraft at the maximum possible threshold crossing height (45 feet for CSAs).

On short runways, the PAPI should be located as near the threshold as possible to provide the maximum amount of runway for braking after landing.

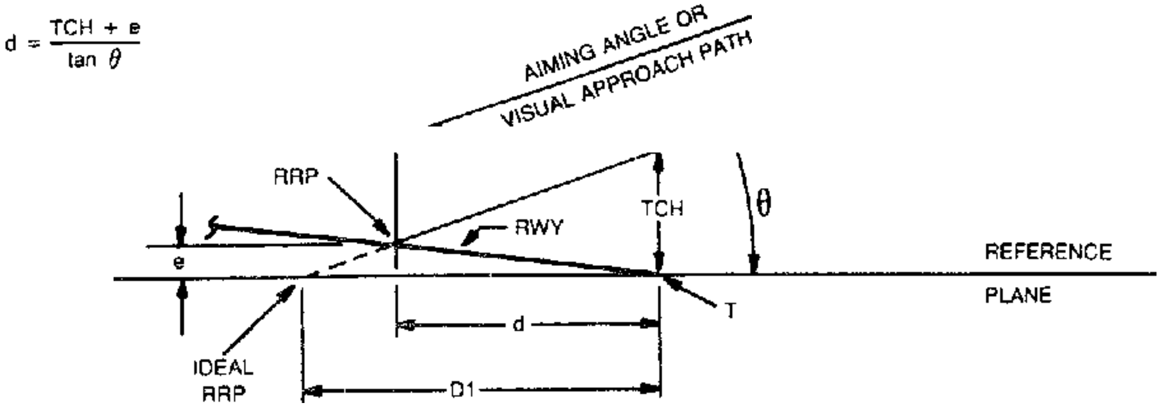


Figure B-1 Siting Station Displaced Toward Threshold

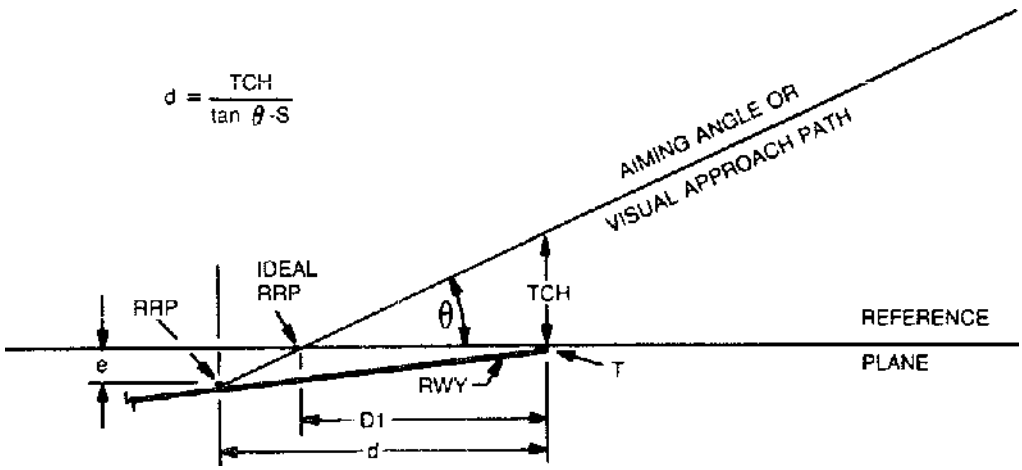


Figure B-2. Siting Station Displaced from Threshold

Symbols in the Above Figures —

D1	=	ideal (zero gradient) distance from threshold
RWY	=	Runway longitudinal gradient
TCH	=	Threshold Crossing Height
T	=	Threshold
e	=	elevation difference between threshold and RRP
RRP	=	Runway Reference Point (where aiming angle or visual approach path intersect the runway profile)
d	=	adjusted distance from threshold
θ	=	aiming angle

S=percent slope of runway e/D1

Table B-1 .Tabulation of PAPI Box Locations for Various Glide Slope Angles

TCH	Distance V	Inner Box Aiming Angle	Outer Box Aiming Angle	Distance from Threshold to Light Boxes
Glide slope Angle = 2.25 Degrees				
20	208	2	3	508
21	233	2	3	533
22	259	2	3	559
23	284	2	3	584
24	310	2	3	610
25	335	2	3	635
26	361	2	3	661
27	386	2	3	686
28	412	2	3	712
29	437	2	3	737
30	463	2	3	763
31	488	2	3	788
32	513	2	3	813
33	539	2	3	839
34	564	2	3	864
35	590	2	3	890
36	615	2	3	915
37	641	2	3	941
38	666	2	3	966
39	692	2	3	992
40	717	2	3	1017

Table B-1. Tabulation of PAPI Box Locations for Various Glide Slope Angles (cont.)

TCH	Distance V	Inner Box Aiming Angle	Outer Box Aiming Angle	Distance from Threshold to Light Boxes
Glide slope Angle = 2.5 Degrees				
20	157	2	3	457
21	180	2	3	480
22	203	2	3	503
23	226	2	3	526
24	249	2	3	549
25	272	2	3	572
26	294	2	3	594
27	317	2	3	617
28	340	2	3	640
29	363	2	3	663
30	386	2	3	686
31	409	2	3	709
32	432	2	3	732
33	455	2	3	755
34	478	2	3	778
35	501	2	3	801
36	524	2	3	824
37	546	2	3	846
38	569	2	3	869
39	592	2	3	892
40	615	2	3	915

Table B-1. Tabulation of PAPI Box Locations for Various Glide Slope Angles (cont.)

TCH	Distance V	Inner Box Aiming Angle	Outer Box Aiming Angle	Distance from Threshold to Light Boxes
Glide slope Angle = 2.75 Degrees				
20	115	3	3	415
21	136	3	3	436
22	157	3	3	457
23	178	3	3	478
24	199	3	3	499
25	219	3	3	519
26	240	3	3	540
27	261	3	3	561
28	282	3	3	582
29	303	3	3	603
30	324	3	3	624
31	344	3	3	644
32	365	3	3	665
33	386	3	3	686
34	407	3	3	707
35	428	3	3	728
36	448	3	3	748
37	469	3	3	769
38	490	3	3	790
39	511	3	3	811
40	532	3	3	832

Table B-1. Tabulation of PAPI Box Locations for Various Glide Slope Angles (cont.)

TCH	Distance V	Inner Box Aiming Angle	Outer Box Aiming Angle	Distance from Threshold to Light Boxes
Glide slope Angle = 3.0 Degrees				
20	81	3	3	381
21	100	3	3	400
22	119	3	3	419
23	138	3	3	438
24	157	3	3	457
25	176	3	3	476
26	195	3	3	495
27	214	3	3	514
28	233	3	3	533
29	252	3	3	552
30	271	3	3	571
31	291	3	3	591
32	310	3	3	610
33	329	3	3	629
34	348	3	3	648
35	367	3	3	667
36	386	3	3	686
37	405	3	3	705
38	424	3	3	724
39	443	3	3	743
40	462	3	3	762

Table B-1. Tabulation of PAPI Box Locations for Various Glide slope Angles (cont.)

TCH	Distance V	Inner Box Aiming Angle	Outer Box Aiming Angle	Distance from Threshold to Light Boxes
Glide slope Angle = 3.5 Degrees				
20	26	3.25	3.75	326
21	42	3.25	3.75	342
22	59	3.25	3.75	359
23	75	3.25	3.75	375
24	91	3.25	3.75	391
25	108	3.25	3.75	408
26	124	3.25	3.75	424
27	140	3.25	3.75	440
28	157	3.25	3.75	457
29	173	3.25	3.75	473
30	189	3.25	3.75	489
31	206	3.25	3.75	506
32	222	3.25	3.75	522
33	239	3.25	3.75	539
34	255	3.25	3.75	555
35	271	3.25	3.75	571
36	288	3.25	3.75	588
37	304	3.25	3.75	604
38	320	3.25	3.75	620
39	337	3.25	3.75	637
40	353	3.25	3.75	653

Table B-1. Tabulation of PAPI Box Locations for Various Glide slope Angles (cont.)

TCH	Distance V	Inner Box Aiming Angle	Outer Box Aiming Angle	Distance from Threshold to Light Boxes
Glide slope Angle = 3.75 Degrees				
20	4	3.5	4	304
21	19	3.5	4	319
22	35	3.5	4	335
23	50	3.5	4	350
24	65	3.5	4	365
25	80	3.5	4	380
26	96	3.5	4	396
27	111	3.5	4	411
28	126	3.5	4	426
29	141	3.5	4	441
30	157	3.5	4	457
31	172	3.5	4	472
32	187	3.5	4	487
33	202	3.5	4	502
34	218	3.5	4	518
35	233	3.5	4	533
36	248	3.5	4	548
37	264	3.5	4	564
38	279	3.5	4	579
39	294	3.5	4	594
40	309	3.5	4	609

Table B-1. Tabulation of PAPI Box Locations for Various Glide slope Angles (cont.)

TCH	Distance V	Inner Box Aiming Angle	Outer Box Aiming Angle	Distance from Threshold to Light Boxes
Glide slope Angle = 4.0 Degrees				
20	-15	3.75	4.25	285
21	-1	3.75	4.25	299
22	14	3.75	4.25	314
23	28	3.75	4.25	328
24	42	3.75	4.25	342
25	57	3.75	4.25	357
26	71	3.75	4.25	371
27	85	3.75	4.25	385
28	99	3.75	4.25	399
29	114	3.75	4.25	414
30	128	3.75	4.25	428
31	142	3.75	4.25	442
32	157	3.75	4.25	457
33	171	3.75	4.25	471
34	185	3.75	4.25	485
35	200	3.75	4.25	500
36	214	3.75	4.25	514
37	228	3.75	4.25	528
38	242	3.75	4.25	542
39	257	3.75	4.25	557
40	271	3.75	4.25	571

Table B-2. Adjustments of Light Box Location for Deviations in Mounting Height

Deviation Above (or Below Crown)	Move Towards Threshold	Move Away From Threshold
Glide Slope Angle = 2.5 Degrees		
1.00	-22.90 FT	(22.90) FT
2.00	-45.81 FT	(45.81) FT
3.00	-68.71 FT	(68.71) Fl
4.00	-91.62 FT	(91.62) FT
5.00	-114.52 FT	(114.52) FT
6.00	-137.42 FT	(137.42) FT
7.00	-160.33 FT	(160.33) FT
8.00	-183.23 FT	(183.23) FT
9.00	-206.13 FT	(206.13) FT
10.00	-229.04 FT	(229.04) FT
Glide Slope Angle = 2.75 Degrees		
1.00	-20.82 FT	(20.82)FT
2.00	-41.64 FT	(41.64 FT
3.00	-62.46 FT	(62.46)FT
4.00	-83.28 FT	(83.28)FT
5.00	-194.09 FT	(104.09)FT
6.00	-124.91 FT	(124.91)FT
7.00	-145.73 FT	(145.73)FT
8.00	-166.55 FT	(166.55)FT
9.00	-187.37 FT	(187.37)FT
10.00	-208.19 FT	(208.19)FT
Glide Slope Angle = 3.0 Degrees		
1.00	-19.08 FT	(19.08) FT
2.00	-38.16 FT	(38.16) FT
3.00	-57.24 FT	(57.24) FT
4.00	-76.32 FT	(76.32) FT
5.00	-95.41 FT	(95.41) FT
6.00	-114.47 FT	(114.47) FT
7.00	-133.57 FT	(133.57) FT
8.00	-152.65 FT	(152.65) FT
9.00	-171.73 FT	(171.73) FT
10.00	-190.81 FT	(190.81) FT

Table B-2. Adjustments of Light Box Location for Deviations in Mounting Height

Glide Slope Angle = 3.25 Degrees

1.00	-17.61 FT	(17.61) FT	
2.00	-35.22 FT	(35.22) FT	
3.00	-52.83 FT	(52.83) Fl	
4.00	-70.44 FT	(70.44) FT	
5.00	-88.05 FT	(88.05) FT	
6.00	-105.66 FT	(105.66) FT	
7.00	-123.27 FT	(123.27) FT	
8.00	-140.88 FT	(140.88) FT	
9.00	-158.50 FT	(158.50) FT	
10.00	-176.11 FT	(176.11) FT	
Deviation Above (or Below Crown)	Move Towards Threshold	Move Away Threshold	From
Glide Slope Angle = 3.5 Degrees			
1.00	-16.35 FT	(16.35) FT	
2.00	-32.70 FT	(32.70) FT	
3.00	-49.05 FT	(49.05) Fl	
4.00	-65.40 FT	(65.40) Fl	
5.00	-81.75 FT	(81.75) FT	
6.00	-98.10 FT	(98.10) FT	
7.00	-114.45 Ft	(114.45) FT	
8.00	-130.80 FT	(130.80) FT	
9.00	-147.15 FT	(147.15) FT	
10.00	-163.50 FT	(163.50) FT	

Glide Slope Angle = 3.75 Degrees

1.00	-15.26 FT	(15.26) FT
2.00	-30.51 FT	(30.51) FT
3.00	-45.77 FT	(45.77) FT
4.00	-61.03 FT	(61.03) FT
5.00	-76.29 FT	(76.29) FT
6.00	-91.54 FT	(91.54) FT
7.00	-106.80 FT	(106.80) FT
8.00	-122.06 FT	(122.06) FT
9.00	-137.31 FT	(137.31) FT
10.00	-152.57 FT	(152.57) FT

Glide Slope Angle = 4.0 Degrees

1.00	-14.30 FT	(14.30) Fl?
2.00	-28.60 FT	(28.60) FT
3.00	-42.90 FT	(42.90) FT
4.00	-57.20 FT	(57.20) FT
5.00	-71.50 FT	(71.50) FT
6.00	-85.80 FT	(85.80) FT
7.00	-100.10 FT	(100.10) FT
8.00	-114.41 FT	(114.41) FT
9.00	-128.71 FT	(128.71) FT
10.00	-143.01 FT	(143.01) FT

Glide Slope Angle = 4.25 Degrees

1.00	-13.46 FT	(13.46) FT	
2.00	-26.91 FT	(26.91) ft	
3.00	-40.37 FT	(40.47) FT	
4.00	-53.83 FT	(53.83) FT	
5.00	-67.28 FT	(67.28) Fl?	
6.00	-80.74 FT	(80.74) FT	
7.00	-94.20 FT	(94.20) FT	
8.00	-107.65 FT	(107.65) FT	
9.00	-121.11 FT	(121.110 ft	
10.00	-134.57 FT	(134.57) FT	
Deviation Above (or Below Crown)	Move Towards Threshold	Move Away Threshold	From
Glide slope Angle = 4.5 Degrees			
1.00	-12.71 FT	(12.71) FT	
2.00	-25.41 FT	(25.41) FT	
3.00	-38.12 FT	(38.12) FT	
4.00	-50.82 FT	(50.82) FT	
5.00	-63.53 FT	(63.53) FT	
6.00	-76.24 FT	(76.24) FT	
7.00	-88.94 FT	(88.94) FT	
8.00	-101.65 Fl	(101.65) FT	
9.00	-114.36 FT	(114.36) FT	
10.00	-127.06 FT	(127.06) FT	

APPENDIX C
Community Service Airport Visual Aids Suppliers

Airside, Inc.
General Aviation Planning and Layout
PO Box 287
Greenbank, WA 98253
Phone: 360-222-3646
E-mail: Airside@Airside.net@
GA airport planning and layout plans

Avlite Systems (USA)
4458 Hwy 268 East
Pilot Mountain, NC 27041
Ph: 336-351-3519
Fax: 336-351-3547
Web site: www.avlite.com
Solar Airfield Lighting

Allen Enterprises
5659 Commerce Dr. Ste 100
Orlando , FL 32839 P.O. Box 560384 Orlando , FL 32856 Ph: 800-662-2177 Ph: 407-857-6778 Fax: 407-857-7993
Total lighting for the airport

Carmanah Technologies Corporation
Building 4, 203 Harbour Road Victoria BC V9A 3S2 Canada Ph: 0011 1250 380 0052
Fax: 0011 1250 380 0062
Email: info@solarairportlights.com@
Web site: www.solarairportlights.com
Solar fixtures

Farlight LLC
846 Watson Ave., Unit C Wilmington, CA 90744 Telephone (310) 830-0181 Fax (310) 830-9066 moreinfo@farlight.com
Remote Airfield Lighting

Flightlight, Inc.
Attn: Isabel Martin, V.P. 3513 La Grande Blvd.
Sacramento, CA 95825-1010
Phone: 800-806-3548
Fax: 916-394-2809
Total lighting for the airport

Hali-Brite Inc.
PHONE 1- 800-553-6269 FAX 218-546-6854
EMAIL: sales@halibrite.com@
Beacons

Jaquith Industries, Inc.
600 East Brighton Avenue
P.O Box 780
Syracuse, NY 13205TEL: [315] 478-5700 FAX: [315] 478-5707
EMAIL: sales@jaquith.com www.jaquith.com
Frangible columns, base stakes & GA cans

Multi Electric Manufacturing
4223 W Lake St
Chicago, IL , 60624-1787
Phone: 773-722-1900
FAX: 773-722-5694

GA PAPI
Manairco Inc
28 Mansfield Industrial Pkwy Mansfield, OH 44903-8999 Phone: 419-524-2121
FAX: 419-525-4790
Total visual aids for the airport

Reinald Bennett International (RBI)
835 Westney Rd South
Ajax, ON L1S 3M4 ,Canada
Phone: 905 686 8833
Fax: 905 686 5619
Web Site: http://www.rbi-inc.com
Retro Reflective Panels

Standard Signs Inc
3190 E 65th St Ste 1 Cleveland, OH , 44127-1492
Phone: 216-341-5611 FAX: 216-341-0652
Toll Free Phone: 800-258-1997
Airports signs

Valley Illuminators
PO Box 3001
Federal Way, WA 98063-300 1
Phone: 253-833-3016
E-mail: Valley(2Valleyilluminators.com Retroreflective markers, signs. Edge lighting, Windcones

APPENDIX D

General Aviation Base Can

APPENDIX E

Source of Photocells

FAA Style Photocells

Manufacturer	Part NO.	NAED
Precision	452FAA	30452
Precision	102FAA	
Sun Switch	6195-12FAA	
Crouse-Hinds	5171 1A	

Utility and Simple Style Photocells

Manufacturer	Part No.	Style	Watts
Precision	D5 30005	U	3000
Precision	D7 30007	U	3000
Precision	P-2275	U	1800
Precision	M-2275	U	1800
Precision	LM-2275	U	1800
Precision	ST-1 5/T-15	S	1800
Precision	T-30	S	3000
Sun Switch	6146	U	1000-1800
Sun Switch	6195-12	U	1000-1800
Sun Switch	6190	U	1000-1800
Sun Switch	7001	S	1000-1200
Sun Switch	7011	S	1000-1200
Sun Switch	7046	S	1000-1800
Fisher Pierce	6690B	S	1800
Fisher Pierce	6690-N	S	1800

Other manufacturers of photocells are General Electric and Tork.

APPENDIX F — Background and Justification for Requirements

Photometric Requirements

Intensity distribution

The minimum intensity as a function of elevation angle for the 4-corner light fixture is plotted in Figure 1. Table 1 to the right of the figure lists the minimum intensity values at particular angles. The values corresponding to approach angles between 0 and 10 degrees are based on a pilot's ability to locate and identify lights at a distance of 5 miles in clear atmospheric conditions. Values corresponding to approach or viewing angles greater than 10 degrees result from calculations, described below, recognizing that less intensity is required for shorter viewing distances.

Laboratory experiments and flight tests were conducted to establish the required intensity to locate and identify an airfield at a distance of at least 5 miles and at altitudes between 2000 and 3000 feet. As a pilot continues to fly toward the airfield at constant altitude, it is desirable to have the lights appear brighter as confirmation and reassurance of correctly locating the airfield. Having the light remain visible for all viewing angles, such as when a pilot performs a fly-over of the airfield before starting the final approach, is also desirable. A relatively low flying altitude corresponds to a small approach angle, especially at far distances from the airstrip; therefore the highest intensity is needed at the smallest angles (measured from the horizon). Larger approach angles occur only as the pilot nears the airfield, and the reduction in viewing distance enables the lights to be visible at lower intensity. The lower intensity requirements for large angles can help to significantly reduce the electrical power demand of the lights.

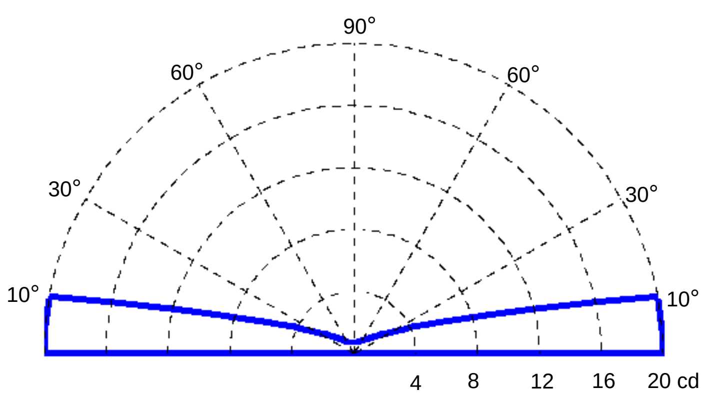


Fig. 1. Minimum intensity as a function of elevation angle.

View angle	Required Intensity
Degrees from horizon	Candela (X = 0.12)
0	20
10	20
30	2.4
60	0.8
90	0.6

Table 1. Minimum intensity values at particular angles

If brightness is operationally defined as illumination at the pilot's eye, then brightness will decrease with the square of the distance, as given by the inverse square law relating illumination to intensity. For constant altitude flight, the distance to the airfield is given by

$h/\sin\theta$, where h is the altitude and θ is the line of sight angle from the plane to the airfield. Constant illumination at the pilot's eye is given by $Eh^2/\sin^2\theta$, where E is the illumination at the pilot's eye. The quantity Eh^2 is approximately equal to 0.6 for a 20-candela (cd) source viewed from a 10° approach angle. The intensity specification, therefore, results in increasing brightness for approach angles below 10°, and constant brightness for approach angles greater than 10° when flying at a constant altitude.

The values of intensity are in units of time-averaged mesopic candela. Time-averaging is a method of quantifying a temporally varying (i.e., flashing) signal to account for its visual effectiveness. Compared to the standard candela unit, a mesopic candela has a modified spectral weighting that accounts for changes in a pilot's visual sensitivity brought about by the state of dark adaptation of the eye during nighttime flying conditions. Precise definitions for this method of measuring intensity are given below. Background information on how these metrics were established are provided in Volume 3: Title TBD, sections TBD.

Time-averaged intensity is defined as:

$$\langle I \rangle = \frac{\int_T I_t \, dt}{T},$$

where I_t is the instantaneous intensity that varies with time, and T is one period of a repeating flash pattern. The $\langle\ \rangle$ brackets around I indicate a time-averaged quantity.

For an example calculation, consider a light flashing on and off at a frequency of 2 hertz (Hz) in a square-wave temporal pattern (i.e., a 50% duty cycle). The light is on for 250 milliseconds (ms) at 40 candela (cd) and off for 250 ms at zero intensity. The time-averaged intensity is:

$$\langle I \rangle = \frac{[40\,\text{cd}][250\,\text{ms}] + [0\,\text{cd}][250\,\text{ms}]}{500\text{ms}} = 20\text{cd}$$

Most photometers measure the time-averaged quantity of illumination, but their response times are optimized for fast readout of 60 Hz modulated signals. Therefore, they respond much too quickly to accurately measure the time-averaged quantity for flash rates between 2 and 4 Hz, yet respond too slowly to provide an accurate instantaneous readout of intensity. Provided the temporal wave shape is rectangular, the time-averaged intensity may be calculated as in the above example from measurements of the peak intensity.

The mesopic candela for an adaptation level of X = 0.12 is calculated according to the following equation:

$$I_{X=0.12} = 0.25 I_{photopic} + 0.75 I_{scotopic}$$

where $I_{photopic}$ is the CIE-defined photopic intensity in units of candela, and $I_{scotopic}$ is the CIE-defined scotopic intensity, also in units of candela.

Photometric instruments with scotopic spectral weighting are quite rare, which makes direct application of the above equation impractical. In addition, most broadband photometers have severely degraded accuracy when measuring sources having narrow bandwidth emissions, such as LEDs. The preferred method of calculating the mesopic intensity is to measure the source spectrally and then apply the photopic and scotopic weighting functions as specified by the CIE (CIE 2004). Combining the photopic and scotopic luminous efficacy functions in the proportions given by the above equation produces the mesopic luminous efficacy function shown in Figure 2 with a peak response at 510 nm.

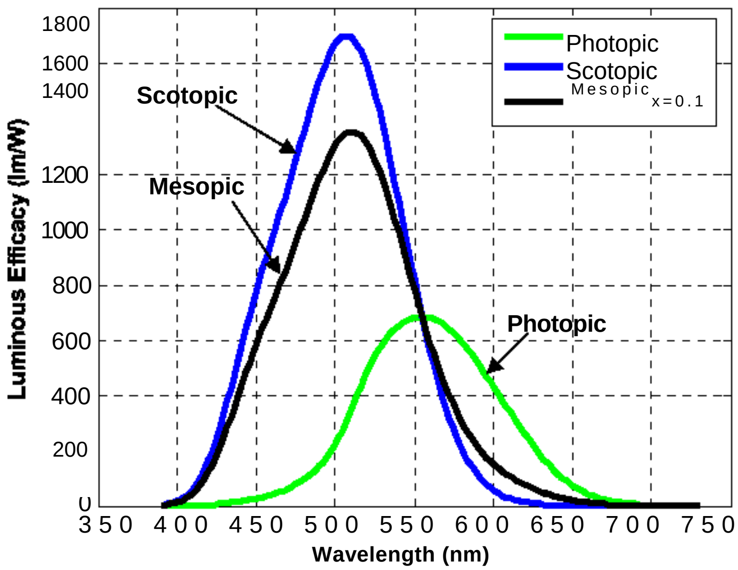


Figure. F-2. Photopic, Scotopic, and Mesopic Luminous Efficacy Functions.

If a scotopic photometer is not available, the Table 2 lists the corresponding photopic and scotopic intensity values for typical LED spectra with different peak wavelengths. Due to the variability of LED spectra of different manufacturers and processes, the values listed in this table are only approximate.

Table F-2. Comparison of Mespoic, Photopic and Scotopic Candela

For Green LEDs

Peak wave nm	Mesopic cd	Photopic cd	Scotopic cd
490	40	7.0	51.0
495	40	8.0	50.7
500	40	9.2	50.3
505	40	10.5	49.8
510	40	12.1	49.3
515	40	13.9	48.7
520	40	15.8	48.1
525	40	18.0	47.3
530	40	20.4	46.5
535	40	23.0	45.7
540	40	25.9	44.7
545	40	29.2	43.6

550	40	32.9	42.4

For Amber LEDs

Peak wave	Mesopic	Photopic	Scotopic
570	40	54.9	35.0
575	40	62.1	32.6
580	40	69.9	30.0
585	40	78.0	27.3
590	40	86.4	24.5
595	40	94.7	21.8
600	40	102.8	19.1

Flash frequency, duty cycle, and phase

Laboratory experiments and flight test trials revealed that the effectiveness of flashing signal lights is much greater than that of steady burning lights, and that certain flash patterns are more efficacious than others at enabling pilots to locate and identify an airstrip. In specifying the flash parameters, consideration was also given to avoiding confusion with other ground-based flashing signal lights, such as obstruction beacons and emergency vehicles. To address the latter consideration, only flash frequencies greater than 2 Hz are recommended. The color specification also addresses this issue by not recommending red or blue signal light colors.

The upper frequency limit of 4 Hz reflects the diminishing effectiveness of flashing signals as the frequency is increased above about 6 Hz. At frequencies above roughly 20 Hz, the flashing perception is lost completely for the dark-adapted viewing conditions experienced during nighttime flying. Along with frequency, the duty cycle of the flashing pattern influences how the signal is perceived. Duty cycles of more than 50% take on characteristics of steady-burning signals, while very small duty cycles require short, intense pulses of light, which are not optimally effective. The 8*f specification ensures that the minimum pulse-width of the flashed light is greater than 80 ms.

APPENDIX G

PSYCHOPHYSICAL LABORATORY TESTING OF A PROPOSED REMOTE AIRFIELD LIGHTING SYSTEM CONFIGURATION VARYING IN INTENSITY, COLOR, AND FLASH FREQUENCY

by

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16. Abstract

A consortium of universities sponsored by the FAA established criteria for lighting remote airstrips for nighttime operation by small general aircraft. A series of laboratory studies were conducted simulating the initial tasks required of pilots when flying to a remote site, namely, to locate the airstrip and determine the orientation of the runway. The goal of the laboratory studies was to establish the remote airstrip lighting system specifications in terms of signal light intensity, spectral power distribution (color) and temporal frequency (flash rate and duty cycle). These specifications would be based upon human performance at locating an airstrip and determining its orientation in a simulated laboratory environment. Limited electrical power was of central concern in framing these specifications.

The studies revealed that locating a simulated airstrip in the dark was governed by off-axis, rod detection and subsequently, determining its orientation was governed, to a measurable extent, by on-axis, foveal cones. These two retinal mechanisms demand slightly different lighting specifications for best performance but, when taken together and in consideration of limited electrical power, it was recommended that green LEDs be modulated between 2 and 4 Hz with an intensity of 5 (time-averaged) cd (e.g., 10 cd at a 50% duty cycle). However, these recommendations must be integrated into complete lighting system specifications to enable pilots to not only locate the airstrip and determine its orientation, but also to approach the runway, land, and stop the aircraft. Further, the entire lighting system specifications must be flight and field tested before they can be responsibly promulgated.

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ABSTRACT

A consortium of universities sponsored by the FAA established criteria for lighting remote airstrips for nighttime operation by small general aircraft. A series of laboratory studies were conducted simulating the initial tasks required of pilots when flying to a remote site, namely, to locate the airstrip and determine the orientation of the runway. The goal of the laboratory studies was to establish the remote airstrip lighting system specifications in terms of signal light intensity, spectral power distribution (color) and temporal frequency (flash rate and duty cycle). These specifications would be based upon human performance at locating an airstrip and determining its orientation in a simulated laboratory environment. Limited electrical power was of central concern in framing these specifications.

The studies revealed that locating a simulated airstrip in the dark was governed by off-axis rod detection, and subsequently determining its orientation was governed, to a measurable extent, by on-axis foveal cones. These two retinal mechanisms demand slightly different lighting specifications for best performance but, when taken together and in consideration of limited electrical power, it was recommended that green LEDs be modulated between 2 and 4 Hz with an intensity of 5 (time-averaged) cd (e.g., 10 cd at a 50% duty cycle). However, these recommendations must be integrated into complete lighting system specifications to enable pilots to not only locate the airstrip and determine its orientation, but also to approach the runway, land and stop the aircraft. Further, the entire lighting system specifications must be flight and field tested before they can be responsibly promulgated.

1. INTRODUCTION

The goal of this project was to establish specifications for remote airfield lighting. Limited electric power was a primary consideration for these specifications, so it was imperative that the recommendations be based upon the maximum efficacy of the lighting system for this unique application. Within specified constraints (below), the efficacy for remote airfield lighting systems was defined here as the maximum visibility of the airport lighting per electrical watt.[1]

A consortium of universities[2] identified the set of sequential tasks performed by pilots attempting to locate a remote airfield and then complete a safe landing:

1. Locate airfield
2. Determine the orientation of the airstrip
3. Orient to the airstrip and approach
4. Land
5. Stop

This report discusses the psychophysical laboratory experiments designed to lay the foundation for the specifications of the first two visual tasks performed by the pilots (locate airport and determine airstrip orientation). Three physical parameters associated with the lighting system were treated as independent variables throughout these experiments: intensity, color, and flash frequency.

Several simplifying assumptions about the remote airfield lighting configuration were decided upon before the experiments began, following discussions among the university consortium members. Again, these decisions were largely based upon minimizing electric power requirements for operating the remote airfield lights. For this reason, the consortium decided that only corner lights for the simulated airstrip would be used in the experiments. It was assumed before testing that one or two lights would be too few for pilots to unambiguously perform the third of the sequential landing tasks, that is to orient to the airstrip and approach. It was also assumed that passive, retro-reflectors could be used along the edges of the airstrip together with forward lighting on the aircraft to aid pilots in the third, fourth, and even fifth sequential landing tasks numbered above; these tasks have yet to be studied experimentally.

Given the expense and the lack of ability to control the independent variables precisely when flying, apparatus for a laboratory study, not a field study, was designed and built. In addition to the decision to use just corner lights, several other decisions not necessarily directly relevant to the laboratory study were made by the consortium. Together these were:

- Pilots would sequentially perform the five basic tasks numbered above.

- Corner lights on the airstrip would be used in the experiments.

[1] The traditional definition of luminous efficacy, lumens per watt, is not applicable for reasons outlined in this report.

- [2] Embry-Riddle Aeronautical University, University of North Dakota - Aerospace, University of Alaska and Rensselaer Polytechnic Institute. Blue and red lights would not be used in the final recommendations because of possible confusion with emergency vehicles and hazard markings on the ground.

- Flash frequencies below 1.5 Hz would not be used in the final recommendations because of possible confusion with emergency vehicles on the ground.
- To enable pilots to maintain visual contact with the airstrip while performing the third task numbered above, the intensity distribution of the corner lights must be such that pilots would be able to see the lights when flying directly over the airstrip.
- To set an electric power budget for the airstrip lighting, it was assumed there would be no more than three landing events per week, but for any given night the system should be able to power two landing events for two hours each.
- All aircraft would be equipped with forward landing lighting to illuminate the airstrip and retro-reflectors demarcating the airstrip edges.
- Pilots must be able to visually locate the airport from a radius of 5 miles.
- Pilots would have been to the airport before in the daytime.
- Response times as well as confidence ratings would be used as dependent variables in the experiment.

In addition, the consortium agreed that the final recommendations should not require sophisticated training to operate and maintain the remote airfield lighting system.

2. METHODS

Apparatus

The experimental apparatus was designed to simulate a nighttime visual scene while flying an airplane from south to north on approach to a remote airport. It consisted of two basic parts: the simulated "ground scene" and the simulated "cockpit."

The simulated "ground scene" was a large, 8 foot (2.4 m) diameter, circular board flanked by two smaller circular boards on opposite sides; all three boards were constructed from plywood and painted matte black (Figure 1). A large number of irregularly distributed end-emitting fiber-optic terminals were inserted into the center board. When illuminated, these fiber-optic terminals simulated ground lights from houses and streets in a small, rural area and produced an illumination of 0.006 lx at the subject's eyes when seated in the simulated "cockpit". The fiber-optic light source was a single 6-Volt halogen lamp.

The two flanking circular plywood boards, both 3 feet (0.91 m) in diameter, held several lighting systems used, in turn, to simulate ground lights of a remote airstrip. For the purposes of this study, it was assumed that the distances between the four corners of the simulated airstrip would be scaled to simulate a remote airstrip 60 feet (18 m) by 2500 feet (762 m). Both flanking boards housed four different simulated remote airstrips, each demarcated by corner lights. Two simulated airstrips on a given board were scaled as if they were being seen from the simulated "cockpit" at 2 miles (3.2 km), one airstrip running north-south and one east-west.

Two more simulated airstrips, again, one airstrip running north-south and one east-west, were scaled as if they were being seen at 5 miles (8 km). Only the five-mile simulation was employed in this study. Each of the simulated airstrip lights used in the experiment were generated using pairs of light emitting diodes (LEDs) housed in hollow spheres 4 inches (105 mm) in diameter, the inside of which was painted with a high reflectance (ρ = 0.885) white paint (Rustoleum, flat white, 1990). Eight spheres were mounted under both of the flanking plywood board; the LEDs within one sphere generated the light for the lights at one end of a simulated airstrip. The spectral power distributions (SPDs) of the light emitted from the pairs of LEDs within the spheres are shown in Figure 2. Light generated for the simulated airstrip lights was emitted through precise, laser-cut apertures in otherwise opaque metal foils. For most experiments, the apertures were circular holes 0.5 mm in diameter. Every aperture provided a well-defined, radially-symmetric Lambertian spatial distribution of light. The intensity, SPD (i.e., color) and temporal frequency of each lighted aperture could be varied through a computer interface. The light-emitting apertures from one sphere comprising the two corner lights at the end of the simulated airstrip were separated by 6.5 mm. In one experiment, the laser-cut apertures were 0.5 mm by 6.5 mm linear holes demarcating the width of the simulated airstrip. As with the circular holes, light from these apertures were well-characterized by a linear Lambertian spatial distribution that could be varied in intensity, color, and temporal frequency.

A control circuit board and motor located under the "ground scene" responded to commands from a computer program in order to reposition the board, creating different simulated "approach angles" of the "ground scene" (20^o and 10^o, Figure 1b). Except for preliminary tests, the board was always set at the 20^o "approach angle."

During the experiment, the left side of the "ground scene" was identified as the east airport and the right side section as the west airport. The two orthogonal airstrips on each flanking board (five-mile simulation) were identified as running east-west and north-south.

Subjects seated inside the simulated "cockpit," comprised of a personal computer, monitor, and response-mouse as well as a chair secured to a low platform (Figure 1a and 1b), were positioned approximately 10 feet (3m) from the center of the simulated "ground scene" during the experiment. From the "cockpit," the "ground scene" with flanking airstrips was 46^o wide and the airstrips were about 20^o, left or right from its center; the longer dimension of each simulated airstrip was about 5^o; the shorter dimension was about 7 feet. On the "cockpit" monitor, a LabVIEW™ program presented a simplified aircraft cockpit instrument display. Subjects were required to rotate a dial on the display using the response-mouse and then to click a "start" button to initiate each trial. The same monitor presented text boxes and response buttons after every trial for subjects to answer queries. The computer monitor had a maximum luminance of 1 cd/m^2 and a minimum luminance of 0.01 cd/m^2 in an attempt to simulate realistic light levels in a cockpit and to maintain a dark environment (Task et al., 2005; Howard et al., 2001).

General Procedures

The experiments were conducted in a dark, windowless laboratory painted matte black; the simulated "ground scene" and "cockpit" instrument lights were the only sources of lighting, in addition to the test conditions, during the experimental trials. To begin a session, a subject was seated in the simulated "cockpit" and after at least 5 minutes of dark adaptation, she or he was asked to perform several practice trials of simulated aircraft instrument operations. The simulated operations were the same as those performed during the experiments and were comprised of a short sequence of simple visual tasks following a start signal presented on the computer monitor.

While a subject completed the simulated operations preceding a trial, the lights for one airstrip were energized for a given experimental condition, that is, for a specified flash frequency, intensity and color. The airstrip position (east or west) was randomly selected by the computer as were, depending upon the experiment, the levels of the independent variables (intensity, color, and flash frequency). After completing the simulated cockpit instrument operations, the subject looked at the "ground scene" and then clicked the response-mouse after she or he detected the location of the airstrip (east or west) *and* determined the orientation of the airstrip (east-west or north-south). The computer recorded the elapsed time from the onset of the trial until the click of the response-mouse. The subjects then answered three questions presented on the computer monitor:

- Is the location of the airport west or east?
- Is the orientation of the airport north-south or east-west?
- What is your confidence rating for this trial (1-5)?

3. RESULTS

Spectral effects

Two experiments were performed to determine the spectral sensitivity of observers when locating the airstrip and identifying its orientation. The goal was to determine for these simulated, sequential tasks the best wavelength for operating the airstrip corner lights. From those data, it would then be possible to specify the best color of the remote airstrip corner lights.

For Experiment 1a, subjects were always presented four corner lights at a constant flash frequency of 4.2 Hz (50% duty cycle), and the airstrip was always positioned at the 20^{o} approach angle with the simulated "ground scene" lights on. All five LED colors (red, amber, white, green, and blue) were used, each presented at five intensities, depending upon the color. Four subjects with normal visual acuity and color perception served as subjects, each being presented 300 trials (5 colors x 5 intensities x 12 replications) in three sessions of 35 minutes each. As in Experiment 1 a, in Experiment 1b three subjects from the first experiment were presented the four corner lights at 4.2 Hz (50% duty cycle) at the 20° approach angle with the "ground scene" lights on. Four colors (amber, white, green, and blue) were used, each at five intensities. (The red LEDs could not generate sufficiently high scotopic intensity and, therefore, the red lights were not used in this experiment.) Subjects each were presented 240 trials (5 intensities x 4 colors x 12 replications) in three sessions.

Figure 3 shows the average total response times required to locate the airstrip (east or west) and determine its orientation (east-west or north-south). Response times for five colors, each at five intensities, are plotted as a function of photopic luminous intensity together with the best fitting equation of the form: where y = response times for a given color, x = $\log_{10}$ photopic intensity + 0.3, and a and e are both free parameters. Best-fitting functions using Equation 1 for each of the five curves yielded r2 values of 0.95 or greater.

Figure 4 shows the average confidence ratings provided by the subjects for the same conditions, also plotted as a function of photopic intensity. These two figures clearly show that the conventional and ubiquitous photopic luminous efficiency function, Vë, is not a suitable rectifying variable for characterizing the SPDs of the airstrip lights in this experiment. Functionally then, the foveal cones cannot be used solely to describe the spectral sensitivity of observers while performing this task, and therefore conventional photometry based upon Vë is not a suitable measure of visual effectiveness for the lights in this experiment.

During a given trial, practiced subjects were observed to look straight ahead at the start of a trial and then to look either left or right before responding with a click of the response-mouse. Based upon these observations of subject head positions during each trial, it was inferred that responses by two retinal mechanisms contributed sequentially to the total time taken by a subject to complete a given trial. Subjects first located the simulated airstrip with their peripheral vision, no doubt dominated by rods at the low light levels from the simulated "ground lights," and then determined the airstrip orientation with their fovea, which, in the center, contains only cones. Indeed, under some of the low-intensity conditions, subjects spontaneously reported that they could detect the airstrip location with their peripheral retina, but when they turned their head to confirm its location, they could no longer see it.

Rea and colleagues (Rea, et al. 2004) have developed a model of mesopic vision that mathematically describes the relative contributions of the photopic and scotopic luminous efficiency functions (Vë and V'ë , respectively) to reaction times to flashed targets presented to the peripheral retina at different light levels. This model is based upon a single detection task, but was used here to see if it could empirically describe the sequential tasks (locate the airport and then determine its orientation) performed by subjects in this experiment. The parameter X is used in the model to describe the contribution of Vë, relative to V'ë, needed to rectify different SPDs into a single stimulus variable for predicting the visual response. A value of X = 1 indicates that visual performance for different SPDs is determined solely by Vë whereas a value of X = 0 indicates that spectral sensitivity is governed by V'ë. Values of X less than 1.0 and greater than 0 indicate that both cones and rods contribute to visual performance. An iterative procedure was used to find the best-fitting value of X to rectify the response functions in Figure 3. Figure 5 shows the results of that procedure, indicating that performance at this sequential task can be best modeled with a value of X = 0.12 with an overall r^2 value of 0.95. Figure 6 shows the results of the same procedure when applied to the confidence ratings. For these data, however, the best-modeled value is X = 0.22. This suggests that subjective levels of confidence do not coincide with performance based upon response time, but the modeling does indicate that cones as well as rods affect both of the measured responses. A second experiment (1b) was conducted to determine if, indeed, performance was determined sequentially by two retinal mechanisms. As described above, the experimental conditions were like those in Experiment 1a except that subjects were instructed to simply detect the location of the airport (east or west) without trying to identify its orientation. The modeled mesopic value of X =0.12 for predicting performance in the first experiment was a poorer fit to the data in this second experiment (r^2 = 0.85) than a model based upon a completely scotopic response, that is, a value of X = 0 (r^2 = 0.97). A completely scotopic response (X = 0) was also best at representing the stimuli for the confidence ratings.

Together, the results of these two experiments suggest that detection of the airstrip was determined by the rods in peripheral vision adapted to scotopic light levels, but identification of the airstrip orientation was governed, at least in part, by foveal cones. In the second experiment where subjects only had to detect the location of the airport, both response times and confidence ratings were governed strictly by rods. It appears, however, that cones influenced the response times and the confidence ratings when determining the orientation of the airstrip. Moreover, despite the relatively small contribution of the photopic luminous efficiency function ($V\lambda$) to the total response times from the model (X = 0.12), the subjective ratings were much more heavily influenced by foveal cones (X = 0.22). This difference might be expected because conscious visual perception is determined largely by the visual sensory cortex, which is much more devoted to information presented to the fovea than to information presented to the periphery (Sekuler and Blake, 1990). In other words, objective performance is probably not completely correlated with subjective response when the task includes both off-axis detection and on-axis (foveal) identification.

Temporal effects

Several experiments were performed to assess the sensitivity of observers to temporal variations in the four corner lights when trying to locate the airstrip and identify its orientation. The goal was to determine for these simulated, sequential tasks the best temporal frequency for operating the corner lights. From those data, it would then be possible to specify the best frequency of the flashing remote airstrip corner lights.

To determine if the amount of energy in the test flash was the stimulus for detection several intensity profiles, all with the same energy but each differing in maximum pulse intensity, were used as stimuli in the simulated, sequential task.

For Experiment 2a, different equal-energy temporal profiles were used to determine the frequencies for which Bloch's law of complete temporal summation would apply under these experimental conditions (Baumgardt, 1972). Figure 7 shows the five different equal-energy stimulus profiles presented to subjects; each of the five profiles was presented to subjects at 4.2 Hz. Six subjects with normal visual acuity and color perception were, in turn, always presented the four corner lights of a constant color (green, Figure 2), and the airstrip was always positioned at the 20^{o} approach angle with the simulated "ground scene" lights on. For Experiment 2b, the same six subjects were presented four green corner lights at the 20° approach angle with the simulated "ground scene" lights on. Three temporal signatures, each presented at five intensities, were used: (i) a steady, unmodulated light, (ii) a regular periodic flash frequency of 4.2 Hz, and (iii) a "dot-dash-dot", temporal Morse code letter "R", pattern with a fundamental frequency of 4.2 Hz. Both of these experiments were performed as one interspersed set of trials, each subject being presented 160 trials (5 equal energy stimuli x 8 replications PLUS 3 patterns (i, ii, and iii) x 5 intensities x 8 replications) in two sessions of approximately 30 minutes each.

The results showed that for the same equal-energy stimulus, the pulse height did not affect detection until a short pulse duration of 40 ms (pulse height of 40 cd) was used. For this target, despite the high intensity, the pulse length was too short for the visual system to completely integrate the pulse energy. Confidence ratings mirrored the performance based upon time to locate the airstrip and identify its direction. The temporal frequency of the 40 cd pulse was 12.5 Hz; therefore, it was assumed that for flash frequencies slower than about 6 Hz, the visual system is able to integrate the total energy within a pulse.

The response times and confidence ratings for the three temporal profiles (i, ii, iii) were then compared to the results for the equal-energy profiles to test this assumption. If performance and confidence ratings simply followed Bloch's Law, for a specific neural integration time, then any number of complex temporal signatures could be used with equal effectiveness. The response times are shown in Figure 8 together with the average response time for the different equal energy pulses below 6 Hz. As can be seen from this figure, the unmodulated light is much harder to find than both flashing stimuli. It is also clear from this figure that that for time-averaged intensities (i.e., equal energy) above about 2 cd, there is no difference between the regularly modulated 4.2 Hz and the more complicated Morse code "R" flashing signal. Moreover, all of the equal energy stimuli with a fundamental frequency below 6 Hz were equivalent to the interpolated values from both periodic flash stimuli. In general, the curves relating performance to flash energy for the two stimulus patterns (4.2 Hz and the Morse code "R") seemed to reach asymptotic values above about 2 (time-averaged) cd. Figure 9 shows that the confidence ratings mirrored the performance times to some extent, although there was less apparent asymptotic behavior in the rated confidence levels. Moreover, there is a slightly higher confidence rating for the Morse code pattern than for the periodic 4.2 Hz signal. Following the deduction from the spectral effects experiments, this seems to be due to the relative dominance of the fovea for determining subjective confidence ratings. The fovea is more sensitive to low frequency patterns than the peripheral retina (Kelly, 1972). The Morse code signal has, in fact, more energy at these lower temporal frequencies. Thus, the difference in the integration characteristics between the fovea and the peripheral retina differently affect response times dominated by peripheral detection than confidence ratings influenced by foveal cones. Here again, then, there is evidence that performance and ratings for this two-part task is determined by different retinal mechanisms.

Although complex temporal patterns including low spatial frequencies, like the Morse code "R", may have slight advantage for foveal tasks, this advantage was not evident in performance of the two-part task (Figure 8). To extend these findings and determine how different temporal frequencies affected performance, a variety of regular temporally-modulated patterns from 1 Hz to 12.5 Hz (50% duty cycle) were studied. Three subjects with normal visual acuity and color perception were randomly presented the four corner lights varying in color (red, amber, green and blue) and temporal frequency (1, 2, 4.2, 6.2 and 12.5 Hz) and intensity while the airstrip was positioned at the 20^{o} approach angle with the simulated "ground scene" lights on. Each subject was presented 400 trials (4 colors x 5 frequencies x 5 intensities x 4 replications) in five sessions of approximately 30 minutes each.

Figure 10 shows the results of this study whereby the response times to perform the simulated, sequential tasks (locate the airstrip and identify its orientation) were plotted as a function of the mesopic intensity (X = 0.12) for the different temporal frequencies. From this figure, it is clear that performance is poorer at the highest temporal frequency, again confirming the failure of Bloch's Law at high temporal frequencies. It also appears that performance at the slowest frequency is slightly worse than that at 2 Hz, 4.2 Hz, and at 6.2 Hz, suggesting a broad optimum performance at temporal frequencies between 2 and Hz (Rea, et al. 2004). Indeed the literature suggests that for these low intensities, performance is at a plateau between about 2 and 5 Hz (Kelly, 1972).

Spatial effects

A final experiment was performed to determine how the spatial characteristics of the runway lights might affect performance. Three conditions were used: the four corner lights as employed in all of the previous experiments, two corner lights, one at each end, and two linear lights along the shorter dimension of the simulated airstrip.

For the same total intensity, it takes longer to see the four corner lights than two corner lights. If the intensities of the two corner lights at each end of the simulated airstrip simply added together to determine performance, then the intensities of the four corner lights would follow Ricco's law and simply have to be reduced by a factor of 0.5 to produce the same level of performance as the two corner lights. If, however, Piper's square root law of partial spatial summation applies (Baumgardt, 1972), the intensities of the additional lights at both ends of the simulated airstrip would have to be discounted by the square root of 0.5, that is, by a factor of 0.71, to produce the same level of performance. As shown in Figure 11, Piper's square root law of partial spatial summation appears to apply to these data, as well as to the linear lights at both ends of the simulated airstrip. These findings indicate that the lights at the end of the simulated airstrip were not seen as one light but as two distinct points and as a line in the experiment. In other words, Ricco's law of spatial summation was violated in this experiment because the pairs of lights were too small to be seen by separate receptive fields in the peripheral retina. Since Piper's square root law of partial spatial summation applies, the two signal lights at the end of the simulated airstrip must not have been viewed by the fovea. These findings further support the conclusion that this experiment was performed by subjects as two sequential tasks, each governed by two different retinal mechanisms. Detection of the airstrip location (east or west) was governed by rods in the peripheral retina, whereas determination of the orientation of the airstrip (east-west or north-south) was performed using small receptive fields in the fovea.

Intensity effects

Figures 3 through 11 (excluding Figure 7) all show that as signal light intensity increases, performance (shorter response times) and confidence (higher ratings) improve. Given the assumed constraints for electric power for signal lights at remote airstrips, a 5 mile (8 km) minimum viewing-distance criterion for pilots was imposed prior to experimental testing. In other words, the airstrip signal lights must be reliably seen at that specified distance. Two converging lines of evidence were used to develop the recommended intensity value.

First, the frequency of missed trials was examined to determine if there was a clear threshold for reliable performance. Figure 12 shows the error rates for the green and amber signal lights in Experiments 1a and 1b. (Error rates are the percentages of trials where the signal lights were completely missed over the course of an experiment.) Experiment 1a required subjects to both locate the airport and determine its orientation, whereas Experiment 1b only required subjects to locate the airport. The signal lights in both experiments were always flashed at 4.2 Hz (50% duty cycle). Clearly, the error rates were higher for the amber than for the green signal lights at matched photopic intensities. Indeed, at or above 10 cd there were few if any missed green signal lights, but approximately 1 in 5 amber signal lights were missed at this intensity.

Second, although visual performance and confidence ratings were roughly proportional to a change in the ratio of light intensity, the electrical power necessary to energize the light is directly proportional to intensity. Thus, the power and the cost to operate the signal lights will grow faster with intensity than the visual effectiveness of those lights. When confidence ratings are plotted as a function of intensity (and thus electric power) on a linear scale, there is a distinct "knee" in all of the response functions (not shown). This "knee" occurs at about 10 cd for the green signal light modulated at 4.2 Hz (50% duty cycle), in close agreement with the near-zero error rate associated with that signal light. Thus, with a view toward minimizing electrical power, it would be hard to justify intensities greater than about 10 cd.

Table 1a shows the unified luminous efficacies (Rea, et al. 2004) of the different LED sources at different values of X. Recognizing then that electric power is assumed limited for this application, it is important that the most efficacious source be used in this application. Further, it was assumed by the university consortium that both red and blue signal lights could not be used due to their possible confusion with emergency vehicles on the ground and other red hazard lights. Under these constraints, the green LED signal light would be chosen. Table 1b shows the unified intensities for the different LED sources at different values of X based on a 10 cd photopic (X = 1) intensity (Rea, et al. 2004). Given the power requirements in addition to the very low error rates, the superior response times and confidence ratings at the simulated five-mile distance, an intensity of 5 time-averaged cd was chosen as the minimum recommended intensity for the green LED signal light (Rea, et al. 2004).

4. DISCUSSION

Based upon these studies, the following conclusions can be drawn and recommendations made regarding the spectral, temporal, and intensity characteristics of remote airstrip lights.

The experiment simulated the first two tasks a pilot would perform when flying to a remote airfield to land, namely locate the airstrip and determine its orientation. It is clear from the results that two retinal mechanisms were sequentially used by subjects to perform the simulation. Subjects first had to locate the remote airfield using rods in peripheral vision because, under the experimental conditions, the retina was adapted to very low light levels. Quickly after subjects located the airport in the periphery, they turned their heads toward the located airstrip and, given enough light, determined its orientation using the fovea.

Two experiments were performed to determine the spectral sensitivity of observers when locating the airstrip and identifying its orientation. Based upon the mesopic modeling of response times to locate airstrip lights of different colors in the two experiments (Rea, et al.. 2004), it was clear that this initial task was dominated by the spectral sensitivity of rods. The subsequent visual task, determining the orientation of the airstrip, was strongly influenced by foveal cones, although it is not clear from these two experiments that cones exclusively contributed to performance. It is clear, however, that the response times needed to complete the two-part visual task required inclusion of the photopic luminous efficiency function, $V_λ$, to model the spectral sensitivity of observers performing the task. That is, both a rod and a cone response were needed to rectify the different colored lights into a single light stimulus parameter (X = 0.12). $V_λ$ was also required to model the subjective confidence ratings to the different colored lights (X = 0.22). Further, it was necessary to utilize Piper's square root law of spatial summation to explain the differences in the performance times for the four corner lights relative to the two corner lights and the linear line at the end of the simulated airstrip. The small separation between the two end lights could apparently be resolved by the subject's fovea when determining the orientation of the airstrip, thus reducing the effectiveness of four corner lights relative to just two corner lights at either end of the simulated airstrip. In summation, the results of these experiments strongly suggest that locating the airstrip is controlled by rods and that determination of the airstrip orientation is supported by cones in the fovea.

At low light levels like those experienced by subjects here, there is a fairly flat plateau in sensitivity to regular periodic flash frequencies between approximately 2 Hz and 4 Hz and this finding is consistent with the literature (Kelly, 1972). It is not completely clear from these data, however, whether temporal modulation of the light was effective for both locating the airport and determining its orientation. Moreover, too few data were collected to determine whether response times and confidence ratings were affected differentially by the peripheral rod and foveal cone mechanisms, although there is an indication that this is true; this inference is again supported by the literature (Kelly, 1972). This means, in effect, that more complicated waveforms, like the Morse code "R," might have--for the same radiant energy--slightly more effectiveness for the cones than the same amount of energy in a regular periodic frequency. This was not the case for peripheral detection by the rods at time-averaged intensities equivalent to 2 cd and above. Nevertheless, it is clear that flashing lights between 2 Hz and 4 Hz are more effective than very low frequency, or steady lights (< 0.5 Hz) and very high frequency flash flashes (> 6 Hz) for both rods and cones at the intensities and colors considered acceptable for locating airstrips at 5 miles (8 km) or greater (that is, > 2 time-averaged cd).

Regarding intensity then, it is obviously true that the greater the intensity the further the light can be seen by a pilot and the higher will be the pilot's confidence ratings. In the context of these remote airfield lights, where electrical power is at a premium, it was decided before the experiments began that pilots must be able to see reliably the remote airfield lights from a 5 mile (8 km) distance. To establish an objective criterion for reliable detection, error rates (percentage of missed trials) was chosen for examination. At a five-mile simulated viewing distance, there were no missed trials for a 10 cd green (LED, $λ_{max}$ = 505 nm) light flashing at 4.2 Hz (50% duty cycle).

Based upon the constraints established before the experiment began, the validity of the results from the two-part simulated task required of subjects in the experiment, the following recommendations are proposed:

Green LED (λ_{max} = 505 nm)

2 Hz to 4 Hz flash frequency, on-period > 80 ms

5 (time –averaged) photopic cd (e. g., 10 cd at 50% duty cycle)

This recommendation is further supported by the fact that the luminous efficacy (photopic lumens per watt) of the green LEDs is, under the simulated conditions, over 10 times more efficacious than the amber LEDs. Thus, to generate 10 cd, the amber LEDs would require 1000% more power that the green LEDs would require. Combining higher-efficacy with better visual performance, both in terms of response times and errors, the green LEDs are, based upon these studies, the light source color of choice.

It should be reiterated, however, that higher intensities will always result in shorter response times and higher confidence ratings for these two tasks, so if electric power is deemed less important as a design constraint, higher intensities and/or different colors could practically be used for this application. Moreover, it should be recalled that this recommendation is based solely upon the simulation of two of the five tasks required by pilots to locate and safely land an aircraft at a remote site. This recommendation must therefore be flight tested and integrated into the entire landing process before final specifications are promulgated.

5. ACKNOWLEDGMENTS

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TABLES

Table 1a. Efficacy of the five LED colors for different levels of adaptation for peripheral vision as given by the value of X; scotopic conditions correspond to X = 0, photopic X = 1, mesopic conditions given by intermediate values of X. Photopic efficacy data are based upon Philips Lumileds Lighting Company datasheet for side-emitting, 1-watt Star Emitters, assuming a 75°C LED operating junction temperature (accessed at http://www.lumileds.com/pdfs/DS23.pdf).

	Efficacy (lm/W*)			
LED Color	**X = 0**	**X = 0.12**	**X = 0.22**	**X = 1**
Red	2	7	11	23
Amber	6	10	13	22
White	78	66	59	30
Green	148	118	100	30
Blue	154	118	95	11

Table 1b. Intensity values corresponding to those of Table 1a assuming a constant photopic (X=1) intensity of 10 cd.

	Intensity (cd*)			
LED Color	**X = 0**	**X = 0.12**	**X = 0.22**	**X = 1**
Red	1	3	5	10
Amber	3	5	6	10
White	26	22	19	10
Green	49	39	33	10
Blue	141	108	87	10

* Lumen and candela values are given according to the unified system of photometry (Rea, et al. 2004)

FIGURES

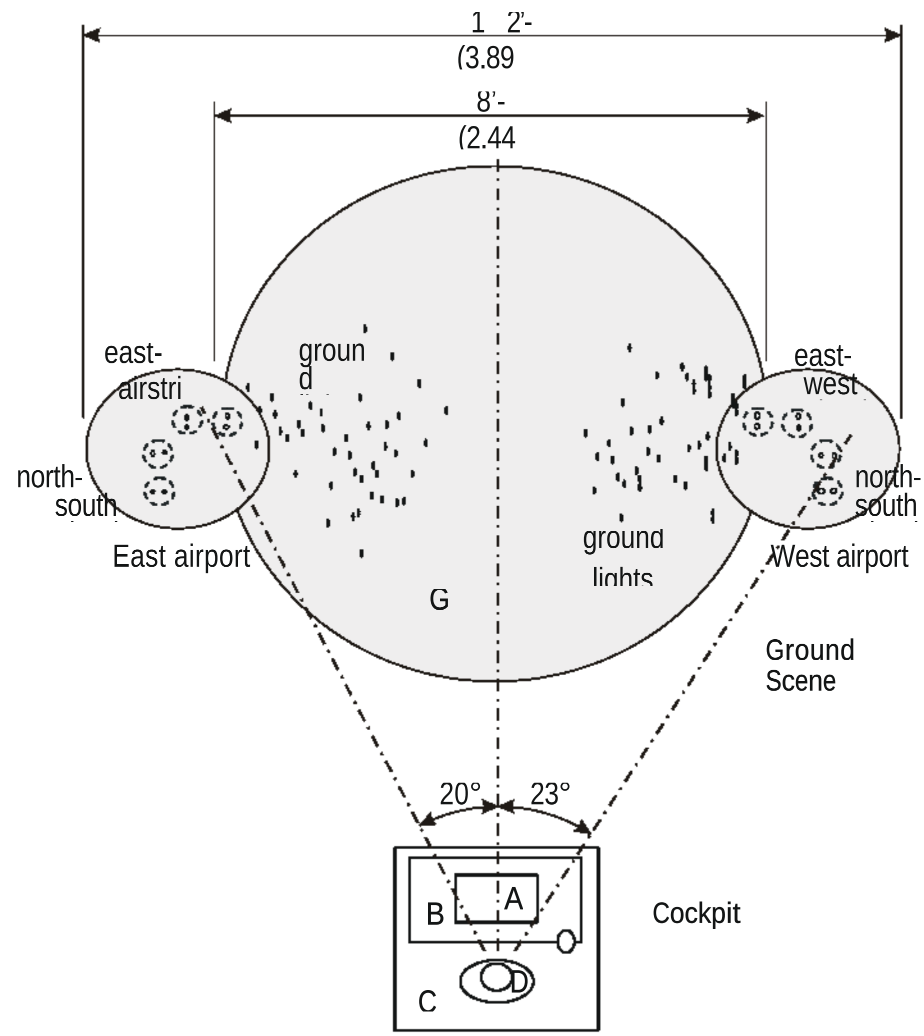


Figure 1a. Plan View of the Experimental Apparatus

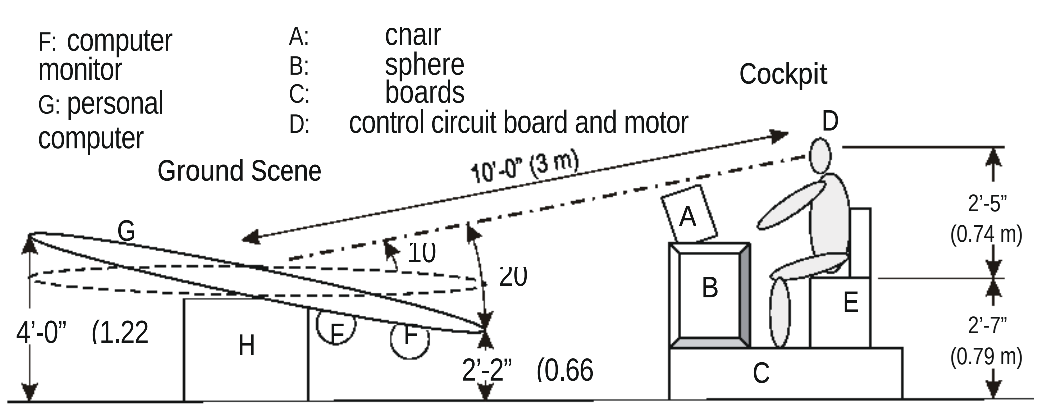


Figure 1b. Elevation View of the Experimental Apparatus

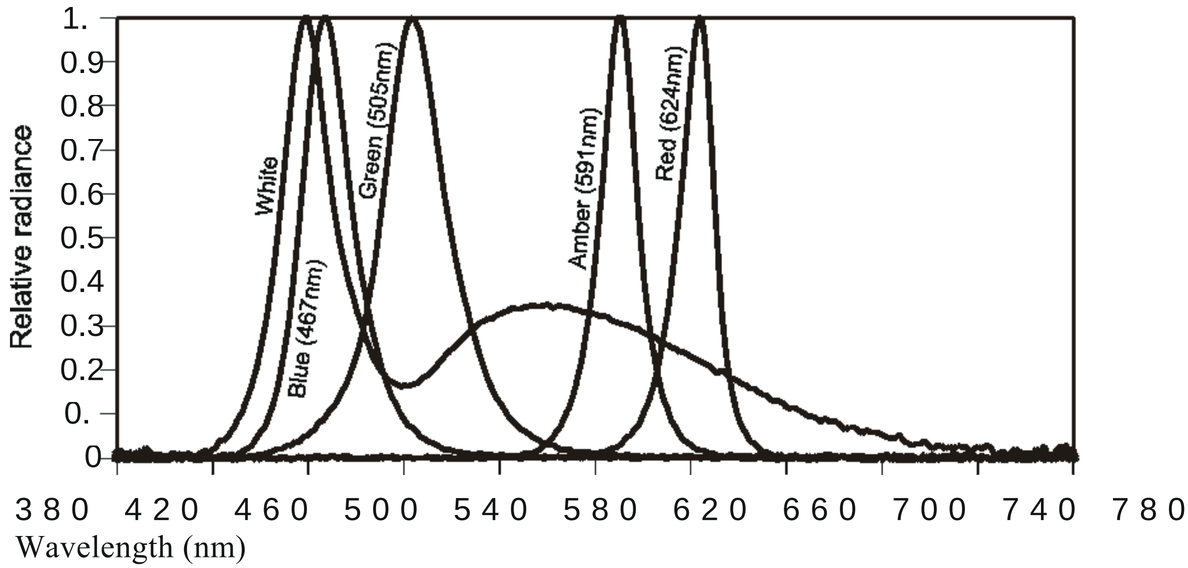


Figure 2. Spectral Power Distributions (SPDs) of light emitted from the simulated corner lights used in the experiment. Each curve is labeled by its nominal color and peak wavelength. All sources were 5 mm diameter LEDs with round, clear epoxy domes.

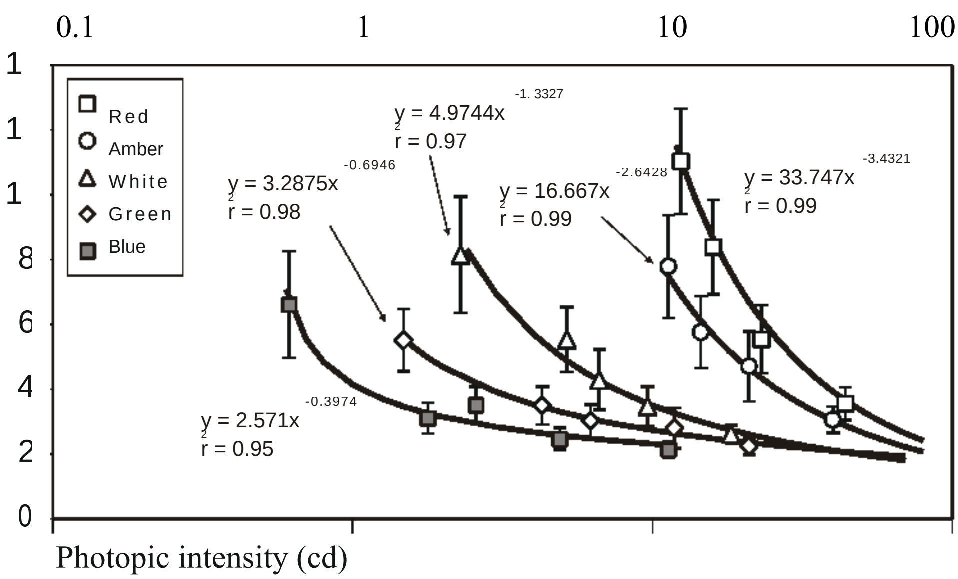


Figure 3 (Experiment 1a). Average response times required to both locate the airstrip (east or west) and determine its orientation (east-west or north-south) for the five light source colors plotted as a function of light source photopic intensity. The signal lights simulated the 4-corner airstrip signals and flashed in synchronicity at 4.2 Hz, 50% duty cycle. Error bars show the 95% confidence limits of the means.

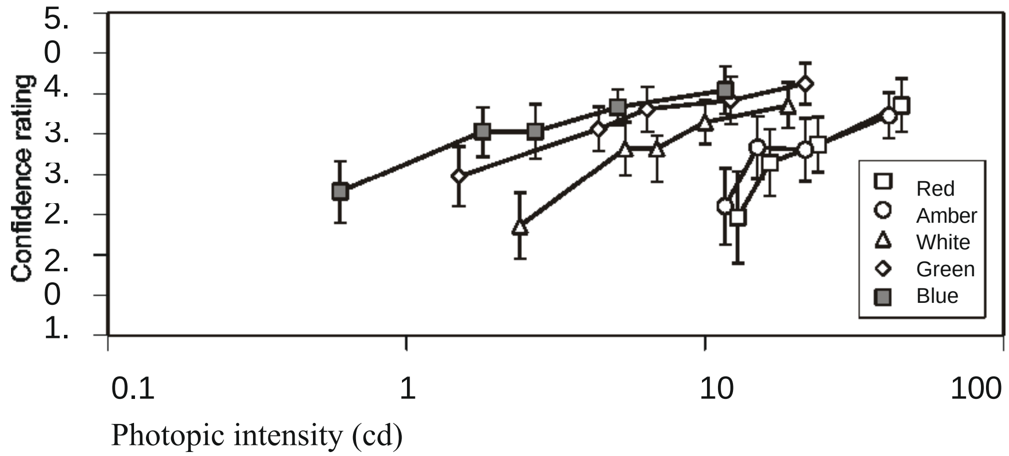


Figure 4 (Experiment 1a). Average confidence ratings provided by the subjects for locating and determining the airstrip orientation for the same conditions as those in Figure 3, plotted as a function of photopic intensity . Error bars show the 95% confidence limits of the means.

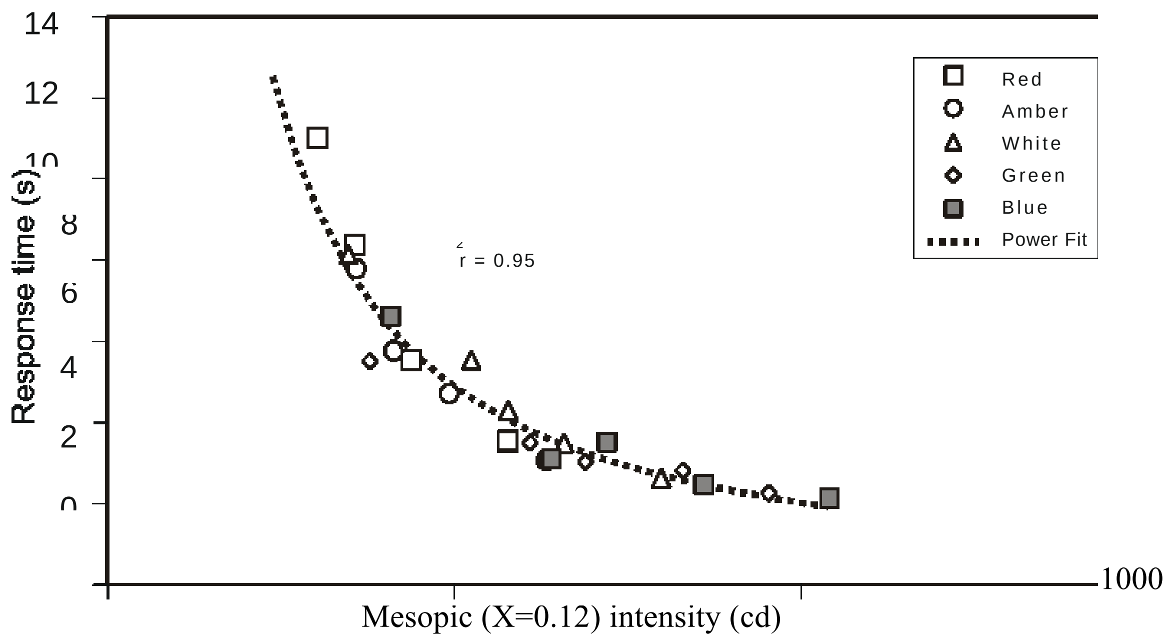


Figure 5 (Experiment 1a). Average response times required to both locate the airstrip and determine its orientation for the five light sources plotted as a function of mesopic intensity using an X value of 0.12 (Rea et al., 2004). The dotted line shows the curve fit for all the data with an r^2 value of 0.95.

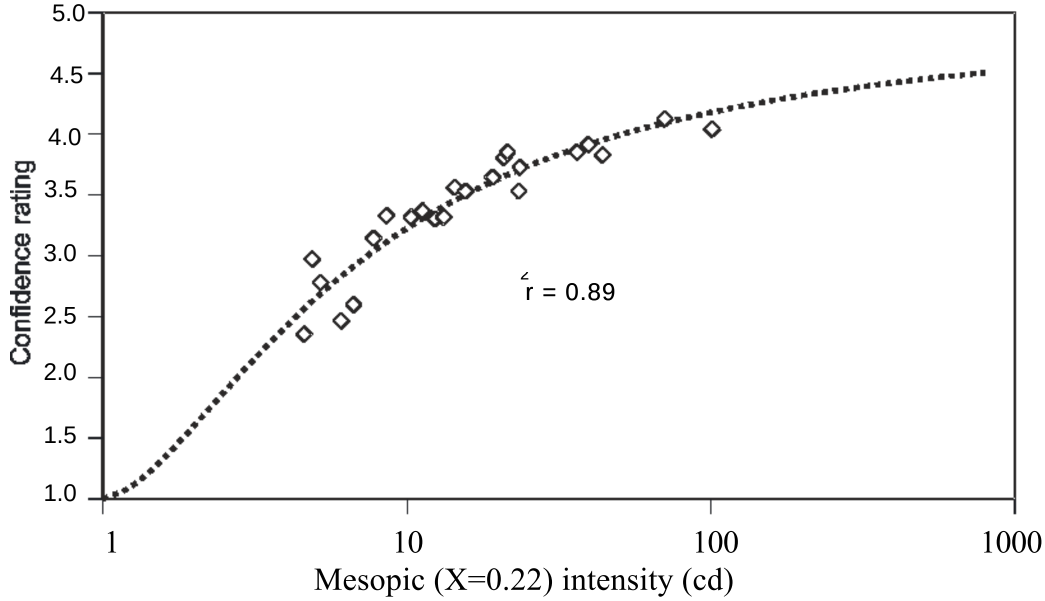


Figure 6 (Experiment 1a). Average confidence ratings provided by the subjects for locating and determining the airstrip orientation for the same conditions of those in Figure 3, plotted as a function of mesopic intensity using an X value of 0.22 (Rea et al., 2004). The line is a logistic curve fit to the data of the form f(x) = ((1-5)/(1~(x/a)^b))~5 where "1" is the minimum value (for confidence); "5" is the maximum confidence rating value; "x" is the corresponding intensity; and "a" and "b" are free parameters.

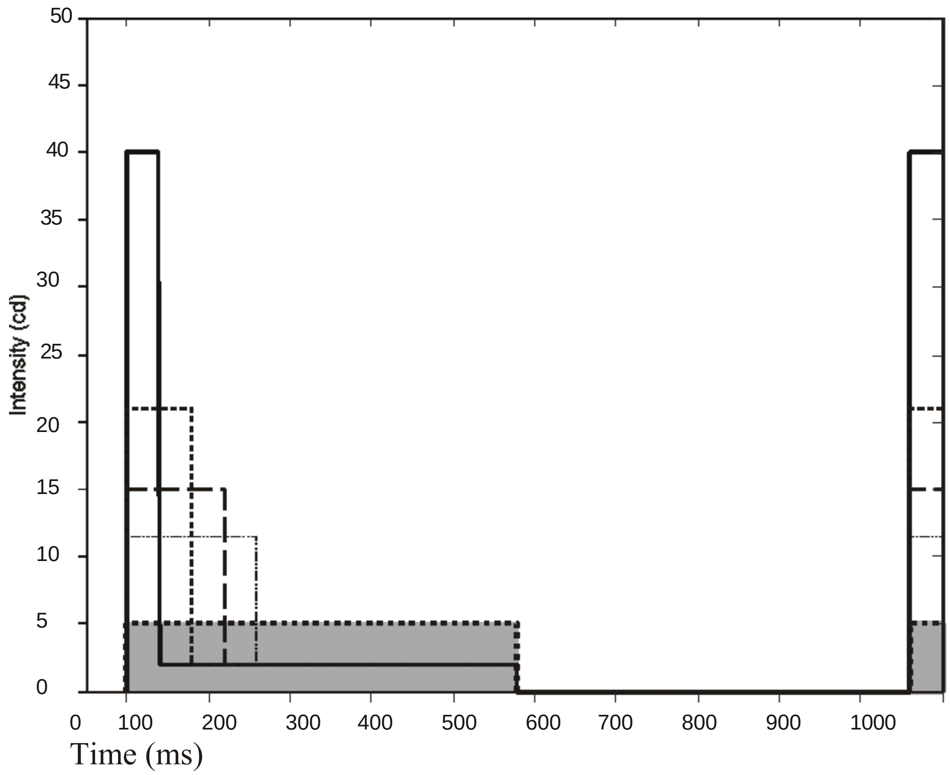


Figure 7 (Experiment 2a). The five different equal-energy stimulus profiles presented to subjects. The shaded region bounded by the dotted line depicts the square-wave profile with 50% duty cycle. The other four profiles consist of an initial rectangular peak followed by a rectangular tail of 2.5 cd extending to the half-period mark.

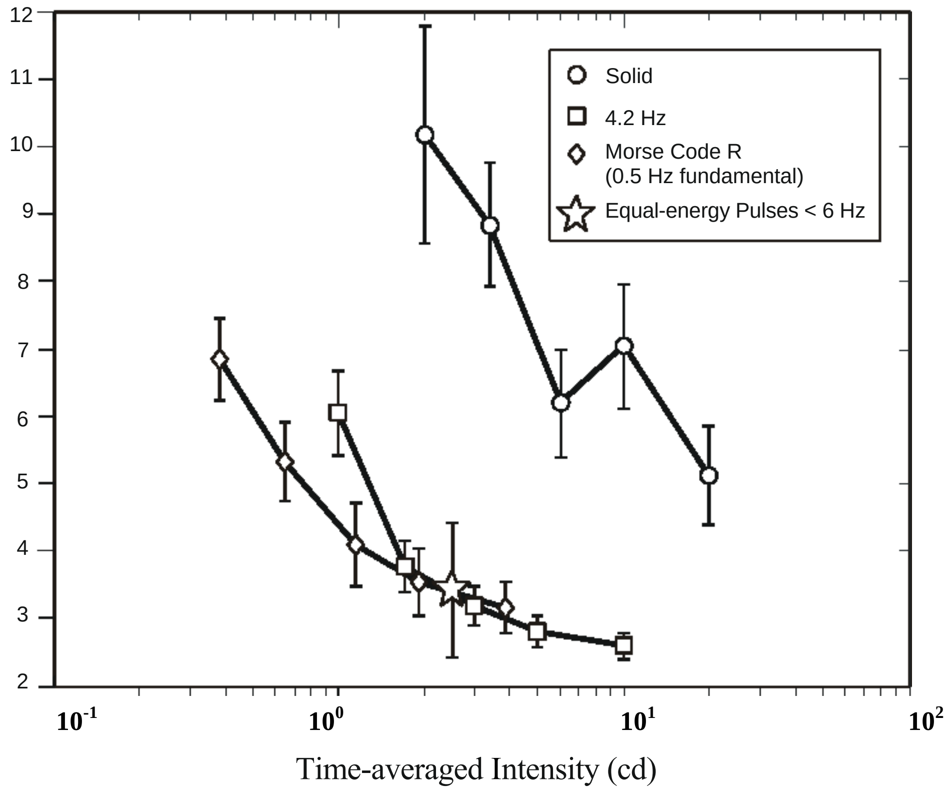


Figure 8 (Experiment 2b). Average response times required to both locate the airstrip and determine its orientation for three different flash patterns plotted against time-averaged photopic intensity: i) a steady, unmodulated light (circles), ii) a square-wave, 50% duty cycle flash profile at a frequency of 4.2 Hz (squares), iii) a “dot-dash-dot”, temporal Morse code letter “R”, pattern with a fundamental frequency of 0.5 Hz (diamonds). The average response times for the four equal-energy profiles with pulse-widths of 80 ms and longer (Experiment 2a) plot in a tight cluster indicated by the star symbol. Error bars show the 95% confidence limits of the means.

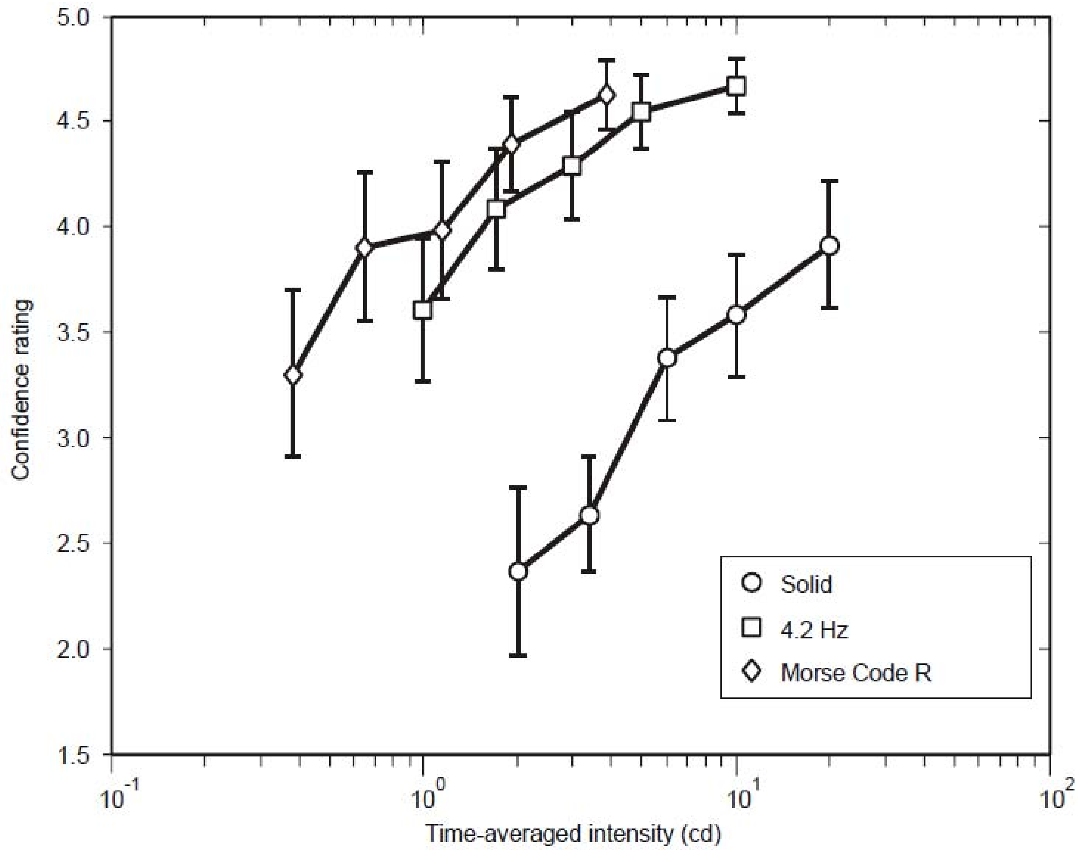


Figure 9 (Experiment 2b). Average confidence ratings provided by the subjects for locating and determining the airstrip orientation for the same conditions of those in Figure 8, plotted against time-averaged photopic intensity. Error bars show the 95% confidence limits of the means.

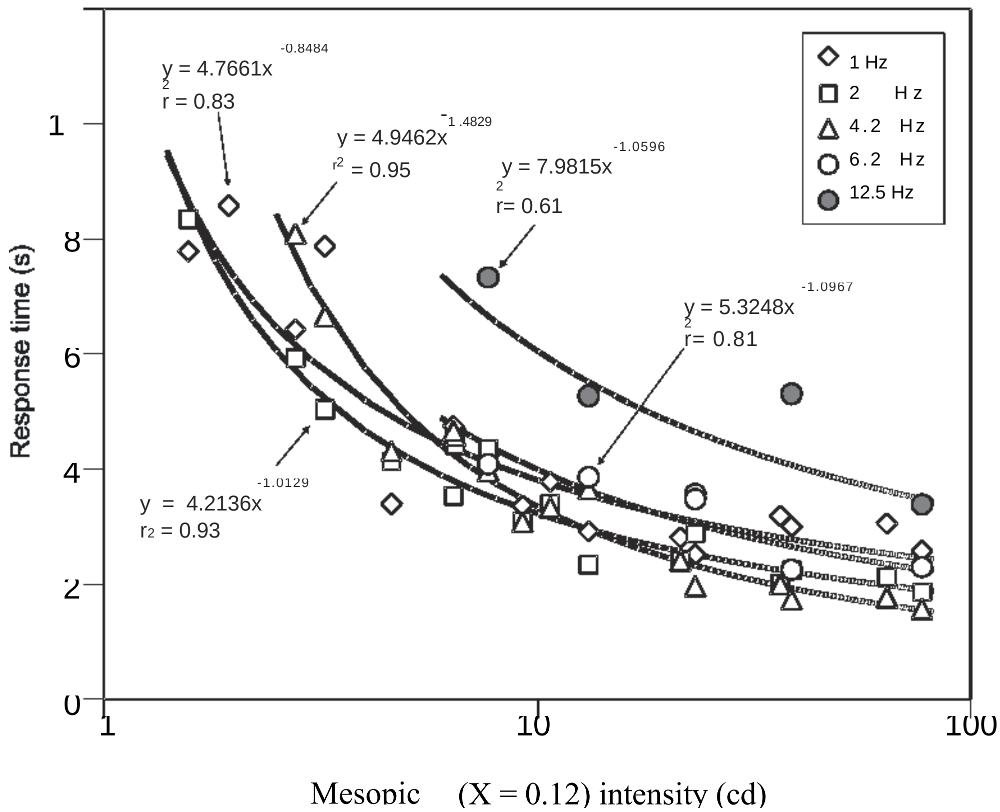
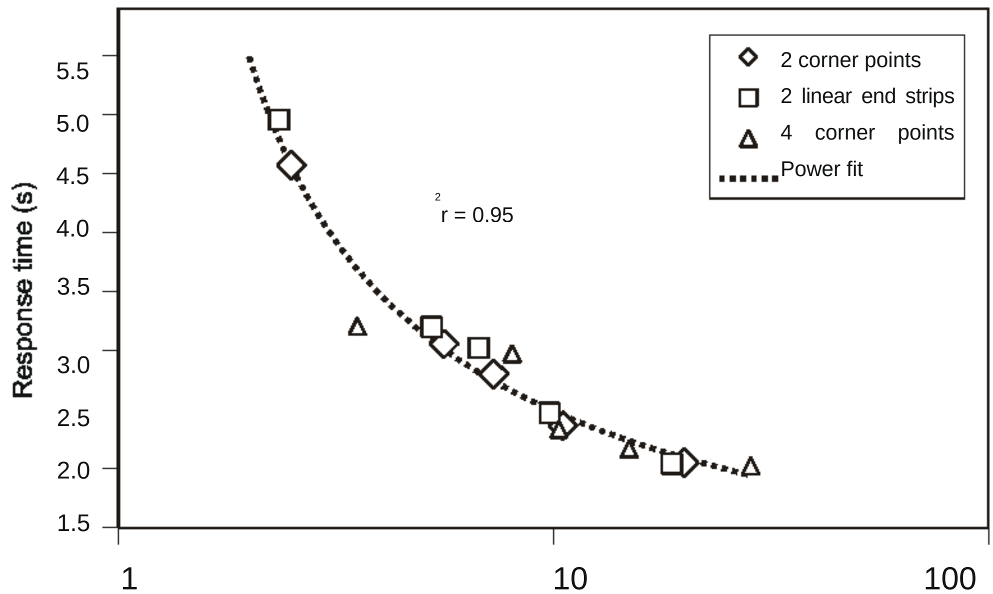


Figure 10 (Experiment 2c). Average response times required to both locate the airstrip and determine its orientation for five square-wave, 50% duty cycle flash patterns ranging in frequency from 1 to 12.5 Hz plotted as a function of mesopic intensity (X = 0.12). Power function curve fits are shown applied to each of the individual frequency data sets.



Photopic intensity (cd)

Figure 11 (Experiment 3). Average response times required to both locate the airstrip and determine its orientation for different spatial arrangements of green airstrip lights: 1) two corner lights, one at each end of the airstrip (diamonds), 2) two linear strips across each end of the airstrip (squares), and 3) four corner lights (triangles). Response times are plotted against photopic intensity after reducing the intensity of the linear and four-corner lights by a factor of 0.71 according to Piper's square-root law of partial spatial summation. The dotted-line shows the power curve fit for all the data with an r^2 value of 0.95.

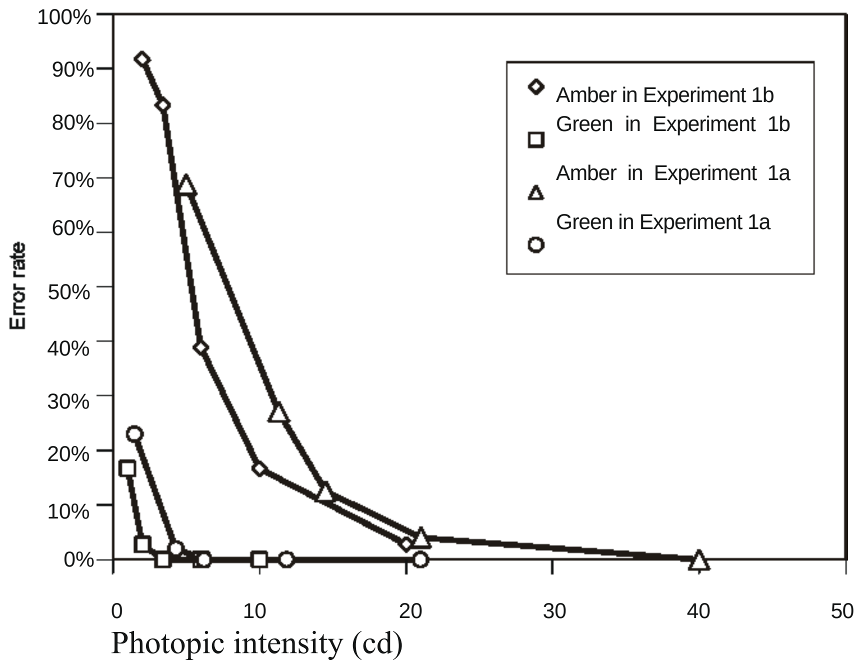


Figure 12 (Experiments 1a & 1b). Error rates for the green and amber signal lights plotted as a function of photopic intensity. Error rates are the percentages of trials over the course of the experiment where the signal lights were not seen within the allowed 20-second period of observation.