DOT/FAA/ND-98/4

Office of Communication,
Navigation, and Surveillance
Washington, DC 20591

Heliport Lighting – U.S. Park Police Demonstration

Scott A. Fontaine
Edwin D. McConkey

Science Applications International Corporation
Air Transportation Systems Operation
Arlington, Virginia 22202

November 1998
Final Report

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

U.S. Department of Transportation

Federal Aviation Administration

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

DTIC QUALITY INSPECTED 3

19991215 075

NOTICE

This document is disseminated under the sponsorship of the United States Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturer's names appear in this document solely because they are considered essential to the object of this report.

U.S. Department
of Transportation
**Federal Aviation
Administration**

800 Independence Ave., S.W.
Washington, D.C. 20591

NOV 20 1998

Dear Colleague:

This report is one of several documenting FAA/Industry research and development efforts on heliport lighting. Reports of interest include the following:

FAA/ND-98-1, Heliport Lighting - Technology Research

FAA/ND-98-2, Heliport Lighting - Configuration Research

FAA/ND-98-4, Heliport Lighting – U.S. Park Police Demonstration

FAA/ND-97/20, Evaluation of a Heliport Lighting Design During Operation
Heli-STAR

These reports document the initial phase of an FAA/Industry effort to develop a cost-effective heliport lighting system for Global Positioning System (GPS) helicopter approaches. They speak of new technologies that could be of use as part of a heliport lighting system as well as military lighting systems that could be useful if optimized for civil heliport applications. The reports also document previous research that has attempted to determine what helicopter pilots need in the way of visual cues for heliport approaches at night or in poor weather.

While these reports address a wide range of heliport lighting issues, they raise more questions than they answer. The possibilities of dealing with these issues are exciting but the range of potential solutions is very broad. We do not yet have answers to all the questions of interest to those who wish to implement improved heliport lighting systems. Additional work is needed. In particular, candidate lighting systems need to be developed, installed, and tested in a variety of operational scenarios in different environments throughout the country. If we were to do all that seems appropriate, the cost would far exceed the available funding. Thus, we are looking for ways to achieve the maximum near term benefits within the limits of available funding. With this in mind, we look to Industry for their recommendations.

The FAA is looking for ways to accomplish more with smaller budgets. By working in Government/Industry partnerships, we have seen that it is possible to do more with less. After

reviewing the reports listed above, we request that you write us with your advice on what future heliport lighting research efforts would be most likely to meet your operational requirements. Please send your comments to:

Federal Aviation Administration
General Aviation and Vertical Flight Program Office, AND-710
Attn: Robert D. Smith
800 Independence Ave. SW
Washington DC 20591

By soliciting Industry's advice, we hope that your ideas will better enable us to choose those heliport lighting research projects that will meet your needs. Your advice would be most effective if we could receive it by January 15, 1999. We appreciate your assistance and we look forward to continued FAA/Industry cooperation on matters such as this.

Steve Fisher

Steve Fisher
Acting Manager, General Aviation
and Vertical Flight Program Office

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/ND-98/4		

4. Title and Subtitle	5. Report Date
Heliport Lighting – U. S. Park Police Demonstration	November 1998
	6. Performing Organization No.
Author (s) Principal Author: Scott A. Fontaine Contributing Author: Edwin D. McConkey	8. Performing Organization Report No.
9. Performing Organization Name and Address Science Applications International Corporation (SAIC) 1213 Jefferson Davis Highway, Suite 1500 Arlington, VA 22202	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFA01-93-C-00030, Task Order C4
12. Sponsoring Agency Name and Address Federal Aviation Administration General Aviation and Vertical Flight Program Office, AND-710 800 Independence Avenue, S. W. Washington, D. C. 20591	13. Type Report and Period Covered Final Report 14. Sponsoring Agency Code AND-710

15. Supplementary Notes
AND-710, General Aviation and Vertical Flight Program Office

16. Abstract
This demonstration/evaluation of prototype heliport lighting system components was part of a larger effort to research the requirements for lighting systems to support precision approaches to heliports. Based on the success of a VFR prototype system demonstrated in conjunction with Operation Heli-STAR (DOT/FAA/AND-97/20), it was decided to continue the demonstration/evaluation at the United States (U.S.) Park Police Heliport in Washington DC. The arrangement has proven to be extremely valuable, due in large part to the cooperation and assistance of the officers, pilots, and aircrew of the U. S. Park Police Aviation Section.

This reports documents the initial evaluation of a laser diode localizer, a laser diode glideslope indicator, a light pipe, cold cathode line-up and landing system, and a light bar "alignment of elements" glideslope indicator. Some insights and lessons learned regarding the use of simulation in lighting system development are also presented.

17. Key Words			18. Distribution Statement
Helicopter	Lighting	Approach	This document is available to the Public through the National Technical Information Service, 5258 Port Royal Road, Springfield, Virginia 22161.
Heliport	Rotorcraft	Landing	
Visual Landing Aids	Powered-Lift Vehicles	Layouts	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	52	

Form DOT F 1700.7 (8-72) Reproduction of this document is authorized

TABLE OF CONTENTS

1.0 INTRODUCTION 1
1.1 United States Park Police 1
1.2 Related Work 2

2.0 BACKGROUND 3
2.1 IFR Approach Procedure Interface Requirements 3
2.1.1 Non-Precision Approach Procedures 4
2.1.2 Precision Approach Procedures 4
2.2 Public and Private Heliports 5
2.3 Simulation 5

3.0 METHOD OF INVESTIGATION 7

4.0 SITE SURVEY 11
4.1 Acquisition 11
4.2 Line-Up 11
4.3 Glideslope 11
4.4 Horizon 12
4.5 Closure Rate 12
4.6 Touchdown 12

5.0 LIGHTING TECHNOLOGIES 13
5.1 Point Light Sources 13
5.1.1 Lasers 13
5.1.2 High Intensity Strobe Beacon 15
5.2 Diffused Lights 15
5.2.1 Light Pipe 15
5.2.2 Cold Cathode Lights 16
5.3 Other Lighting Technologies 17

6.0 PROTOTYPE LIGHTING INSTALLATIONS 19
6.1 Laser Localizer and Glide Slope Indicator 19
6.2 High Intensity Strobe Beacon 20
6.3 Light Pipe and Cold Cathode System 20
6.3.1 Configuration 21
6.3.2 Color 22
6.3.3 Operational Factors 22
6.3.4 Human Factors 24

TABLE OF CONTENTS (CONTINUED)

7.0 DISCUSSION OF RESULTS 25
7.1 Laser Guidance 25
7.2 High Intensity Strobe Beacon 27
7.3 Light Pipe and Cold Cathode System 28
7.3.1 Prototype Layout 28
7.3.2 Evaluation Results 29
7.4 Alignment of Elements Glideslope Indicator 30
7.5 Demonstration Flights 31

8.0 CONCLUSIONS 33
8.1 General Conclusions 33
8.2 Light Pipe and Cold Cathode Conclusions 34
8.3 Acquisition Beacon 35
8.4 Laser Localizer and Glideslope 35
8.4 Alignment-of-Elements Glideslope 35

9.0 RECOMMENDATIONS 37
9.1 General Recommendations 37
8.2 Light Pipe and Cold Cathode Recommendations 37
8.3 Acquisition Beacon Recommendations 38
8.4 Laser Lighting Recommendations 38
8.4 Alignment-of-Elements Glideslope Recommendations 38

REFERENCES 41
APPENDIX A ACRONYMS 43

LIST OF FIGURES

Figure 1 VFR Approach Procedure to the U.S. Park Police Heliport....8
Figure 2 Prototype Lighting Layout at the U.S. Park Police Heliport....9
Figure 3 Laser Visual Guidance System – Lateral and Vertical....14
Figure 4 Laser Guidance Approach to the U.S. Park Police Heliport....20
Figure 5 Light Pipe Line-Up Cues....22
Figure 6 Alignment-of-Elements Glideslope Design....23
Figure 7 Human Eye Response (Rods and Cones) to Light Wavelengths....24
Figure 8 Glideslope Intercept Geometric Relationships....26

LIST OF TABLES

Table 1 Time and Distance Traveled Perpendicular to Laser Localizer Beam....25
Table 2 Time and Distance Traveled Across Glideslope Beam....26

1.0 INTRODUCTION

This demonstration/evaluation of a prototype heliport lighting system was part of a larger effort to research the requirements for lighting systems to support precision approaches to heliports. The design of heliport lighting plays an important role in aiding the pilot during the transition from the final approach segment to the visual segment of an instrument procedure. Well-designed lighting systems can provide "credits" that reduce required visibility minimums for instrument flight rules (IFR) approaches. The approach lighting system should "reach out" from the landing area, assuring the pilot that a landing site is ahead, and visually guide a pilot to this landing site.

Flight tests conducted for the Federal Aviation Administration (FAA) by the University of Tennessee Space Institute (UTSI) and Science Applications International Corporation (SAIC) identified new technology lighting systems with great potential to meet the requirements for IFR approaches to heliports. Initially, these lights were briefly evaluated in a downtown environment. The color and characteristics of the cold cathode lights were so unique to the well-lit city environment that they were easily identified in the midst of a variety of traditional city lights. These unique characteristics also improved the ease with which the pilot maintained visual contact with the heliport environment (simulated during these tests) and significantly increased the amount of information provided to the pilot as compared to conventional incandescent heliport lights.

These tests were sufficiently promising that the FAA decided to evaluate these lights in an operational city environment. A system was designed and built to support the Helicopter Short-Haul Transportation Aviation Research Program (Operation Heli-STAR), a joint FAA and industry initiative that applied advanced technology in a real-world operational setting under visual flight rules (VFR). After a limited but positive evaluation, documented in reference 1, the system was modified slightly and installed at the United States (U.S.) Park Police Eagles' Nest Heliport in Washington, DC.

1.1 UNITED STATES PARK POLICE

The U. S. Park Police Aviation Section is currently the only public service aviation provider within the District of Columbia. Its missions include aviation support for law enforcement, medical evacuation, search and rescue, high-risk prisoner transport, and Presidential and dignitary security. The U. S. Park Police have provided accident–free aviation services to our Nation's Capital for over 25 years. The Aviation Section operates one Bell 206L-3 Long Ranger and one Bell 412SP helicopter from their heliport, the Eagles Nest, located adjacent to the Anacostia Naval Station on the Anacostia River. This work would not have been possible without the superb cooperation and professionalism shown by the officers, pilots, and aircrew of the U. S. Park Police.

1.2 RELATED WORK

This report is one of several recent FAA-sponsored reports on heliport lighting. Other reports addressing this topic include:

- DOT/FAA/ND-97/20, Evaluation of Heliport Lighting Design During Operation Heli-STAR (reference 1)
- DOT/FAA/ND-98/1, Heliport Lighting – Technology Research (reference 2)
- DOT/FAA/ND-98/2, Heliport Lighting – Configuration Research (reference 3)

2.0 BACKGROUND

The heliport/vertiport precision instrument approach lighting system must provide or enhance the visual cues necessary to safely acquire the landing environment, decelerate, and land during the visual (final) segment of an IFR precision approach. This visual segment of a helicopter instrument approach is very different from a fixed-wing visual segment. The major difference is the requirement for the helicopter pilot to decelerate to a stop while maintaining a constant glide path. The lighting system, in addition to providing or enhancing cues for heliport acquisition, lineup, horizon, glideslope, and touchdown, must provide the pilot with strong closure rate cues. In comparison with airport lighting systems, all of this must be accomplished by lighting equipment located in a very limited physical space.

FAA report FAA/CT-TN89/21 (reference 4) documented the flight testing of the HALS system, currently the only FAA-approved instrument approach heliport lighting system. Within the document it was stated that "The HALS is considerably smaller than runway approach light systems." Yet, at 900 feet in length, it is not short. The document stated further that "The FAA looks at lighting as one alternative for ensuring the safe operation of rotorcraft under lower minimums than what would otherwise be possible. In the near to mid-term, the number of heliports/vertiports that will install such a system may be small. However, the more alternatives available, the better the position the industry will be in to pick the combination of alternatives that make sense for each application of interest. As other alternatives become apparent, the FAA will consider testing them to see what they offer the industry in terms of operational benefits."

Lower visibility lighting credits are applied at instrument approaches where the landing environment can be identified from the missed approach waypoint (MAWP) or at the decision waypoint (DWP) in visibility less than the distance to the runway threshold. Currently, this is accomplished by installing lines of lights that essentially move the runway threshold closer to the MAWP or DWP. At many heliports, a new means of achieving safe operation at low weather minimums is desired. Although, this demonstration effort did not directly evaluate such a system, some of the technologies examined may be suitable for such an application. This is actually the most difficult cue to provide in a cost effective (real estate efficient) manner. It will require an innovative solution and should be the focus of a dedicated research and development effort.

2.1 IFR APPROACH PROCEDURE INTERFACE REQUIREMENTS

As the aircraft approaches the MAWP, or DWP, the pilot must transition from a heads-down instrument scan to a heads-up outside scan. The pilot must not only identify the landing environment and make the decision to continue the approach or initiate the missed approach procedure, he (or she) must acquire the other visual cues, both natural and augmented, at this site and transition to the visual segment of the approach. During this segment, the remaining altitude will be lost and the remaining speed will be depleted.

2.1.1 Non-Precision Approach Procedures

The starting point for the visual segment of a non-precision approach should be level flight and a constant speed between 60 knots and approximately 70 knots[1] (reference 5). Having acquired the landing environment and having decided to continue the approach, the pilot must acquire a glideslope indication or identify a visual descent point. It is here that the design characteristics of the visual glideslope indicator (GSI) must be evaluated. The GSI must be acquired and interpreted in time to initiate a descent that will put the aircraft on the proper glideslope. The closer to the heliport that the descent is initiated, the steeper the approach. Also the helicopter must be decelerated on glideslope, which also requires a low power setting. If the glideslope is overflown on a steep approach, the pilot may have to establish an excessively high rate of descent at low altitude. Reference 5 directs that the visual segment descent angle (VSDA) be measured from the minimum descent altitude (MDA) at the MAWP to the elevation at the center of the heliport (helipoint). Maximum VSDA is 10.2 degrees, optimum is 6.0 degrees, and the minimum is 3.0 degrees. At 60 knots, a 6-degree VSDA requires a rate of descent of 638 feet per minute (fpm); a 10.2-degree VSDA requires a rate of descent of 1,093 fpm.

Sufficient time must be allowed for the pilot to intercept the visual glideslope, adjust the descent rate, and null the error to zero without flying through the glideslope. The time required for a smooth transition can be transformed to a distance value and added as a buffer to the distance from the heliport.

The interface between final approach course (heads down navigation) and visual segment line-up guidance will most likely not be as critical as the descent angle interface. For some visual localizer systems, however, a buffer, similar to a GSI's, is also required to ensure a smooth transition.

2.1.2 Precision Approach Procedures

Rotorcraft precision approach terminal instrument approach procedures (RPTERPS) are currently under development. Recent tests demonstrated an automatic approach (coupled) to a decision waypoint (DWP) of 82 ft AGL, 35 knots, and only 581 feet from the helipoint. At such a low altitude, a GSI would not be required, but at DWP's further out the pilot may have to acquire a GSI while already in a descent. The type and characteristics of the GSI will impact this transition. The pilot will have to transition from an electronically guided glide path to a visual glide path.

The exact distance where a pilot transitions from a GSI to the total landing environment for glideslope cues will depend on the site and ambient lighting conditions. Even in the darkest conditions, a pilot will have to transition his scan away from the GSI inside 1/4 to 1/8 nm to avoid missing critical closure rate cues.

[1] The slowest allowable IFR approach speed is set by the helicopter type certification and is defined as the minimum IFR speed (V_{MINI}). Typical V_{MINI}'s are 50 to 70 knots indicated airspeed.

2.2 PUBLIC AND PRIVATE HELIPORTS

At private-use heliports, prior permission is required before landing. This allows heliport operators to control the training and proficiency of the pilots flying to and from the facility. Because the operator has this control, some alternatives to lighting might be suitable for guiding the pilot to the heliport. It is questionable whether heliport operators take full advantage of this control. This is an area where Government/Industry cooperation and research might prove fruitful.

Some private heliports have developed a set of VFR course rules that provide guidance in the form of landmarks. Depending on their character and locations, available landmarks may help the pilot to position an approaching helicopter on the desired final approach course, simplify the acquisition problem by limiting the focus of the pilot's search for the landing environment, and cue the initiation of the descent at a safe point. However, caution should be employed when establishing these course rules. Overly complex procedures make it difficult to accommodate visiting pilots who may be unfamiliar with the heliport. Neither the FAA nor industry has developed any guidelines on the content, format, or accuracy of the heliport information that should be provided to a pilot as an aid in preflight planning. At most heliports in the U.S., this information is not readily available.

Public heliports, however, must provide easily interpreted guidance and cues to a pilot who may be flying the approach to the heliport for the first time in the worst possible conditions (IFR and/or VFR). Specialized lighting systems that require specific training will be difficult to implement at a public heliport. Specialized lighting systems that require specific training may also be difficult to implement at private-use heliport.

2.3 SIMULATION

The original test plan for this effort called for simulation of these lights prior to actual flight tests. However, development efforts revealed that simulation cannot easily capture and duplicate the characteristics that make these lights unique. Simulation uses some of the cues that a lighting system is designed to provide as a means to "trick" the eye (and the brain's perception of what the eye sees). Simulation makes the brain perceive distance where there is no distance, speed where there is no speed, and depth where there is no depth. It is difficult to use these false cues to evaluate specific characteristics and differences between lighting technologies. The evaluation becomes a function of the quality of the simulation and a real world validation of the simulation becomes necessary. In short, with current technology the simulation becomes a development project in and of itself and is no longer a cost-effective tool. This is not to say that simulation has no value in lighting development, but simulation should be used carefully and sparingly for appropriate testing.

In the early phases of this research, simulation was used in a number of ways to minimize costs. Some discussion of the results is necessary here to explain how this demonstration/evaluation became possible and to provide some lessons learned regarding the use of simulation in heliport lighting research.

The next form of simulation used in this effort proved to be very effective. UTSI used a "tabletop" simulation (reference 2) composed of small ornamental lights arranged in innovative patterns, laid out to scale, and evaluated by pilots positioned to a scaled design eye point. A tabletop simulation was also used to design a glideslope indicator, which was later built and tested at full scale.

Although inexpensive to build, reconfiguring these tabletop simulations can be time consuming. A computerized version, installed on a desktop computer with three-dimensional graphics capability would be a powerful developmental tool. If the design eye point is programmed to move down the glideslope using a virtual camera, a dynamic simulation is possible. An executable program can be developed that could be distributed for evaluation and comment.

The original lighting evaluation task called for a full-scale simulation in an engineering simulator. The test plan called for initial configuration evaluations to be conducted with groups of pilots viewing a large screen while an operator moved the virtual camera to various points on and off the approach path. Approaches were to be flown, recorded and then played back to the group in an effort to narrow the evaluation to only the most promising configurations. The evaluation would then have continued to evaluate the final prototypes in the simulator with operational pilots flying realistic approaches in varying simulated weather conditions.

This simulation development effort was working in parallel to the identification of new lighting technologies. The simulation effort was stopped when scheduling conflicts delayed the program and when it was realized that the development effort was better suited for a less expensive level of simulation. An accurate depiction of the new lighting technologies evaluated herein was beyond the scope of the planned simulation.

One other form of simulation has potential as a tool for the development of lighting systems. This simulation has not been used in aviation and is known as "rendering" or modeling of light output. Illumination rendering programs have been used to model the light output of various office lighting products and predict how that light interacts with the surrounding environment. Newer, more powerful programs are capable of modeling the great outdoors. These models will be capable of accurately depicting ambient lighting conditions as well as the proposed lighting systems. Coupled with a 3-dimensional desktop computer simulation an illumination-rendering program may have the potential to assist in the design of site-specific heliport lighting systems in a cost-effective manner.

3.0 METHOD OF INVESTIGATION

With a simulation effort delayed indefinitely and a prototype lighting system already built (as part of Operation Heli-STAR during the 1996 Olympic Games in Atlanta), the FAA elected to start a parallel effort to demonstrate and operationally evaluate promising new lighting technologies. To that end, an agreement was made with the United States Park Police in Washington DC.

The Park Police heliport was chosen as the site for this demonstration evaluation effort for a number of reasons. The Washington DC location facilitates the demonstration of promising new lighting technologies to decision-makers within the Federal Government, especially the FAA sponsor. The heliport is located near the intersection of two heavily traveled helicopter routes in Washington DC. Many private and public helicopter operators pass the site on a regular basis. The Federal status of the Park Police operation eased coordination with the FAA. The success of this effort is due in large part to the cooperation and assistance of the Park Police Aviation Section and the participating lighting manufacturers.

Figure 1 shows the landmarks in the vicinity of the Park Police heliport and the VFR approach procedure to the heliport. The procedure calls for the pilot to fly south down the Anacostia River toward the 11th Street Bridge at a heading of about 240 degrees. At the 11th Street Bridge, the aircraft intercepts the final approach course at an altitude of 200 feet and a distance of about 2,100 feet from the helipad. At the 11th Street Bridge, the pilot makes a slight left turn to a heading of 210 degrees and proceeds to the heliport. This provides a glideslope angle of about 5.25 degrees.

Since the prototype lighting system had not been thoroughly evaluated during Project Heli-STAR, it was decided not to replace the existing Park Police Heliport lighting system. The prototype system was instead installed on a little-used, overflow parking pad that is set back a distance from the main landing pad, as depicted in figure 2. Because it was noted that the cold cathode perimeter lights provided significant illumination of the landing surface, the Heli-STAR system was modified slightly. The Park Police system was installed without the additional illumination provided by incandescent surface floodlights and electroluminescent panels.

As the prototype system was installed, additional systems became available and were also installed and evaluated. The technologies are described in section 4. The systems installed (not all at the same time) at the heliport are listed below:

- laser guidance (lateral and vertical) on the main helipad with conventional perimeter lights (figure 2)
- high intensity strobe beacon (flashing Morse code "H" , four quick flashes) (figure 1)
- light pipe and cold cathode lighting system (figure 2)
- glideslope indicator that used the "alignment of elements" concept (figure 2)

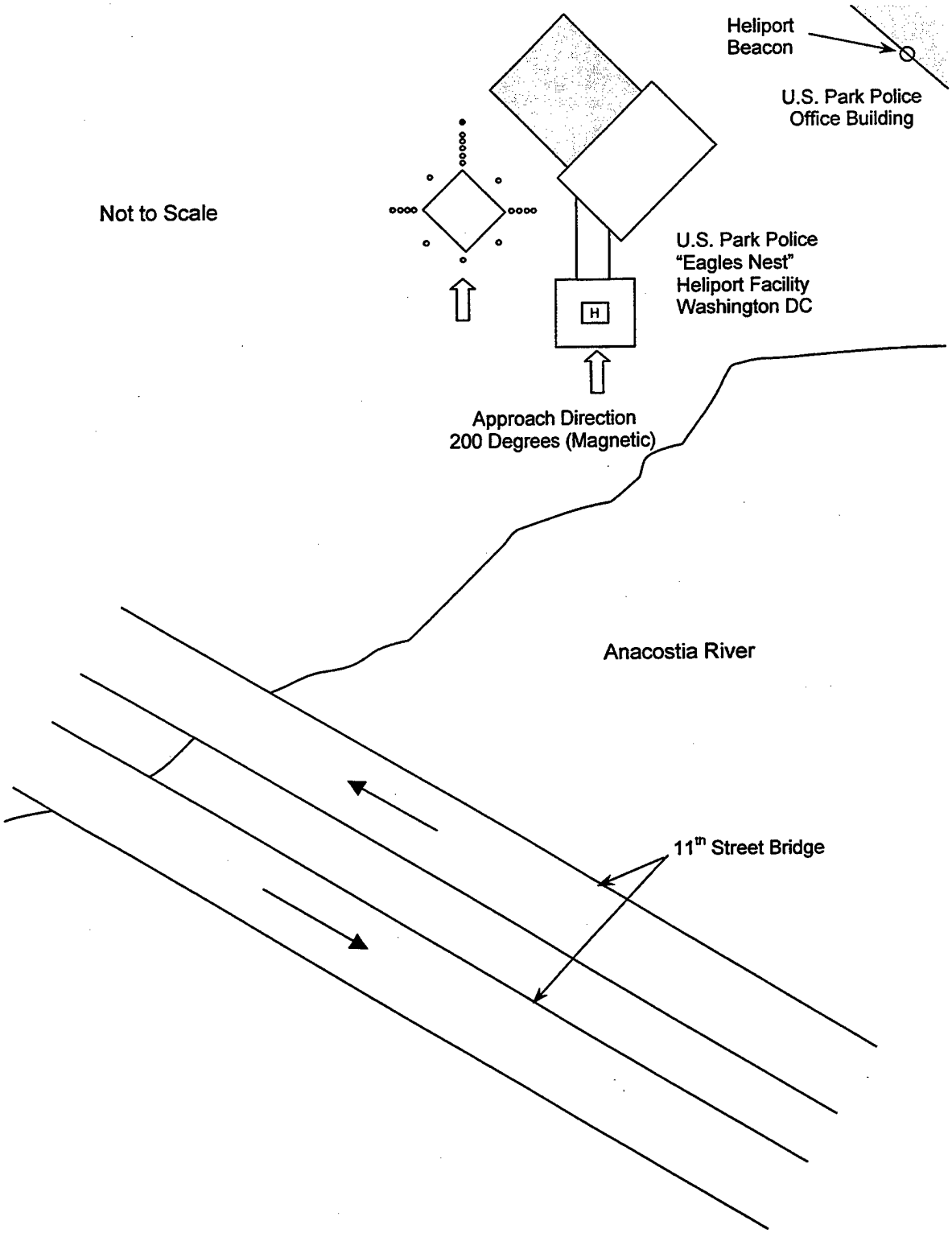

Figure 1 VFR Approach Procedure to the U.S. Park Police Heliport

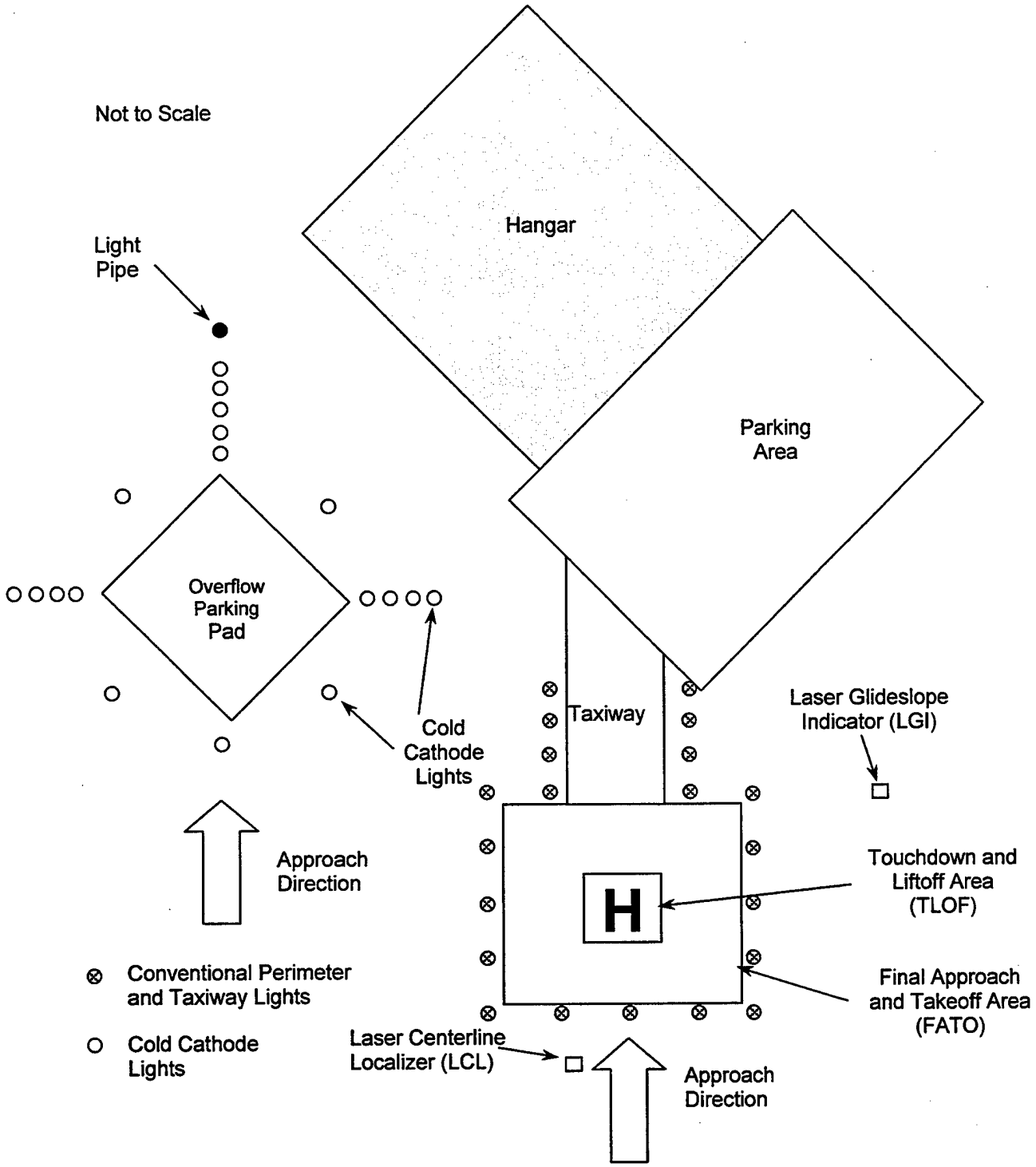

Figure 2 Prototype Lighting Layout at the U.S. Park Police Heliport

It was originally anticipated that the installation of new lighting systems on such a heavily traveled route would engender significant interest from local operators, public and private. To encourage that interest, availability of the prototype systems were briefed at a local helicopter operator's association safety meeting and the pilots were encouraged to visit the site. The briefing was followed up with a letter invitation, written briefing, and evaluation forms. Unfortunately, very few operators visited the site, and even fewer responded with written evaluations.

Because of the limited response, the emphasis was shifted to using the site to demonstrate the new technologies to FAA, military, and industry helicopter association officials. As new systems became available, they were installed, a limited evaluation was conducted, and feedback was provided to the FAA and the manufacturer.

4.0 SITE SURVEY

Complimentary research reported in reference 3 suggests that a site survey be conducted as the first step in heliport lighting design. Because the cues available from the surrounding environment can be different at each site and because the operational constraints of each heliport operator may be different, optimum heliport lighting designs may be site specific and operation specific. As the task reached an end, the researchers believed that additional insight could be gained by evaluating the cues available without the prototype systems installed. The following observations were gained by flying in and around the heliport and by interviews with local helicopter pilots and pertain to operations without the prototype system installed.

4.1 ACQUISITION

By far the largest challenge in operations in the Washington DC area is visual acquisition of the heliport. No rotating beacon is installed at the heliport. The amber perimeter lights are difficult to separate from the variety of amber and white lights in the city environment. Typically, the heliport is identified and then the perimeter lights are located in relation the entire heliport.

Even with all the difficulties noted above, acquisition is generally not a problem for the Park Police pilots and aircrew. Generally, the Park Police pilots are the only ones using the facility. The pilots are all well-trained in local course rules that have been developed to augment the shortage of visual cues. When possible, the helicopter routes around the city are oriented over the rivers and approaches to the heliport use the river and bridges as landmarks to orient and initiate all approaches. The pilots locate the helicopter routes, proceed along them until reaching the easily identifiable bridge and locate the heliport in relation to the river, often by the absence of light as opposed to unique lighting.

4.2 LINE-UP

No specific line-up lighting aids were designed as a part of the original lighting system. Inside approximately ½ nm, the taxiway lights become visible and the angle to the approach course may provide some line-up guidance to the pilot that repeatedly flies into the same pad on the same course. A pilot new to the heliport would likely miss this cue.

Again, local course rules augment available lighting cues. The final approach course is a simple matter of flying over the illuminated road signs at the end of the bridge while pointed at the heliport. The approach path is clear of obstructions between these two points. A significant cross wind could cause some drift, but the ground is visible from this altitude and the pilot would notice the drift.

4.3 GLIDESLOPE

No glideslope lighting was available in the original lighting system. Because the rectangular pad, outlined by 10 amber perimeter lights, is set at an oblique angle to the approach course (i.e., not at a right angle), It is unlikely that it provides any strong perspective cues for control of

glideslope. The trees and hangar most likely provide depth perception cues that the pilots may use to control glideslope.

Once again, local course rules augment the lighting cues. The approach is started from approximately 200 feet over the signs at the end of the bridge. This results in an approximate ½ nm final approach on close to a 5.25-degree glideslope that is easily maintained with the available cues. With facility-specific training, the consistent starting point and repeatability of each approach makes the available cues easier to assimilate and useful for detecting deviations.

4.4 HORIZON

The well-lit city environment provides ample horizon cues. Overcast conditions may intensify the ambient light by reflecting city lights.

4.5 CLOSURE RATE

The high ambient light levels combined with the consistent approach starting point make closure rate control adequate with no special lighting.

4.6 TOUCHDOWN

The landing pad is black asphalt, poorly lit by the amber perimeter lights. The pad is not used for landing, however, and the transitions to and from a hover are augmented by the pilot's use of a trainable landing light. The aircraft are parked in front of the hangar, on a flood lit ramp, set well back from the landing pad. Overhead floodlights illuminate the ramp. The floodlights are not dimmable and do create glare. The ramp operation was not addressed in this effort, however.

5.0 LIGHTING TECHNOLOGIES

This demonstration/evaluation effort was not able to consider all lighting technologies with potential for application for heliport lighting systems. The effort has put in place, however, an initial evaluation process that can handle "pop up" lighting technologies in a cost-effective manner. The technologies evaluated are described in the following paragraphs.

5.1 POINT LIGHT SOURCES

Point light sources are characterized by a very bright point of light typically generated by a glowing filament or arc. These lights are most often shielded from direct view of pilots because of the negative impact on night vision adaptation and because of the "after- image" effect. If a bright enough light is viewed directly, it leaves an after-image on the retina that continues to be seen for several seconds or longer. If incandescent lights are not shielded, they are typically filtered with colored lenses, or directed away from the pilot. Exceptions to this are approach lighting systems where hundreds of 300-watt incandescent lights are aimed at the pilots of approaching aircraft.

Point light sources commonly used in aviation are the common tungsten filament and the high intensity halogen incandescent lights. Halogen is used to slow the vaporization of the tungsten filament and increase the life of the lamp.

Point light sources were used in the original perimeter lighting around the main landing pad at the Park Police heliport. Overhead floodlights are used to illuminate the parking ramp in front of the hangar.

5.1.1 Lasers

The demonstration/evaluation included a laser glideslope indicator and a laser localizer provided by LaserLine Corporation of Pasadena, CA. Figure 3 depicts the course guidance signals provided to a pilot. The systems use red, green, and amber monochromatic, eye-safe diode lasers to guide a pilot from beyond 10 nm through an approach to a landing. The altitude constraints in the Washington Class B airspace limited the use of this guidance to a little over 2 nm. This system was designed for, and has been successfully tested onboard, U.S. Navy aircraft carriers for fighter aircraft and is now being tested for applicability in civil helicopter and airplane operations.

Two units were evaluated. One is a Laser Glideslope Indicator (LGI) and the other is a Laser Centerline Localizer (LCL). Both systems use low power eye safe diode lasers coupled with special optics to provide diverging beams of laser light in three colors for guidance information. The LCL uses seven lasers arranged, from left to right, fast flashing red, flashing red, steady red, amber, steady green, flashing green, and fast flashing green. Red is used to indicate left of course, amber indicates on course, and green indicates right of course. Color and the rate of flash indicate the magnitude of the course error. The LGI is arranged similarly, with red on the bottom, but uses only five lasers, eliminating the two fast flashing beams. Beam widths are

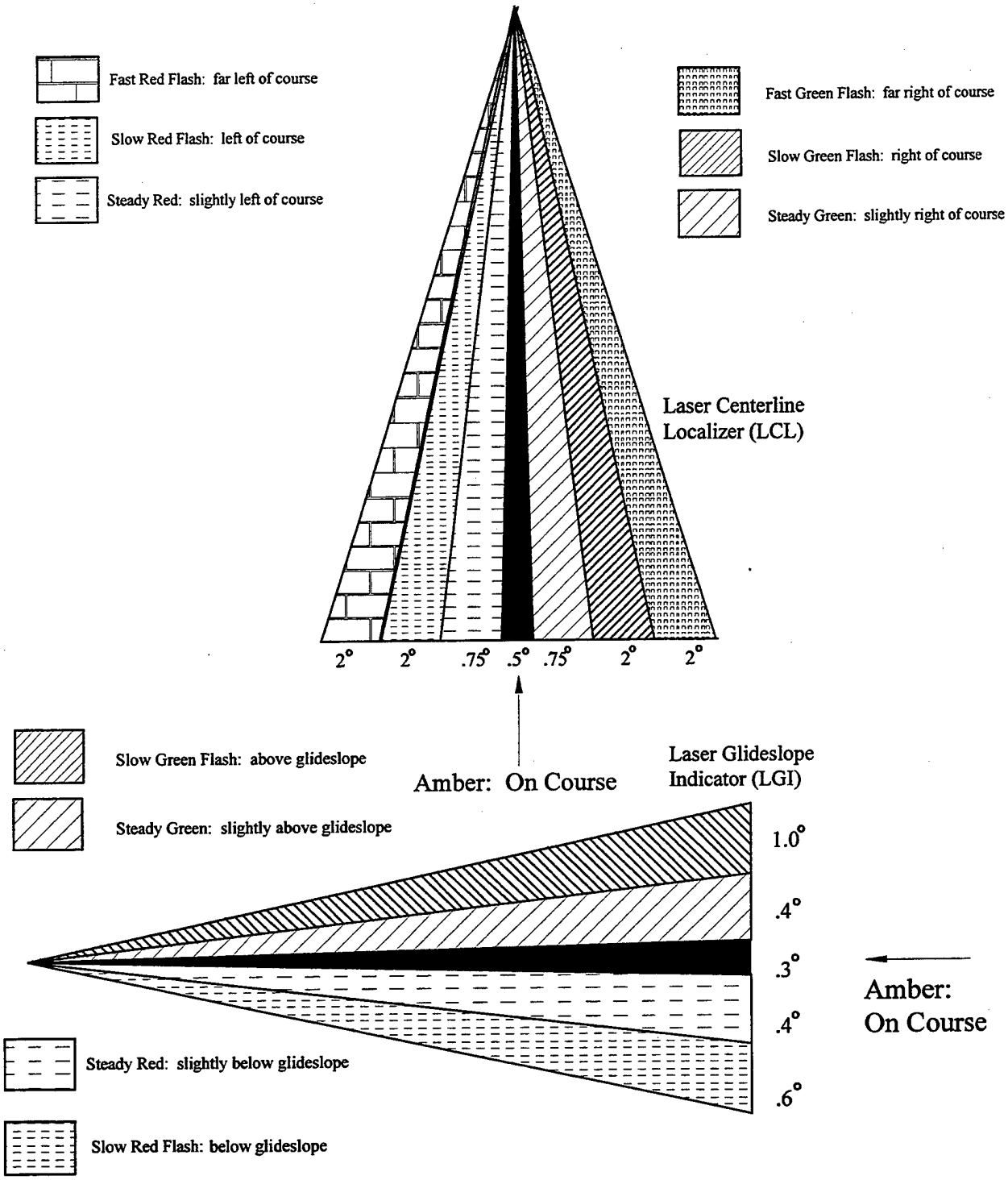

Figure 3 Laser Visual Guidance System – Lateral and Vertical

narrow, making the LCL usable from ½ mile out to 10 miles in clear weather. (For civil use, the system would need to be redesigned for use from about 1 or 2 miles down to a few feet from the landing pad.) The laser systems differ from conventional optical guidance devices in that there is no overlap from beam to beam[2]. Each beam has a sharply controlled "knife-edge" and they are separated by a very small gap of no light at all.

Power Requirements: 120 VAC
Advantages:
- High intensity
- Narrow divergence of light beams (useful at long ranges)
- Potential for improved performance (over conventional lights) in reduced visibility (not yet evaluated)

Disadvantages:
- High cost
- High pilot workload due to the difficulty in following narrow beams

Current Applications:
- Used on U.S. Navy aircraft carriers for long range line-up

Potential Aviation Applications:
- Visual localizer
- Visual glide slope indicator
- Closure rate indicator (not yet prototyped, but flash rate could indicate closure rate)

5.1.2 High Intensity Strobe Beacon

A strobing acquisition beacon provided by Flash Technologies of Brentwood, TN was installed to aid pilots in initially acquiring the landing site. Located on a rooftop adjacent to and southwest of the Eagles' Nest, the beacon is readily identified by its distinctive flash pattern. The beacon emits a group of four omnidirectional flashes (Morse code "H") every 0.5 seconds with an interval of 1.5 seconds between the groups. Pilots at a distance of more than 8 miles have readily seen this beacon. Initially the beacon was installed with a timer and operated continuously from dusk to dawn. The Park Police have modified the beacon to be pilot-controlled via radio.

5.2 DIFFUSED LIGHTS

5.2.1 Light Pipe

The "Lite Pipe," manufactured by Automatic Power, Incorporated, of Houston TX, is an extruded clear acrylic tube, 8 inches in diameter, lined with a thin clear prismatic film. A light source is located at one end, backed by a parabolic reflector, which directs the light along the length of the pipe towards a mirror at the other end. Through the property of total internal

[2] Designers of multi-colored beams have had to deal with the mixing of colors where the beams overlap. This is not a trivial issue. When green was used as the "on glideslope" color in one system, the overlap with the red "low" beam created a brief flash of yellow which could be confused with the amber "high" beam (when the pilot was actually below glideslope.) This influenced the Navy to use amber for the "on glideslope", green for "high", and red for "low" in shipboard GSI's. Since this is the Navy standard, it was used in these laser prototypes.

reflection, the light is diffused uniformly across the internal surface of the pipe. The prismatic material allows a portion of the light to "leak" out producing a uniform long line of light. Shielding any section of the tube with a reflector intensifies the light diffused through the uncovered portions. Color can be varied through the use of filters that are located between the light source and the pipe. Typically, the use of filters reduces the output of the light by 20 to 30 percent.

Statistics:
- Power, efficiency, and life: (dependent on light source, which can be varied with certain restrictions)
- Color: variable through the use of filters
- Operating temperatures: light pipe runs cool, lamp itself is internal

Advantages:
- Produces a single line of light that is easily recognizable
- Provides high intensity lighting up to 400 watts per foot
- Currently available in lengths up to 40 feet
- Long life
- Available in a variety of colors
- Viewing angles are adjustable
- Low maintenance
- Easy to service
- Automatic bulb changer available

Disadvantages:
- High initial cost (approx. $4,000 for a 20-foot pipe)
- Maximum intensity varies with color selection

Current Applications:
- Coastal and Waterway markings
- Bridge markings

Potential Aviation Applications:
- Heliport acquisition and line-up lighting
- Hover aids
- Glideslope indicators
- Taxiway lights
- Approach lights

5.2.2 Cold Cathode Lights

Manufactured by LiteBeams, Incorporated, Burbank, CA, cold cathode lights are not new technology. They have been used as obstruction lights for 30 years. The lights work on the same principle as a neon sign. The lights generate an arc in an inert gas in a glass tube coated with metal compounds. Mercury is used to help initiate and sustain the arc. The combination of gas and metal coating determines the color. Cold cathode lights produce a more uniform light output than the high intensity concentration that is typical of an incandescent light. Consequently, cold cathode lights leave no after image on the retina, even after looking directly at the light. An after image is created by the slow recovery of the retinal neurons (rods and cones) following exposure to concentrated light. Since the light emitted from a cold cathode light is more evenly distributed

across the retina, the retina recovers more quickly. This is important in aviation applications, especially for helicopter operations, because the cold cathode lights allow the pilot to see the ground around the light and not just the light itself.

Statistics:
Power: 25 watts (sized to match light output of standard 69-watt incandescent aviation lamp)
Efficiency: approx. 65 percent of energy converted to light, 35 percent lost to heat (compared to 95 percent to heat and 5 percent to light for a typical incandescent lamp)
Color: color can be controlled without the use of filters
Life: 20,000 to 40,000 hours (compared to 2,000 hours for a typical incandescent lamp)
Operating temperatures: Lamp burns cool; electrodes reach 300 degrees F.

Advantages:
Monochromatic in a wide variety of colors
Does not leave an after image on the retina
Low initial cost
Long life
Low power consumption
Operates on battery or 120 VAC power
Compatible with night vision devices
Can be operated as a strobe or steady burning light

Disadvantages:
Medium to Low intensity only
Requires special intensity level controls (cannot vary intensity by varying input voltage)
Requires a ballast to condition input power.
Ability to melt ice and snow in winter has not yet been demonstrated

Current Applications:
Obstacle lighting

Potential Aviation Applications:
Runway lighting
Taxiway lighting
Heliport lighting (acquisition, line-up and approach applications)

5.3 OTHER LIGHTING TECHNOLOGIES

The scope of the effort did not allow for demonstration/evaluation of other promising lighting technologies. However, other technologies do show promise and should be evaluated in further research efforts. Some of these lighting technologies are:

- Fiber Optics
  - End emitting fibers: a single light source can "pump" light through these fibers to multiple optics. Originally restricted (by cost and capacity) to special applications such as lighting in explosive atmospheres, new fibers make applications with potential savings in maintenance and reliability possible.
  - Side emitting fibers: new fibers may allow a lighting designer to outline landing areas and obstructions with long lines of diffused light.

- Non-Imaging Optics (the science of directing and shaping light output as opposed to reproducing an image)

  - Advanced reflectors – designed with the aid of computer algorithms to yield more efficient, more precise, and more even distributions of light output.
  - Constructive occlusion – uses specifically designed reflective surfaces to produce a very even distribution of light over the desired beam shape with sharp cutoffs to limit the amount of light distributed in undesired parts of the beam shape.

- Light Emitting Diodes (LED's)

  - LED Lines of Light: LED's are connected together in flexible lines that can be placed in pavement as a centerline marker or can be used with side-emitting fiber optics to outline landing pads and/or obstacles.
  - Replacement lamps: LED's have been grouped together in the shape of a standard incandescent "bulb" as a screw in replacement. The LED bulb is more efficient, longer lasting, and distributes the light output over the surface of the bulb, eliminating the intense bright filament at the center of an incandescent bulb.

6.0 PROTOTYPE LIGHTING INSTALLATIONS

6.1 LASER LOCALIZER AND GLIDESLOPE INDICATOR

Pilots were provided with the following system description and procedure instruction material:

These visual aid devices use red, green and amber monochromatic, eye-safe lasers to guide the pilot in maintaining proper glide slope and centerline with flashing and steady-on lights to indicate how much correction is needed.

For this test, the localizer system was set to be intercepted on the Anacostia River in the area of the East Capitol Street Bridge at approximately 500 feet mean sea level (MSL). The localizer lasers (top portion of figure 3) are mounted horizontally and follow conventional lighting for aircraft and ships; green for right (starboard) and red for left (port). If you are right of centerline, you will see a green light; on centerline you will see an amber light; and if to the left, you will see a red light. When the approach is a little right of centerline you will see a steady green light, which will flash as you deviate farther right---slowly at first (60 pulses per minute) and more rapidly (120 pulses per minute) the more off-center the approach is flown. Note that there is no blending of the colors or flash rates as you move around on the approach. The change in color from amber to red or green, or from a slow flash rate to a fast flash rate, is instantaneous. Depending on how slow your change is, there may be a fraction of a second when you will see nothing as you move from one corridor to the next.

The width of the corridors is very narrow: fast red - 2.0 degrees, slow red - 2.0 degrees, red - 0.75 degrees, amber - 0.5 degrees; green - 0.75 degrees, and slow and fast green - 2.0 degrees. Height on all corridors is 5.0 degrees. At two nautical miles, the amber "on line-up" cue is only 106 feet wide. On a 90-degree base leg at 60 knots, you will fly through the amber in only one (1) second.

The glideslope laser (bottom portion of figure 3) provides the same type of cues, however there are only five light corridors compared to seven for the localizer, and only one flash rate (80 pulses/minute) for flashing green and flashing red. Green indicates you are above glideslope, amber - you are on glideslope and red – you are below glideslope. The height of these corridors is also narrow: flashing green - 1.0 degrees, green and red - 0.4 degrees, amber - 0.3 degrees, and flashing red - 0.6 degrees. All of the glideslope corridors are 5.0 degrees wide. Look for the glideslope indicator at 3/4 nm from the pad at 500 feet MSL. This is a 6 degrees glideslope. At this distance, the amber "on-glideslope" cue is only 24 feet high. As you approach the pad, you will enter and pass through the fast flashing red sector, then the slow flashing red sector, then the steady red sector and then the amber sector. At sixty knots, your initial descent rate will be approximately 660 fpm in order to stay on the glideslope. Lead your descent, i.e., start your descent when you see the flashing red, in order to catch the amber with close to a 660-fpm rate of descent. (See approach layout in figure 4.)

When on short final and assuming you are on glideslope and localizer, you should conduct a VFR cross check by ensuring that you are over the signs on the east end of the 11th Street Bridge at an altitude of 195 feet.

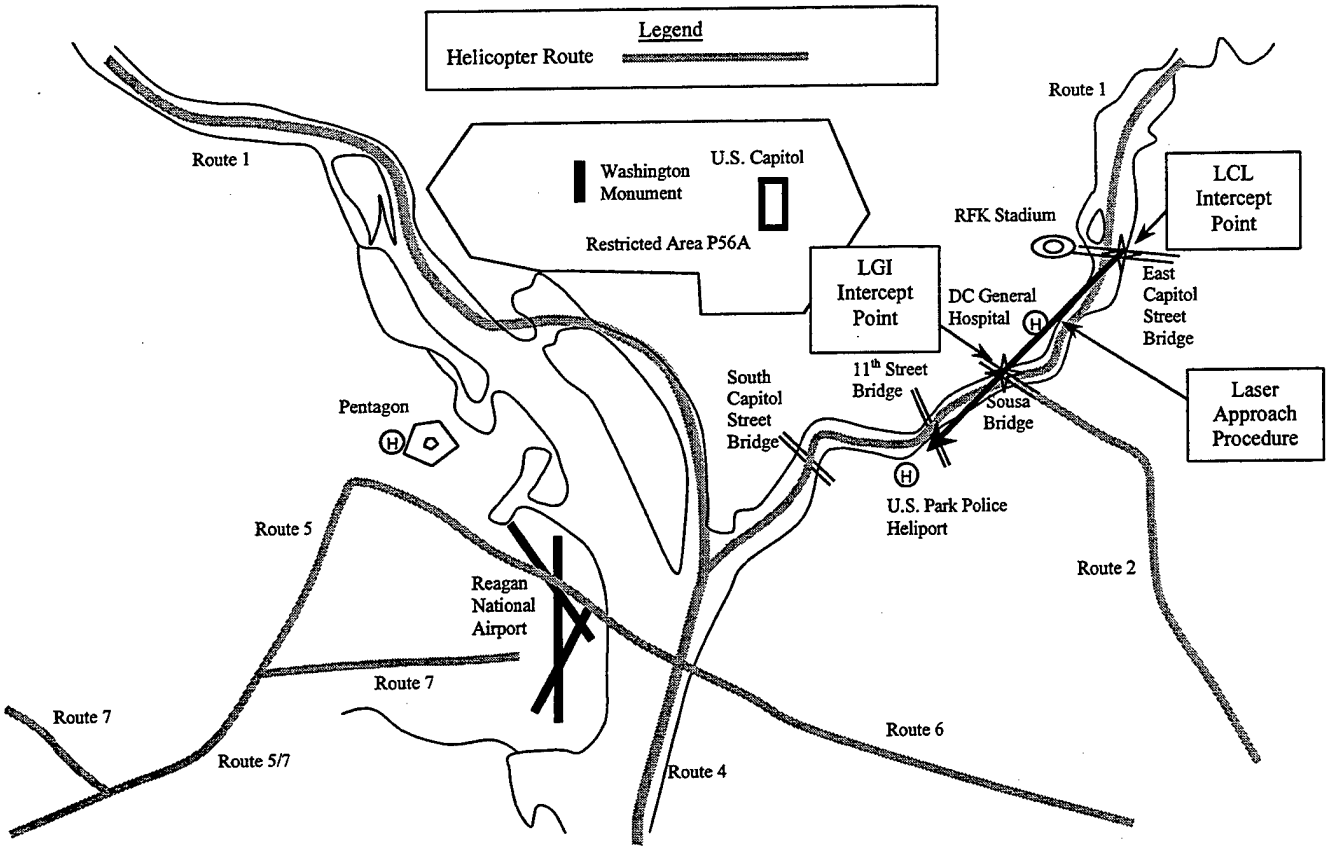

Figure 4 Laser Guidance Approach to the Park Police Heliport

6.2 HIGH INTENSITY STROBE BEACON

The strobe was mounted on top of the roof of an adjacent office building in order to avoid temporarily blinding the pilots while the aircraft was operating in and around the heliport.

6.3 LIGHT PIPE AND COLD CATHODE SYSTEM

The light pipe and cold cathode prototype system was originally built for and moved from Operation Heli-STAR in Atlanta for continued evaluation and demonstration in Washington, DC. Details of the Atlanta evaluation can be found in reference 1. The following design description is taken from that report and modified to address the slight differences in the two systems. The design goals of the prototype lighting system were to provide specific cues to a pilot, rather than merely flooding the landing area with light. The various lighting technologies were selected for several reasons:

- The cold cathode lights do not leave an after image.
- One intensity setting can be selected for both the cold cathode lights and the light pipe. At this setting, they can be seen from a distance, but will not blind a pilot hovering over the pad.
- The cold cathode lights illuminate the surrounding ground providing the pilot with "texture" cues required to sense movement of the helicopter.

- The 20-foot light pipe emits a uniform line of light that is recognizable from long distances and is unique in the midst of many point light sources in an urban environment.

6.3.1 Configuration

The light configuration shown in figure 2 was selected for the following reasons:

- The extended line-up lights provide line-up cues that remain in the pilot's field of view throughout the entire approach, including the hover and landing. Conventional approach lighting is located prior to the threshold. Thus, it is overflown and out of sight on short final, hover, and landing.

- The wing bars or extensions to the left and right of the pad provide the pilot with a peripheral cue to aid in centering the aircraft over the landing spot. The wing bars also aid the pilot in detecting a rate of climb or settling while in a hover. Fore and aft translation can also be detected by scanning the relative positions of the wing bars with peripheral vision. The 90-degree angle between the extended lineup lights and the horizontal line of lights of the wing bars provide line-up cues. The wing bars are also intended to draw the eye to the point of the array where the optical expansion rate (closure rate) cue is the strongest. One other important cue provided by the wing bars is an attitude or horizon cue.

- The number of helipad perimeter lights arranged in a circular pattern in conjunction with wing bars were designed to provide surface lighting sufficient to illuminate microtexture[3] and provide an easily recognizable pattern to aid the pilot in determining and controlling closure rate.

- The light pipe provides an easily identifiable line of light to aid in acquisition and identification of the heliport. Its vertical orientation, in conjunction with the extended line-up lights, provides a very strong line-up cue. This cue is a natural, or intuitive cue. It requires no training for the pilot to be able to determine the aircraft's position relative to the desired approach course. This is illustrated in figure 5. This cue was adapted from U.S. Navy shipboard visual landing aids. This effect was labeled the "hockey stick effect" by some of the pilots.

- An "alignment of elements" glideslope system, shown in figure 6, can be integrated into the line-up system shown in figure 2, to provide a visual glideslope in areas where sufficient space is available. This solution calls for locating the horizontal element behind the light pipe. An alternative solution is possible by locating the horizontal element in front of the light pipe thereby presenting less of an obstruction problem. Only the configuration shown in figure 6 was investigated during the evaluation period.

---

[3] Fine-grained details, such as blades of grass, the roughness of nonskid surfaces, or cracks in the landing surface, are classified as "microtexture." Lack of fine-grained detail can result in a substantial increase in the workload required to simply control the helicopter in a hover or in low speed flight close to the surface (reference 9). Conditions that lead to a lack of microtexture include a smooth featureless surface (e.g., still or dark water, poor visibility conditions, and/or an unlit surface).

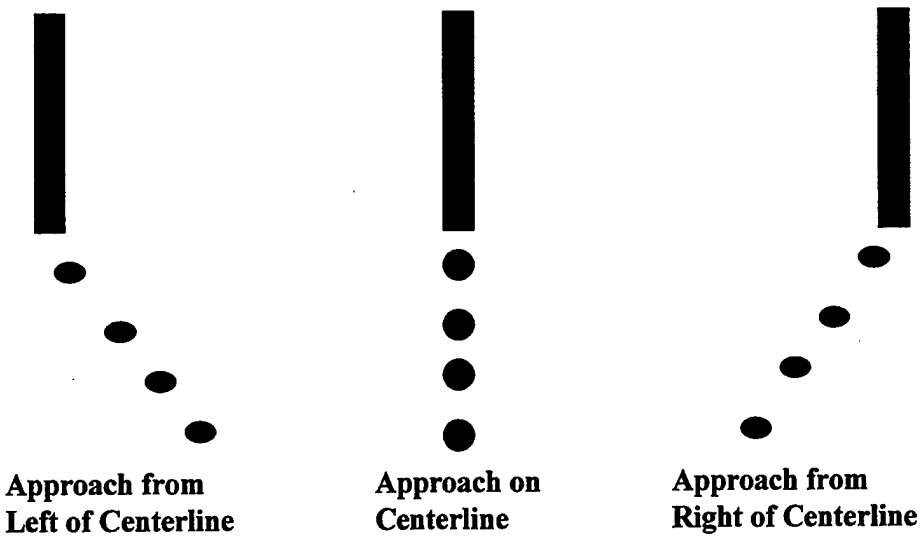

Figure 5 Light Pipe Line-up Cues ("Hockey Stick Effect")

6.3.2 Color

The color of the cold cathode lights was selected by UTSI to maximize the ability of the eye to detect the light. The lights used were modified from the Operation Heli-STAR lights to be closer to the recommended blue-green color with a wavelength of 512 nanometers (reference 3). As shown in figure 7, a wavelength of 512 nanometers is a compromise of the most efficient wavelength for the rods and the cones in the eye. Although a compromise, this wavelength is quite visible to both the rods and cones. Coincidentally, it is a color that is quite unique, even in an urban environment. The spectral luminous efficiency, shown as the vertical axis in figure 7, is inversely proportional to the amount of energy required to produce equal perceived luminance, hence a measure of efficiency.

6.3.3 Operational Factors

The vertical light pipe forms an angle with the extended line-up light when the approaching helicopter is off course, thereby providing an easily interpreted line-up cue to the pilot.

Unlike traditionally located lead-in lights that pass behind you during an approach, the lead-in lights installed at the Park Police heliport were located beyond the landing site providing extended line-up cues that remain in the pilot's field of view throughout the entire approach, including hover and landing.

Two sets of wing bars positioned at right angles to the line-up lights and left and right of the landing zone provide peripheral cues in centering the aircraft over the landing spot and aid the pilot in detecting any increase or decrease in altitude while at a hover.

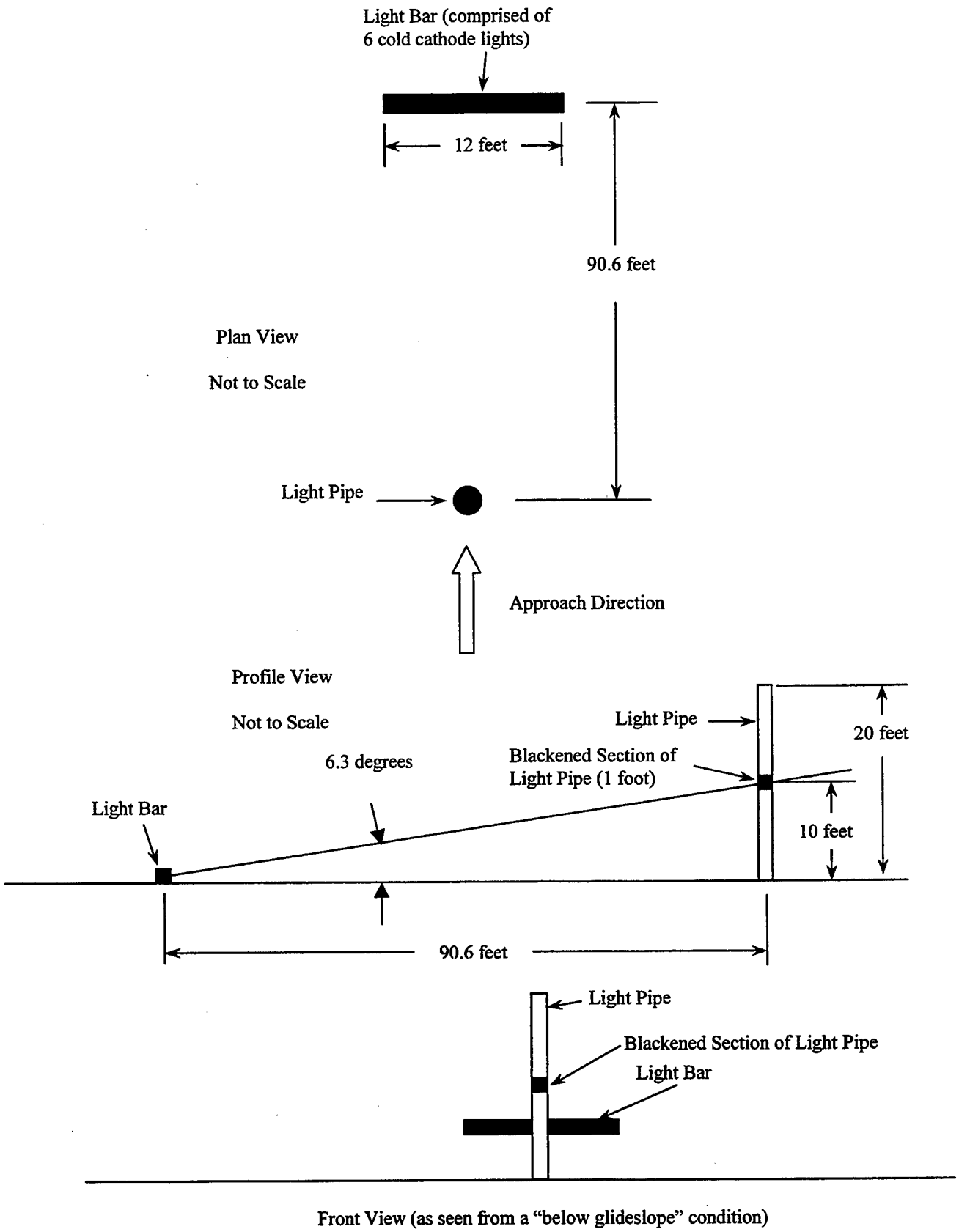

Figure 6 Alignment-of-Elements Glideslope Design

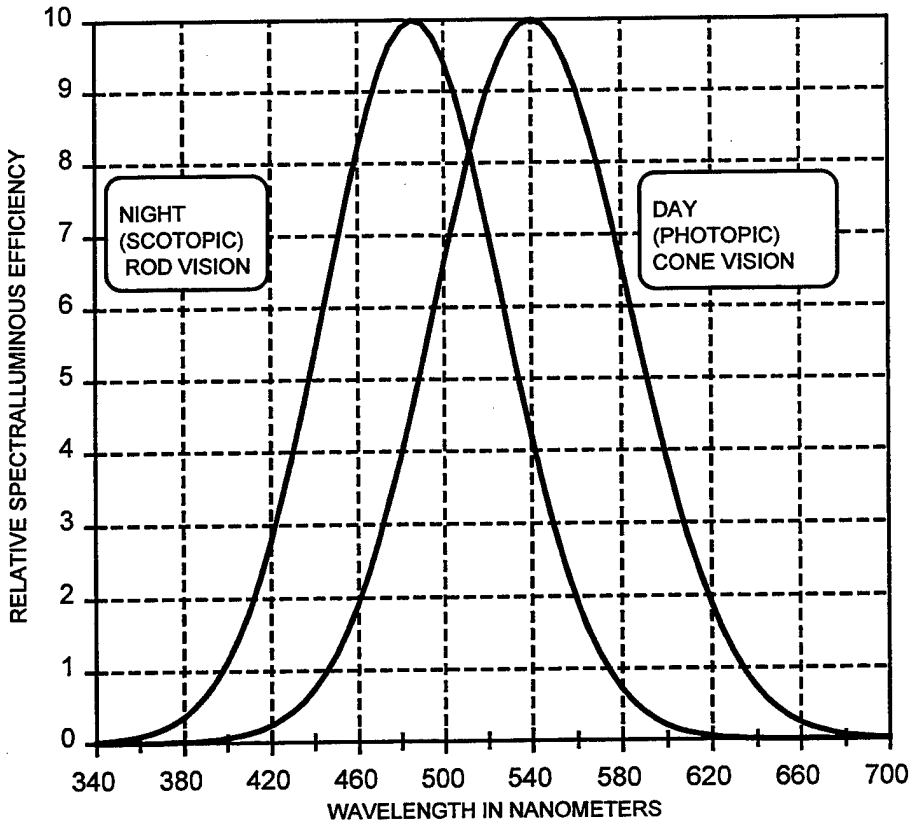

Figure 7 Human Eye Response (Rods and Cones) to Light Wavelengths

6.3.4 Human Factors

The distinctive blue-green color of the cold cathode lights is very easily identified. The color was selected by UTSI because it maximizes the ability of the eye to detect the light. This is because the blue-green wavelength (512 nanometers) is equidistant between the best frequency for the rods and the best frequency for the cones in the eye. Additionally, the cold cathode lights use a gas filament that tends to disperse the light leaving no after image on the retina. By comparison, the hot burning metal filament (point-source light) of an incandescent light will burn an after image onto the retina that and causes a reduction in night vision. The pilot can see the cold cathode lights from miles away in good weather and then view the lights directly while at a hover without any loss of night vision and without any dimming required.

As the helicopter approaches the heliport, the lights of the wing bars appear to separate from what was a solid line of lights into individual lights. As the heliport comes closer, the pilot sees a growing separation distance between the lights[4]. These wing bars, along with the remaining 12 cold cathode lights, were configured in an easily recognizable pattern to provide sufficient surface texture lighting and to aid the pilot in determining and controlling closure rate.

[4] This phenomenon has been referred to as spatial summation, hyperacuity, and shape factor by various authors.

7.0 DISCUSSION OF RESULTS

7.1 LASER GUIDANCE

The LCL and LGI used in the demonstration at the Park Police heliport were designed for operations by fixed-wing aircraft landing on an aircraft carrier. The laser system was not modified for this evaluation. The beams were designed to provide guidance out to 8 nm and are too narrow for use at a heliport due to the increased pilot workload that this feature caused. These systems do provide very accurate guidance and pilot comments become more favorable after training and experience with the systems.

The systems were installed as described in section 6, in order to allow the maximum possible distance for a straight-in approach. Because of airspace and altitude limitations of the Class B airspace and helicopter routes, the approach was limited to approximately 2 nm. The pilots were instructed to fly parallel to the East Capitol street bridge to acquire the localizer visually. Again, the design for an 8-nm intercept significantly affected this aspect of the approach. Table 1 illustrates the time that the aircraft will be in each beam when crossing the localizer at 60 knots. If the pilot visually acquires the localizer, identifies the fast flashing red beam as soon as the aircraft enters it, and starts a standard rate turn immediately, the aircraft will have traveled through the amber "on course" beam, through the steady green right of course beam, and well into the slow flash green beam before reaching the final approach heading. This is exactly what occurred, despite the best efforts of the pilots flying the system. By the time the pilot corrected back to the on course signal, it was time to look for the flashing red "low" signal from the LGI.

Table 1 Time and Distance Traveled Perpendicular to Laser Localizer Beam (2 nm from Heliport)

Beam	Beam Width (feet)	Time in beam at 60 knots (seconds)	Distance from edge to centerline (feet)	Time to centerline at 60 knots (seconds)
Fast Flash Red (Left)	424	4.2	1,063	10.5
Slow Flash Red (Left)	424	4.2	637	6.3
Steady Red	159	1.6	212	2.1
Amber (on course)	106*	1.0	53	0.5

* Distance to centerline is 53 feet.
Note: The perpendicular distance traveled in a 90-degree, standard-rate turn (3 degrees/sec) at 60 knots is 1,934 feet.

Table 2 lists the distance and time traveled for the helicopter to pass through the glideslope at a level altitude of 500 feet above ground level. The relationship describing the geometry of the glideslope intercept is shown in figure 8. The 500-foot altitude was selected because it is the altitude that the Park Police pilots were instructed to intercept the laser localizer near the Capitol Street Bridge. This altitude produces a glideslope angle of 5.25 degrees to the center of the heliport and it is consistent with the nominal approach angle flown to the heliport by the pilots.

Table 2 Time and Distance Traveled Across Glideslope Beam in Level Flight (500 feet above Heliport)

Beam	Beam Width (feet)	Time in beam at 60 knots (seconds)	Distance from edge to centerline (feet)	Time to centerline at 60 knots (seconds)
Slow Flash Red (Below)	894	8.8	1,534	15.1
Steady Red (Below)	479	4.7	640	6.3
Steady Amber (on course)	313*	3.1	161	1.6
Steady Green (Above)	367	3.6	**	**
Slow Flash Green (Above)	729	7.2	**	**

Note: Glideslope angle is assumed to be 5.25 degrees.

* Distance to centerline is 161 feet.

** Glideslope is assumed to be captured from below, therefore for these cases the aircraft is beyond the glideslope centerline.

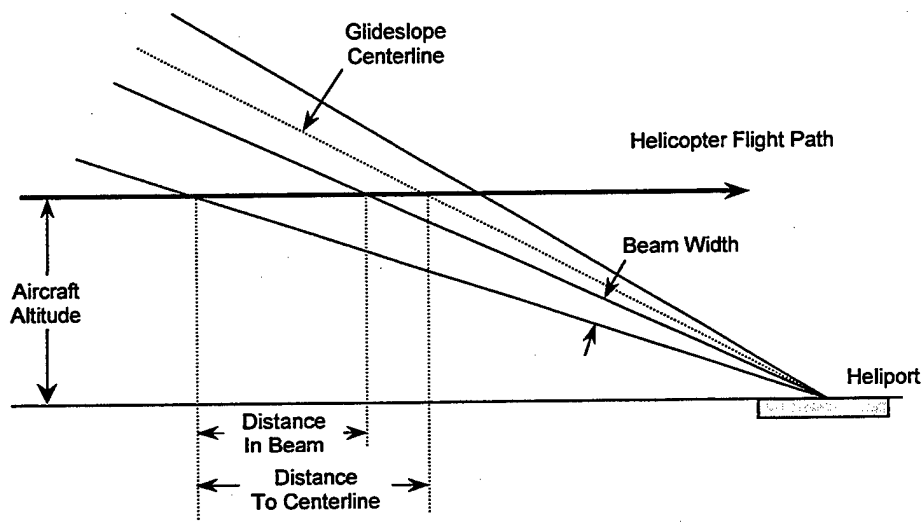

Figure 8 Glideslope Intercept Geometric Relationships

All the pilots who flew the system complained that the beams were very difficult to acquire and re-acquire. All the pilots were aware of where the LCL and LGI were positioned in relation to the main landing pad. However, the landing pad, outlined with 60-watt amber perimeter lights, was also difficult to acquire visually with a background of city lights. This caused the subject pilots to work harder to maintain the two systems in their scan.

The original system was designed for a Navy ship, with very few lights, in the middle of a very dark ocean. The manufacturer also demonstrated a newer version of the system that was much easier to see from a distance. The newer design had increased laser power, while staying within eye safe limits, and had paired two systems in a way that doubled the beam widths. However, the newer design was not evaluated in a helicopter. Rather, it was observed at an airport in a

fixed-wing, general aviation aircraft. Preliminary observations indicate that the newer design should be easier to fly in a helicopter.

The narrow beams also increased the workload to the point of distraction. The narrow beams required pilots to work very hard to maintain the aircraft on-course. Also, pilots believed that the narrow beams produced a level of precision tracking that was unnecessary. Within ½ nm of the helipad, the ambient lighting conditions at the heliport provided sufficient visual cues to enable the pilot to maintain both line-up and glideslope within comfortable limits. The extra work required to stay within the laser guidance of both systems was tolerated for the purposes of evaluation and comment, but most pilots would not use the system unless asked.

The installation at the Park Police necessarily differed from the design installation on the carrier. On the carrier, the LCL is located below the level of the flight deck on the stern of the ship. It is aligned so that the aircraft flies out of the beam approximately ½ nm behind the ship. This allows (forces) the pilot to shift his scan from the point source LCL to the line-up lights on the flight deck. This arrangement was not possible at the Park Police heliport and the system provided guidance that got more and more sensitive inside ½ nm to the heliport.

One pilot concentrated so intensely on flying both the LCL and the LGI guidance that he arrived over the pad with excessive speed and decided to execute a missed approach. This may have been a result of the combined effects of excessive workload and scan fixation. Scan fixation was most likely due to the low intensity point source guidance of both systems. It was also noted that it becomes more difficult to scan both systems as the aircraft gets closer to the pad. Since the LCL was located in front of the pad and the LGI behind and to the right, the visual angle between them increases and the pilot must shift his/her focus from one to another, possibly missing the first indication of an off-course or off-glideslope signal.

7.2 HIGH INTENSITY STROBE BEACON

The strobe was first installed with a timer that turned on the strobe at dusk and turned it off at dawn. Park Police pilots preferred the strobe to the rotating beacons that are commonly used at several area hospitals. The strobe was much easier to acquire and re-acquire visually. (It should be noted that it is unknown whether the rotating beacons at the local hospitals conform to recommended practices for design and installation.)

One Park Police pilot credited the strobe with assisting his location orientation in deteriorating weather. During a law enforcement support mission, the pilot was orbiting a crime scene at low altitude for an extended period of time. When the scene was safe for ground police officers, the helicopter mission was concluded and the pilot initiated a climb and tried to orient himself. Noting that his compass was unslaved and that it had begun to snow, the pilot looked for the high intensity strobe beacon. He quickly acquired the four quick flashes of the beacon and turned towards the heliport. At that time the strobe was operating continuously after dark.

Park Police pilots noted that they used a large red neon sign as an acquisition aid for a local hospital. Although a rotating beacon was located at the hospital, it was not easily acquired until

the helicopter was quite close to the hospital. With sufficient altitude, the neon sign was visible from several miles away.

The pilots did note, however, that the strobe was distracting on takeoffs in the direction of the strobe. They suggested that a radio control would allow them to turn the system on only when it was needed. The manufacturer subsequently supplied a pilot-activated radio control unit for the strobe. The pilot activation of the system also aids in acquisition. When the pilot is looking in the general direction of the heliport and activates the strobe, it is immediately recognizable as "the" heliport strobe beacon. Any doubt as to whether the pilot has identified the heliport strobe can be overcome by turning the strobe off and then on again. This feature could also be used to mitigate community objections to a constantly flashing strobe light.

When operating helicopters near airports, pilots often desire to stay beneath Class B airspace. In these cases, they are altitude-limited with airspace ceilings, sometimes as low as 1,000 feet. This limits line-of-sight range to landmarks and increases the difficulty of navigation and acquisition tasks. The high intensity strobe can be seen as it reflects from cloud layers and from surrounding structures. Direct view of the strobe is not always required to acquire the heliport.

When asked if the high intensity strobe beacon was worth keeping at the heliport, a senior pilot noted that in addition to its value in times of disorientation, the strobe beacon is a valuable aid to visiting pilots unfamiliar with the heliport. Construction at the original strobe location has forced the Aviation Section to relocate the strobe. The pilots noted that the radio control allows them to site the beacon in locations that would be inappropriate for a beacon that is on full time. It should be noted that continuous beacons that are in view of residential areas or businesses sometimes generate complaints from the public.

7.3 LIGHT PIPE AND COLD CATHODE SYSTEM

7.3.1 Prototype Layout

The light pipe and 18 cold cathode lights were configured as shown in figure 2. There were four basic elements to the layout:

1. The light pipe was mounted vertically in line with and behind the line-up lights and the helipad.
2. The line-up lights, a set of 5 cold cathode lights, were located behind the helipad and aligned with the final approach course. These lights work in conjunction with the light pipe to provide a line-up cue to the pilot.
3. The wing bars, a second set of 8 cold cathode lights (4 on each side of the helipad), were aligned perpendicular to the line-up lights. As described in section 5, the wing bars provide several cues:

    - a horizon;
    - fore and aft transition from forward flight to hover;
    - alignment with the center of the helipad; and
    - closure rate as the wing bar lights separate from a solid line of light into individual lights.

4. The perimeter lights, a set of 8 lights arranged at 45-degree increments in a circular pattern around the helipad, were intended to provide surface illumination and to evaluate pattern recognition as a closure rate cue. Three of the perimeter lights were shared with other lighting elements; one was an element of the line-up lights and two were elements of the wing bar lights.

7.3.2 Evaluation Results

The design goals of the prototype light pipe and cold cathode lighting system were to provide specific cues to a pilot, rather than merely flooding the landing area with light. Evaluation of the system took place within approximately 3 miles of the heliport.

The light pipe provided a unique line of light that was easily identifiable in the midst of higher intensity city lights. It could be easily seen from at least 3 miles, yet required no dimming during approach or hover. Mounted vertically in this prototype lighting system, the light pipe provided acquisition cues, horizon cues, hover cues, and a strong easily interpreted line-up cue. The line-up cue is a natural or intuitive cue. It requires no training for the pilot to be able to determine the aircraft's position relative to the desired approach course. This is illustrated in figure 5.

The cold cathode lights could also be easily seen and identified at ranges of at least 3 miles yet did not need to be dimmed during an approach or in a hover over the lights. The pilots particularly liked the distinctive blue-green color of the cold cathode lights. This color was very distinctive when contrasted with the surrounding city lights. The cold cathode lights provided adequate illumination of the heliport surface. This illumination of the ground provided microtexture to the pilot, which allowed the pilot to control altitude and hover.

The extended line-up lights provided line-up cues that remained in the pilot's field of view throughout the entire approach, including the hover and landing. The pilots commented that conventional approach lighting is located prior to the helipad on the approach. Thus, it is overflown during the approach and it is behind the helicopter and out of sight of the pilot on short final, hover, and landing.

The wing bars on the left and right of the pad provided the pilot with several approach and landing cues. During approach, the wing bars provided a roll attitude or horizon cue. Also during approach, the 90-degree angle between the extended lineup lights and the wing bars provided a line-up cue. Nearing the heliport, the wing bars provided a peripheral cue to aid the pilot in centering the aircraft over the landing spot. Fore and aft translation was also detected by scanning the relative positions of the wing bars with peripheral vision. The wing bars also aided the pilot in detecting a rate of climb or settling while in a hover. Finally, because they were constructed from individual cold cathode lights spaced 5 feet apart, the wing bars provided optical expansion rate cues near the helipad. The optical expansion rate cue became apparent at a point in the approach where the individual lights of the light bar appeared to "break apart" from what was theretofore an apparent solid line of light. From this point to the heliport, the individual lights appeared to separate at rate proportional to the optical expansion rate. The time constraints of the evaluation only permitted evaluation of the 5-foot spacing of the lights of the wing bar. Other separation distances should be evaluated in future testing.

The cold cathode perimeter lights were configured in a circular pattern with 8 lights at 45-degree intervals around the helipad. In an approach glideslope of 5 to 6 degrees, the 8 lights were not sufficient to differentiate a circular helipad from a square or rectangular helipad. Clearly, 8 lights are insufficient to define a circular pattern. Consequently, the effectiveness of lighting patterns as approach and landing aids was not evaluated at the U.S. Park Police heliport.

7.4 ALIGNMENT-OF-ELEMENTS GLIDESLOPE INDICATOR

The alignment-of-elements glideslope indicator shown in figure 8 was installed at the U.S. Park Police heliport. Time permitted only a few approaches using this glideslope system. The results are as follows:

- The interpretation of the display had mixed results. During the first flight, sensing appeared correct, i.e., when the bar was low the pilot interpreted it to be low on glideslope and vice versa. The pilot indicated that the display was very easily interpreted. However, during the next evening, other pilots flew 3 more approaches and corrected low when indicator was showing low. These pilots indicated that the display looked similar to a vertical deviation indicator in an instrument landing system glideslope display. With this interpretation, the sensing of being above or below glideslope is incorrect. Therefore, pilots corrected low when they were below glideslope and corrected high when they were above glideslope. This display can be designed for sensing opposite of that demonstrated if the horizontal light bar is moved to a position in front of the light pipe. This configuration was not evaluated due to lack of time.

- One unexpected benefit was discovered in the glideslope evaluation. When rolling onto final, the light bar starts out to one side of the light pipe and moves to a centered position when on line-up. One pilot found that he used the display as a line-up aid first, then transitioned to the descent when established on line-up. He did not consciously refer to the "hockey stick" effect (figure 5) for lineup, but he centered the horizontal light bar behind the light pipe.

A few problems were discovered during the "alignment of elements" glideslope evaluation. These were as follows:

- The light from the light bar and the extended lineup lights overwhelmed the light pipe. The light bar and the extended lineup lights were composed of cold cathode lights that were operating at full power. Also, the cold cathode lights were located in front of the light pipe. Future designs should take into account the relative intensity and location of each of these lighting components with respect to the approaching helicopter.

- The 12-inch center section of the light pipe that was masked was too small. The darkened section was only apparent inside of 0.3 nm. Beyond that distance, the light pipe looked like a continuous line of light even though the center was darkened.

- The horizontal light bar was not long enough. Only 5.5 feet of the light bar was visible on each side of the light pipe (which was 20 feet tall) and it appeared out of proportion. Future efforts should evaluate longer light bars, at least 10 feet on each side.

- The light bar was one continuous 12-foot line of light located behind the light pipe. The alignment of the bar relative to the pipe may be more apparent if two light bars are used. They should be placed symmetrically on each side of the light pipe with some noticeable gap between them. This may help prevent overpowering of the light pipe. Another solution is to place the bar to one side of the light pipe. In this configuration, the glideslope indication would appear similar to a vertical tape display commonly used as an airspeed indicator on some flight director displays.

7.5 DEMONSTRATION FLIGHTS

One of the largest benefits of the prototype heliport lighting installation at the U.S. Park Police heliport was the ability to demonstrate the system to numerous government and military officials. The U.S. Park Police was most cooperative in arranging for demonstration flights or accommodating visiting pilots. Specifically, demonstration flights were arranged for several FAA officials that deal with research and acquisition of aviation lighting systems. In addition, the system was demonstrated to helicopter operational personnel at the U.S. Marine Corps and corporate aviation departments in the Washington, DC area. These demonstration flights were very useful in gaining management understanding and support for the prototype landing system.

8.0 CONCLUSIONS

The structure and intent of the demonstration/evaluation did not allow quantitative analysis of the systems installed at the heliport. It did, however, facilitate the demonstration of new lighting technologies to a wide variety of government, military, and industry personnel while providing initial subjective evaluations. The installation at the U.S. Park Police heliport enabled this to be accomplished in a very cost-effective manner.

A number of conclusions have been reached, some supported by complimentary research. The conclusions are grouped below in general and system-specific categories. Since only one version of a prototype system was available for each new lighting technology, some conclusions are specific to that prototype and may already have been addressed by the manufacturers in subsequent versions of these systems.

8.1 GENERAL CONCLUSIONS

As the U.S. Park Police demonstration has highlighted, "local course rules" can be used to increase the safety of VFR heliport operations. Such non-regulatory "rules" work best in situations where there is some mechanism or authority to provide the discipline necessary to ensure consistent compliance with the "rules." For example, such discipline is displayed in offshore operations in the Gulf of Mexico where a number of corporations each serve as a ruling authority while working together under the auspices of the Helicopter Safety Advisory Conference (HSAC). The discipline displayed in these operations has led to the achievement of lower accident rates.

Looking at the full breadth of heliport operations, however, it is clear that "local course rules," if they even exist, are not consistently being used under the discipline of any ruling authority. The VFR equivalent of an IFR approach chart is seldom available for a private VFR heliport. The heliport equivalent of the information contained in an airport directory is seldom available for a private heliport. As a consequence, visiting pilots, in particular, are at a disadvantage and this results in a smaller safety margin than what would otherwise be possible. Such charts could provide pilots with "local course rules" including key heliport information. Information could include:

- the azimuth of the heliport approach and departure paths,
- landmarks in the area,
- locations and altitudes of nearby obstructions,
- size and weight of the heliport's design helicopter,
- elevation of the landing pad, and
- telephone number of the heliport operator.

A first step toward encouraging heliport designers, heliport operators, and state aviation authorities to develop and distribute such guidelines would be to develop guidelines on the content, format, and accuracy of such charts.

The site survey process lends valuable insight into what the local pilots use to augment available cues. It is possible that these methods can be integrated into the approach design process to provide assistance to pilots flying instrument approaches to public facilities. The instrument approach may provide the same consistency in approach procedures that local course rules provide in a private operation.

The public heliport, in general, has more demanding requirements than the private heliport. The public heliport must accommodate pilots with a wide variation in experience and skill. Private heliports can control who is permitted to use the heliport and can require specific training for pilots using the facility. For commercial operators, this can be done in a disciplined manner based on an operational requirements document developed by the operator in cooperation with their FAA Principal Operations Inspector (POI).

One size will not fit all. Lighting requirements may be site specific and operation specific. The heliport designer and operator need assistance from the FAA in identifying new lighting technologies and guidelines for installation for individual systems that will provide or augment specific visual cues.

Some heliport sites will not accommodate certain types of lighting. The prototype system requires some amount of space for the lighting layouts used at the U.S. Park Police facility. Some heliports, such as rooftop heliports, have very little space and lighting alternatives must be considered.

Much of the conventional incandescent lighting, currently in widespread use in airport and heliport lighting, blends into the city lights.

Park Police pilots have been navigating for years using the easy-to-identify neon signs (cold cathode technology) around the city as landmarks. In other cities, well-lit buildings and structures are used in a similar manner, e.g., bridges and skyscrapers in New York. While such landmarks can be very useful, their location is beyond the control of aviation interests and there is no guarantee that they will be operating when needed.

8.2 LIGHT PIPE AND COLD CATHODE CONCLUSIONS

The pilots were favorably impressed with the light pipe and cold cathode prototype lighting system. They found the light pipe and line-up cues very easy to interpret. The wing bars were useful in providing cues for horizon, fore and aft position of the helicopter over the helipad, and hover over the helipad. Some of the pilots also found the wing bars to be useful as an alignment cue when used in conjunction with the line-up lights.

Eight helipad perimeter lights were not sufficient to define the circular pattern of the helipad.

The pilots were very favorably impressed with the blue-green color of the cold cathode lights and the light pipe. This color was very distinctive when contrasted with the yellowish-white incandescent lights of the surrounding city.

As an indication of the positive impression of the prototype lights, the U.S. Park Police helicopter unit is interested in a permanent installation of cold cathode lights at their heliport.

8.3 ACQUISITION BEACON

The flashing acquisition beacon was very effective in locating the heliport among the many city lights. The pilots preferred the radio-controlled version of the beacon to the continuously flashing beacon because they were more confident of positive identification of their beacon when they initiated the beacon function. The radio-controlled version is likely more acceptable to residents and businesses located in the vicinity of the beacon.

8.4 LASER LOCALIZER AND GLIDESLOPE

The laser lighting system (designed for fixed-wing, shipboard operations) has beam widths too narrow for civil heliport operations. The pilots flew through the localizer signal without having sufficient time to turn the aircraft to acquire and track the centerline signal. This is a chronic problem with many localizer systems designed for fixed-wing operations when they are applied to heliport applications.

Difficulties in acquiring the localizer signal prevented a full evaluation of the glideslope signal.

8.5 ALIGNMENT-OF-ELEMENTS GLIDESLOPE

The alignment-of-elements glideslope display had mixed results. There is a strong indication that the configuration installed at the U.S. Park Police heliport (the light pipe in front of the horizontal light bar) has reverse sensing for some pilots. There were also a number of technical items that caused problems during the evaluation that included:

- Intensity levels for the various elements (cold cathode lights overwhelmed the light pipe)
- Length of the horizontal light bar was too short (suggest increasing from one 12-foot bar to two 12-foot bars or one 12-foot bar on only one side of the light pipe)
- Center target on the light pipe was too small (suggest increasing from 12 inches to 24 inches)

As with all items near a heliport that are raised above the surface, the potential hazard presented by the components of such a glideslope system is a concern.

9.0 RECOMMENDATIONS

9.1 GENERAL RECOMMENDATIONS

Research into heliport lighting should be continued. The tests reported in references 1 through 3 and this report all indicate that there are promising developments in new technology lighting and in enhancements to lighting configurations. There should be additional research and development that addresses the following heliport lighting areas:

- Develop FAA lighting standards that are pertinent to the light produced by a specific lighting subsystem rather than assuming an incandescent lights/lens combination as do some current FAA lighting standards.

- Develop the necessary FAA lighting standards and FAA approval actions that permit new technology lighting components to be listed as FAA-approved lighting for acquisition under the Airport Improvement Program.

- Develop FAA lighting standards for heliports and vertiports that are clearly distinct from airport lighting. As advanced technology rotorcraft (such as tiltrotor aircraft) are brought into widespread operational use, it is anticipated that helicopter and advanced vertical flight aircraft operations at airports will increase substantially during the next decade. It is also anticipated that many of these operations will occur at landing areas that are not on the fixed-wing runways. To assure that pilots of fixed-wing aircraft not mistake the vertical flight landing areas for runways, lighting for these landing areas should be clearly distinct from that used for runways. Also, advanced rotorcraft will likely operate from vertiports that may have short rollways that could be mistaken for runways. Lighting at these vertiports should also be distinct from that of runways so that these rollways will not be mistaken for runways.

The FAA should develop draft guidelines on the content, format, and accuracy of heliport approach charts and heliport directory charts. Draft guidelines should be presented to industry for their review and comment. The FAA should consider how such guidelines could best be promulgated. Publication in a technical report or an advisory circular is one means that could be considered.

9.2 LIGHT PIPE AND COLD CATHODE RECOMMENDATIONS

The cold cathode lights should be evaluated under various environmental conditions. These environmental conditions include various types of restricted visibility such as fog, smoke, rain and snow. The cold cathode lights should also be evaluated to see whether the heat generated by these lights is sufficient to melt ice and snow accumulations. Tests should be performed in daylight restricted visibility conditions to determine their effectiveness in comparison to conventional lighting. Daylight fog conditions may provide the most demanding visibility requirement for heliport lighting.

Tests should be undertaken to determine pilot evaluations of various light pipe and cold cathode light configurations. Two configurations that should be tested include the light pipe and cold

cathode line-up lights versus cold cathode lights arranged in a perpendicular pattern of line-up lights and wing bars.

Tests should be undertaken to evaluate the effectiveness of the closure rate cue derived from the wing bar lights. This phenomenon occurs when the wing bar lights seem to separate from a solid line of light into individual lights as the aircraft approaches the heliport. The tests should obtain data from multiple subject pilots. The test should also evaluate various separation distances between cold cathode lights. The evaluation at the U.S. Park Police heliport used a 5-foot separation, but a much broader set of pilots and separation distances needs to be tested before the usefulness of this closure rate cue can be determined.

Tests should be undertaken to determine the minimum number of heliport perimeter lights necessary to establish a specific lighting pattern. The evaluation at the U.S. Park Police heliport used 8 lights to try to establish a circular pattern, but 8 lights were insufficient. Typical heliport patterns should include square, rectangular and circular helipads.

9.3 ACQUISITION BEACON RECOMMENDATIONS

A previous study (reference 6) has evaluated pilot preferences for heliport beacons by comparing the U.S. Standard heliport beacon (rotating beacon with white, green and amber lights) and the International Civil Aviation Organization (ICAO) standard heliport beacon (strobe flashing the Morse code letter "H"). The results of this study indicated that there were strengths and weaknesses with each type of beacon, but there was no compelling reason to change the U.S. standard. There is some anecdotal evidence from the evaluation at the U.S. Park Police heliport indicating that, in restricted visibility conditions, a radio-controlled strobe beacon may be operationally useful. This is because the pilot can activate the radio control and immediately see the response from the heliport beacon strobe. An evaluation of the two heliport beacons during restricted visibility conditions should be undertaken to determine if there might be an operational advantage to either beacon during IFR or Special VFR conditions.

9.4 LASER LIGHTING RECOMMENDATIONS

The beam width of the laser localizer must be widened considerably to reduce pilot workload. The beam widths should take into consideration the distance from the heliport where the pilot intercepts the localizer and the speed of the helicopter during the intercept procedure. Similarly, the sensitivity of the laser glideslope should be evaluated based on the glideslope intercept distance from the heliport and the nominal descent angle of the approach procedure. Typically for the instrument landing systems, the glideslope sensitivity decreases as the glide path angle increases.

9.5 ALIGNMENT-OF-ELEMENTS GLIDESLOPE RECOMMENDATIONS

The evaluation of the alignment-of-elements glideslope was very limited in scope. Several additional tests should be performed to evaluate the effectiveness of various configurations of this glideslope indicator:

- The display should be evaluated for sensing opposite of that demonstrated by moving the horizontal light bar to a position in front of the light pipe.

- A longer light bar (at least 10 feet on each side) should be evaluated. Also, two light bars, one on each side of the light pipe, should be used to make the display proportional. Two bars will also allow a separation between the bars and the pipe for increased visibility of the center target. The display should also be modified to allow the use of only one light bar set up on one side of the pipe. (This should make the display appear similar to a vertical tape altitude display with a pointer on one side.)

- Both the light bar and the extended lineup lights should be dimmed in order to prevent the overpowering of the bottom half of the light pipe.

- The center target (masked section) should be increased in size from 12 inches to 24 inches.

- The display should be evaluated as a lineup aid as well as a glideslope indicator.

- The display configuration should be adjusted to evaluate various glideslope angles and sensitivities.

- The design and location of this prototype system should give particular attention to the potential for this system to present an obstacle hazard.

REFERENCES

1. Fontaine, S. A., Evaluation of a Heliport Lighting Design During Operation Heli-STAR; FAA Report No. DOT/FAA/ND-97/20; Washington, DC; June 1998.

2. Kimberlin, R.D., Sims, J. P., and Bailey, T.E.; Heliport Lighting – Technology Research, FAA Report No. DOT/FAA/ND-98/1;Washington, DC; October 1998.

3. Fontaine, S. A., Cherry, A. C., and McConkey, E. D.; Heliport Lighting – Configuration Research; FAA Report No. DOT/FAA/ND-98/2; Washington, DC; October 1998.

4. Billman, B.R. and Schollenberger, S.; Helicopter Visual Approach Segment Approach Lighting System (HALS) Test Report; FAA Report No. DOT/FAA/CT-TN89/21; Atlantic City, NJ; June 1989.

5. Anonymous; FAA Order 8260.42, Heliport Non-precision Approach Criteria Utilizing the Global Positioning System (GPS), Federal Aviation Administration, Washington, DC; February 15, 1996.

6. Jones, P.H.; Heliport Identification Beacon; FAA Report No. DOT/FAA/CT-TN89/31; Atlantic City, NJ; April 1989.

APPENDIX A

ACRONYMS

AGL	Above Ground Level
AND-710	FAA General Aviation and Vertical Flight Program Office
DWP	Decision Waypoint
F.	Fahrenheit
FAA	Federal Aviation Administration
FATO	Final Approach and Takeoff Area
GSI	Glide Slope Indicator
H	Symbol for Heliport
HALS	Helicopter Approach Lighting System
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
LCL	Laser Centerline Localizer
LED	Light Emitting Diode
LGI	Laser Glideslope Indicator
MAWP	Missed Approach Waypoint
MDA	Minimum Descent Altitude
MSL	Mean Sea Level
NASA	National Aeronautics and Space Administration
nm	Nautical Mile
Operation Heli-STAR	Helicopter Short-Haul Transportation and Aviation Research
POI	Principal Operations Inspector
RPTERPS	Rotorcraft Precision Terminal Instrument Procedures
SAIC	Science Applications International Corporation
TLOF	Touchdown and Liftoff Area
U.S.	United States
UTSI	University of Tennessee Space Institute
VAC	Volts Alternating Current
VFR	Visual Flight Rules
V_{MINI}	Minimum IFR Airspeed
VSDA	Visual Segment Descent Angle