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Washington, DC 20591

Evaluation of a Heliport Lighting Design During Operation Heli-STAR

Scott A. Fontaine

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

June 1998

Final Report

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Administration**

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

JUN 18 1998

Dear Colleague:

Enclosed is a copy of the report **FAA/ND-97/20, Evaluation of a Heliport Lighting Design During Operation Heli-STAR**.

The Federal Aviation Administration (FAA) is currently evaluating lighting requirements to support global positioning system (GPS) approaches to heliports and vertiports. As part of the requirements evaluation, a prototype lighting system was developed and tested during Operation Heli-STAR at the Atlanta Olympic Games. This report presents the results and recommendations of this effort.

The prototype lighting system shows great promise and industry helicopter pilots have reported that their first impressions are favorable. This report makes recommendations on future work needed to optimize this new technology lighting system and to test it in a variety of environments.

This effort is one of a variety being conducted to enable the FAA and other organizations to plan for the infrastructure needs of both helicopters and tiltrotors.

Sincerely,

Steve Fisher

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

Technical Report Documentation Page

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16. Abstract
The FAA is evaluating the lighting requirements for support of differential GPS approaches to heliports. Previous lighting systems developed by the FAA to support instrument approaches to heliports are the Heliport Instrument Lighting System (HILS) and the Heliport Approach Lighting System (HALS). The HALS, a 1,000-foot long system, is a scaled-down version of a runway approach lighting system. At many heliports the land required to install a HALS will not be available.

As a part of the requirements evaluation, a prototype lighting system was developed and tested by the University of Tennessee Space Institute. After a limited evaluation in Tennessee, the FAA conducted further evaluation as part of Operation Heli-STAR, a demonstration helicopter transportation system established in Atlanta, GA during the 1996 Olympic Games.

The prototype system used a 20-foot light pipe, green cold-cathode lights, and electroluminescent panels. A semi-permanent installation was built, improvements were made, and many parameters were identified for further evaluation in simulation and flight testing. First impressions of pilots were favorable. The lighting system has been moved to Washington, DC for further evaluation.

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1.0 INTRODUCTION

The Federal Aviation Administration (FAA) General Aviation and Vertical Flight Program Office is currently investigating lighting systems that could support precision instrument approaches to heliports using the Differential Global Positioning System (DGPS). Previous lighting systems developed by the FAA to support instrument approaches to heliports are the Heliport Instrument Lighting System (HILS) and the Heliport Approach Lighting System (HALS). The HALS, a 1,000-foot long system, is a scaled-down version of a runway lighting system (figure 1). At many heliports, the land required to install a HALS will not be available. This is particularly the case at rooftop and city-center heliports.

The 1,000-foot requirement is stated in the National Airspace System (NAS) Requirements document, NAS-SR-1000 (reference 1). A proposed configuration change, NAS Change Proposal (NCP) 12485 (reference 2), recognizes that "some heliports, due to their location, may not have enough available real estate to provide 1,000 feet of lights." In those cases, it is recommended that a waiver of the 1,000-foot requirement be obtained. The proposed change does not, however, give any guidance on how HALS should be changed.

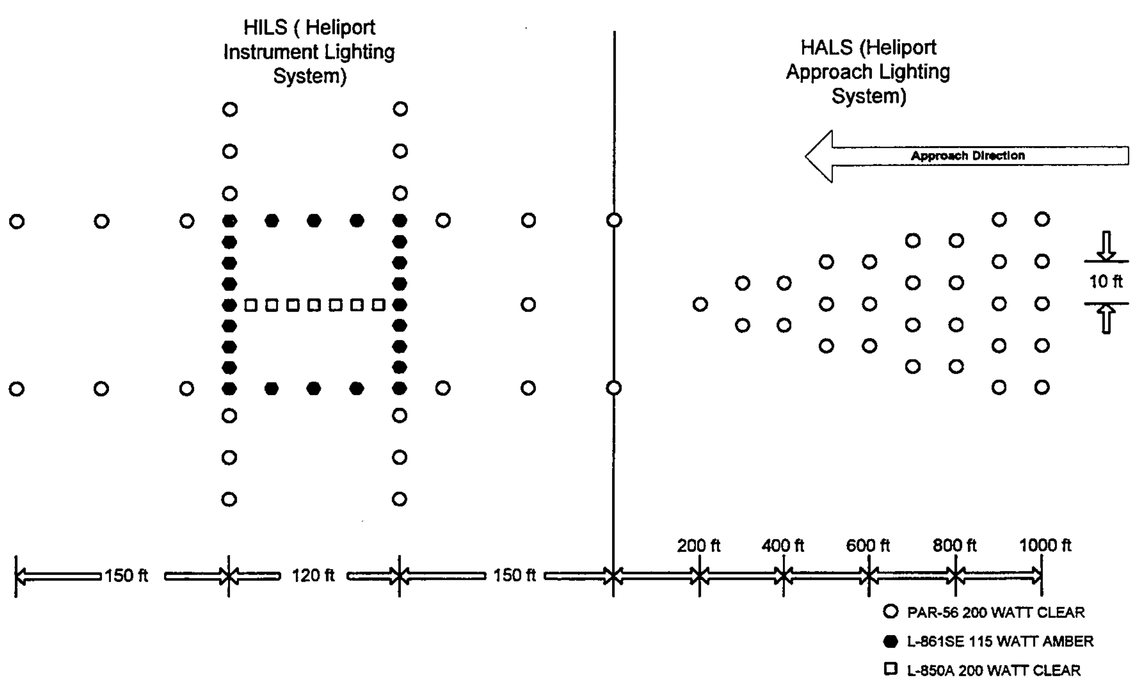

Figure 1. The FAA Standard Heliport Lighting System (HILS) and Heliport Approach Lighting System (HALS) Require Significant Amounts of Real Estate (reference 5)

As part of the requirements evaluation, a prototype lighting system was developed by the University of Tennessee Space Institute under subcontract to SAIC. After limited evaluation in Tennessee, the FAA conducted further evaluation as part of Operation Heli-STAR, a demonstration helicopter transportation system established in Atlanta, GA during the 1996 Olympic Games (see reference 4).

2.0 OPERATION HELI-STAR

The Helicopter Short-Haul Transportation Aviation Research Program, Operation Heli-STAR, was a joint FAA and industry initiative that applied advanced technology in a real-world operational setting. During its planning and development phase, Operation Heli-STAR was known as the Atlanta Short-Haul Transportation System (ASTS). It was conceived as an innovative urban transportation system design, and it was created to meet the demands of the 1996 Olympics. Operation Heli-STAR provided an opportunity to perform research and development to yield valuable data that could support urban helicopter transportation systems, world-wide.

Some of the features of Operation Heli-STAR are listed below. Operation Heli-STAR:

- used commercially available technology featuring the Global Positioning System (GPS) and two-way data link as part of an automatic dependent surveillance (ADS) system to jointly support pilot, user and air controller requirements in areas where no low altitude radar services were available;
- enhanced safety by providing improved surveillance and communications support to Olympic Security, air ambulance providers and local law enforcement agencies;
- demonstrated an intermodal transportation concept -- a "highway in the sky" system to complement the extensive ground transportation system developed for Atlanta and the Olympic events; and
- included a system of heliports, the supporting ground and air infrastructure, a broad collection of users and missions, a community outreach effort, and new technology applied to both air traffic and user applications.

3.0 HELIPORT APPROACH LIGHTING REQUIREMENTS

The Heliport Design Advisory Circular (reference 5), recommends an enhanced perimeter lighting system (7 omni-directional perimeter lights on both the upwind and downwind sides of the helipad, 14 lights total) and HILS be installed to support non-precision instrument approaches. The guide also states that HALS, the enhanced perimeter lighting system, and HILS are "... necessary for a helicopter precision instrument approach procedure with the lowest minimums." The guide notes that, "The FAA is continuing its study of configurations for precision instrument approach lighting systems."

NAS-SR-1000 requires a heliport approach lighting system to provide the pilot with "... visual information on horizontal path alignment, roll guidance, deceleration or rate-of-closure determination, and height perception for precision approaches." These requirements are similar to the requirements for airport approach lighting systems with the addition of a requirement for closure rate information. NAS SR-1000 also states that the desired performance for a heliport approach lighting system is an effective visual range during clear weather of at least 3 statute miles during the day and 20 statute miles at night.

Under a related task order, SAIC performed a search of both civilian and military literature regarding heliport lighting systems. This search revealed extensive work done by the United States Navy. During their NAVTOLAND program, the Navy performed an extensive analysis of information required by a pilot during approaches to ships. This analysis was very comprehensive and much more specific than the FAA's requirements stated in NAS-SR-1000. One NAVTOLAND program report (reference 6), identifies 25 types of information required by a pilot on approach to a ship underway. The approach is first divided into six terminal flight phase segments: homing, orientation, initial approach, final approach, hover, and vertical landing. The homing segment is unique to the ship environment, since it deals with ship course and speed and the relative motion problem of an approaching helicopter. The other segments apply to a civil heliport approach. The visual cues required are identified by the phases of flight and by the type of information required. This includes whether magnitude and rate of error are required in addition to the direction of error. The report also details a level of information required that identifies whether or not a warning is needed, for example, a flashing red signal from a glide slope indicator to warn the pilot that the aircraft is dangerously low on the approach. When the unique shipboard requirements are eliminated, the 25 categories of information required for an approach to a hover can be simplified to the following:

- identity
- inbound heading
- wind direction
- clearance to land
- range
- range rate
- lateral tracking error
- approach slope tracking error
- range milestone (non-continuous visual range cue)
- obstacle clearance
- relative altitude
- longitudinal hover position error
- lateral hover position error
- horizontal reference (horizon)
- hover height
- closure rate error

There are also differences in the level and type (as defined above) of information required for heliport approaches as compared to the shipboard approaches discussed in the NAVTOLAND report. It should also be noted that not all the required information is meant to be provided by the lighting system. Although on-board systems and displays are noted as necessary for some of the information, the intent of the recommended lighting system is to minimize the requirement for pilots to shift their scan from the visual scene to flight displays and back to the visual scene.

To maintain maximum operational utility for the lights, the criteria for evaluating requirements included looking at approaches in both the visual and instrument approach environment. Although this lighting system is being specifically developed to support precision approaches to heliports, these systems will also be used to support non-precision instrument approaches and visual approaches. This led to considering approaches performed under the FAA's Visual Flight Rules (VFR), Special Visual Flight Rules (SVFR), and well as Instrument Flight Rules (IFR). Applying this criteria means that lighting will be optimized for the precision approaches and will also provide required cues to a helicopter pilot on other types of approaches.

Current lighting systems have been supporting VFR operations for many years. In order for a new system to be practical, it will have to provide, at a minimum, a significant improvement in performance, reduced life cycle costs, and/or added capability (for example, a credit for landing visibility minima). The following statements summarize the basic premises for the evaluation.

- Lighting is required to support VFR, SVFR, IFR non-precision, and IFR precision operations.
- Many heliport sites will not accommodate lighting systems that require large amounts of real estate.
- Cost is a very important factor.
- Current lighting systems support VFR operations.
- Improvements must be investigated in the context of credit for reductions in takeoff and landing minimums.

During the course of an instrument approach, the pilot will have to perform a series of tasks. At or before the decision waypoint (DWP), the pilot will have to visually acquire the landing environment, transition to a visual scan, and proceed to a safe hover and landing. Therefore, the landing environment will have to provide all the information, in the form of visual cues, that the pilot requires to land the helicopter with an acceptable workload. These required visual cues are:

- visual acquisition of landing environment
- horizontal reference (horizon)
- lineup
- closure rate
- glideslope
    - relative altitude
    - obstacle clearance
- touchdown

These cues are consistent with the required information identified by the NAVTOLAND report and with the FAA's NAS requirements. The information not included in the above listed cues can be obtained by other means, e.g., radio communications and publications.

Not only are these cues required when things are going well, that is, when the pilot is on glideslope and on course with a constant rate of descent (stabilized) at the DWP, but these cues must also assist the pilot who is off course and/or glideslope to complete corrective action. VFR approaches will be commenced from multiple directions. For an approach to a confined area such as a city center, visual guidance may be required to inform the pilot (or warn the pilot) when the aircraft is too far off course (or off glideslope, or too fast) to effect a safe landing.

Visual cues can be provided by a variety of methods. Some examples are listed in Table 1. It should be noted that some lighting systems provide multiple cues. It is also important to realize that some of the cues provided by the various lighting subsystems are very weak, and may not be sufficient by themselves. Also, some of these lighting systems may have undesirable attributes, such as, maintenance difficulties, high cost, excessive real estate requirements, interference with other lighting systems, interference with pilots' night vision, or risk of pilot disorientation.

Table 1. Pilots Receive Cues from Various Lighting Elements during Approach and Landing

Lighting Type	*CUES*				
	Acquisition	*Lineup*	*Closure Rate*	*Touchdown*	*Glideslope*
Beacon	x				
Approach	x	x	x[1]		x
Perimeter	x		x	x	
Glideslope Indicators	x	x	x		x
Perimeter Light Extensions	x	x	x		
Approach strobes (rabbit)	x	x			
Centerline Lights	x	x			
Centerline Light Extensions[2]	x	x			
Surface Flood Lights	x		x	x	
Hangar Face Light[3]	x		x	x	
Flood lights	x		x	x	
Touchdown	x	x		x	x

1) if the lighting system is sufficiently long.
2) forward (upwind) of the pad.
3) for landing pads immediately in front of a hangar or structure

The desired system is a generic heliport lighting system that can be tailored for installation at a variety of sites, including city center, elevated, offshore, and off-airport heliports. The desired system must be able to support future approaches at angles steeper than six degrees and should require minimum ground area for installation.

4.0 PROTOTYPE HELIPORT LIGHTING DEMONSTRATION

Operation Heli-STAR provided a unique opportunity to demonstrate the prototype heliport lighting system. Flight tests identified new technology lighting systems with great potential to meet the requirements for IFR approaches to heliports (reference 7). These lights were tested in a runway environment and some were briefly evaluated in a downtown environment. The color and characteristics of these lights are unique to the well-lit city environment, and they are easily identified in the midst of a variety of traditional city lights. These unique characteristics also improve the ease with which the pilot maintains visual contact with the heliport environment (simulated during these tests) and significantly increase the amount of information provided to the pilot as compared to conventional incandescent heliport lights.

These tests were so promising that the FAA decided to continue to evaluate these lights in an operational city environment. The original test plan called for simulation of these lights prior to actual flight tests. Testing revealed, however, that simulation will not be able to correctly capture the characteristics that make these lights unique and will therefore be limited to evaluations and refinements of the geometry of the proposed lighting systems.

Operation Heli-STAR provided an opportunity to obtain a side-by-side comparison of these new lights, arranged in the configuration shown in figure 2, with current FAA specified lights. Operation Heli-STAR also allowed pilots in an operational environment to compare the prototype lighting system to standard incandescent lights arranged in configurations recommended by the Heliport Design Advisory Circular.

5.0 NEW APPLICATIONS FOR PROVEN LIGHTING TECHNOLOGY

Three manufacturers assisted the evaluation by providing lights for evaluation. The prototype heliport lighting system utilized a 20-foot "light pipe," cold cathode lights and electroluminescent light panels. None of these lights were "new" technology, but the heliport lighting system was a new application for two of these technologies. The light pipe is used extensively to mark obstructions and channels in maritime environments and the cold cathode lights are used to mark obstructions, but not runways, in airport environments. The electroluminescent panels are used in various heliport lighting systems.

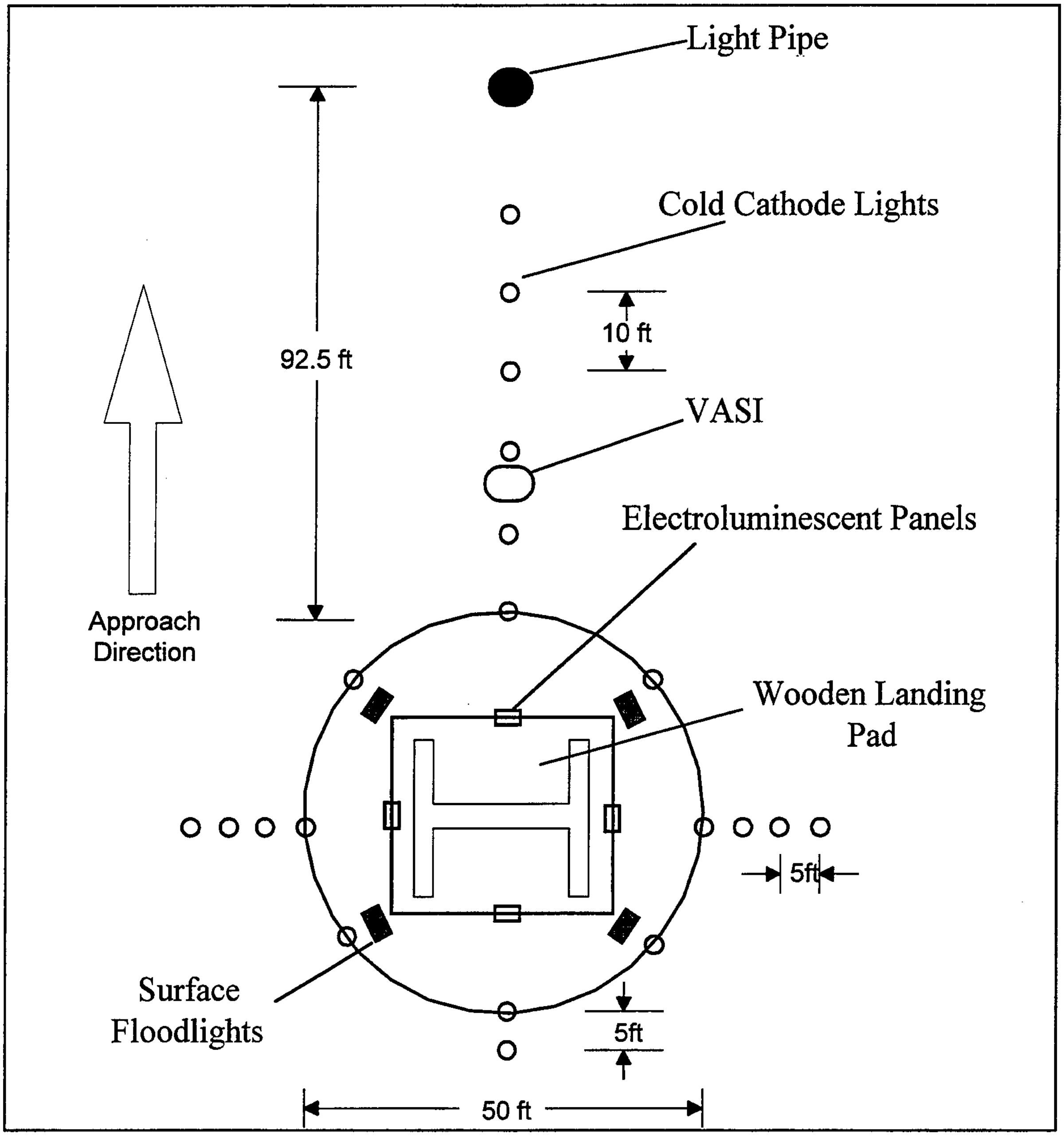

Figure 2 The Prototype Lighting System Was Installed at the NationsBank Southside Heliport in Atlanta to Support Operation Heli-STAR.

Note: As shown above, surface floodlights were installed within the FATO for this demonstration. However, this is NOT recommended due to the obstruction hazard presented by such lighting.

5.1 Light Pipe

The light pipe, provided by Automatic Power of Houston, Texas, is a hollow tube with a reflective semi-transparent coating on the inside. A light is mounted on one end, with a filter if color is desired. The light is reflected along the length of the tube, emitting a uniform light along its length. The light pipe provides a unique line of light that is easily identified in a high light density urban environment. Furthermore, it utilizes only one light source. A mirrored film can be inserted to limit the portion of the circumference of the tube that emits light. This has the effect of both limiting the viewing angle of the light pipe and increasing the intensity of the emitted light (since the area of transmission is decreased). Light pipes are presently being used by the United States Coast Guard to provide obstruction identification and channel line-up information to maritime pilots. In this heliport prototype, the light pipe was mounted vertically, as shown in figure 3, to provide acquisition, line-up, and hover cues.

5.2 Cold Cathode Lights

The cold cathode lights, provided by LiteBeams of Burbank, California, also provide a light that is very different from the incandescent "point source" lights found in urban environments and commonly used in aviation lighting. The cold cathode lights use a gas filament that tends to disperse the light instead of a hot burning metal filament that burns an after-image onto the retina. The cold cathode lights leave very little, if any, after-image even after the pilot has looked directly at the lights. The cold cathode lights were laid out in a pattern that replaced traditional lead-in lights with an extended line-up installed beyond the landing site. The pattern also included two wing bars to the left and right of the landing circle. The cold cathode lights are effectively monochromatic. The lights tested had a greenish hue.

5.3 Electroluminescent Lights

Electroluminescent (EL) light panels were used to outline the perimeter of the landing pad. EL light panels also provide light without leaving an after-image on the retina. EL lighting uses phosphors to generate light by sandwiching a dielectric between two conducting surfaces. The result is a very thin, flat light panel that can be strengthened to allow it to be placed on landing and taxiway surfaces. Aircraft and ground vehicles can be taxied or driven over the panels. The approximate life span, according to a manufacturer of an EL panel, is 28,000 to 45,000 hours. Intensity and the exact wavelength of the light is dependent on the frequency of the power source (reference 7).

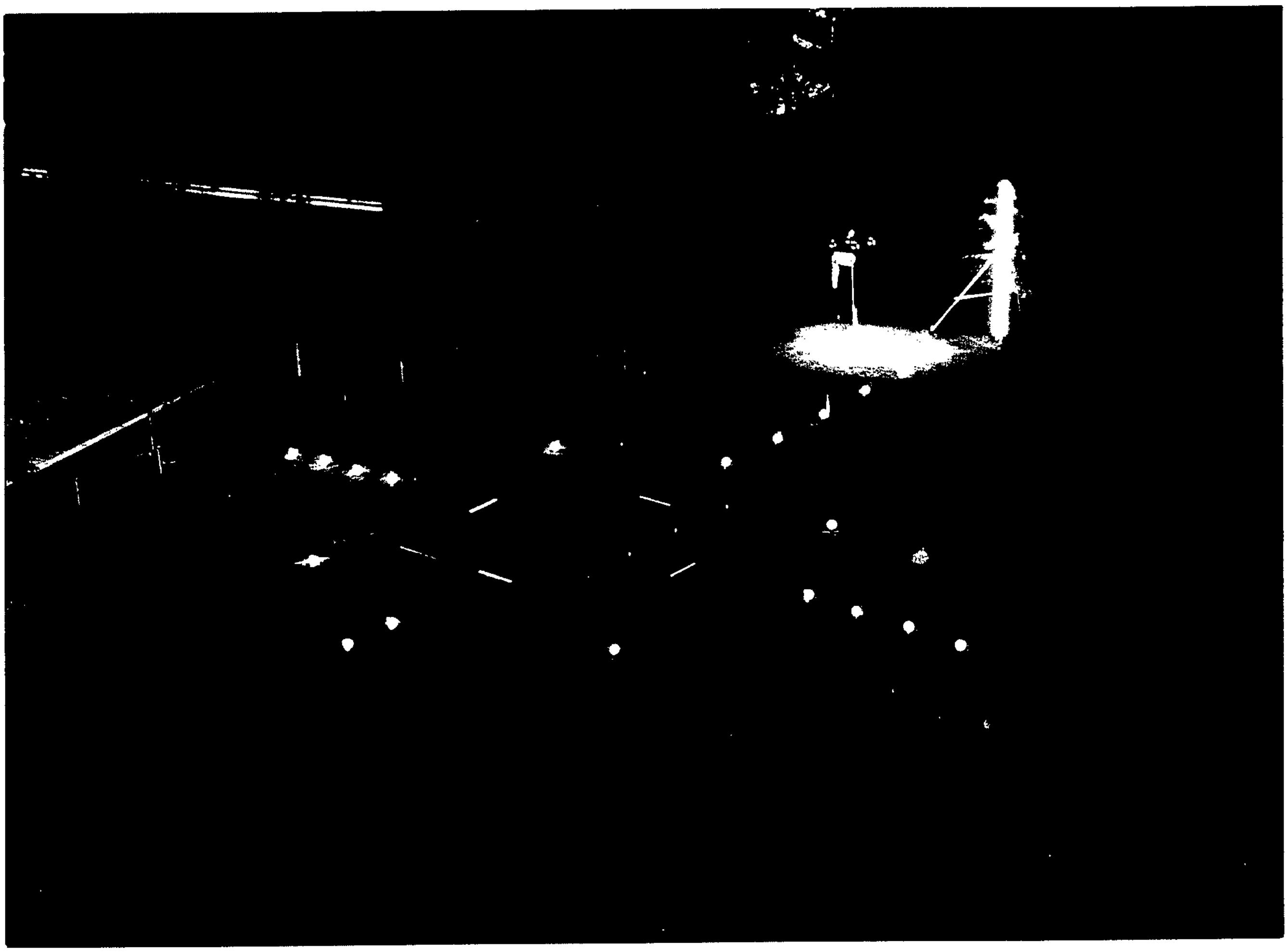

Figure 3. The Unique Lights of the Prototype Heliport Lighting System Made the NationsBank Southside Heliport Clearly Visible Even with Many Other Lights in the Vicinity

6.0 OPERATION HELI-STAR PROTOTYPE HELIPORT LIGHTING SYSTEM

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 miles away and yet 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 the myriad point source lights in an urban environment.
- The EL panels effectively outline the landing pad without introducing an obstacle.

6.1 Configuration

The light configuration shown in figures 2 and 3 was selected for the following reasons:

1. 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, particularly on steep approaches.

2. 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. Line-up cues are provided by the 90-degree angle between the extended lineup lights and the horizontal line of lights provided by both wing extensions. 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 last cue provided by the wing bars is an attitude or horizon cue.

3. The number of lights and circular pattern with wing bars were designed to provide surface lighting sufficient to illuminate microtexture[1] and to provide an easily recognizable pattern that will aid the pilot in determining and controlling closure rate.

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[1] Fine grained detail 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 simply to control the helicopter in a hover or in low

4. 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 4. This cue was adapted from Navy shipboard visual landing aids.

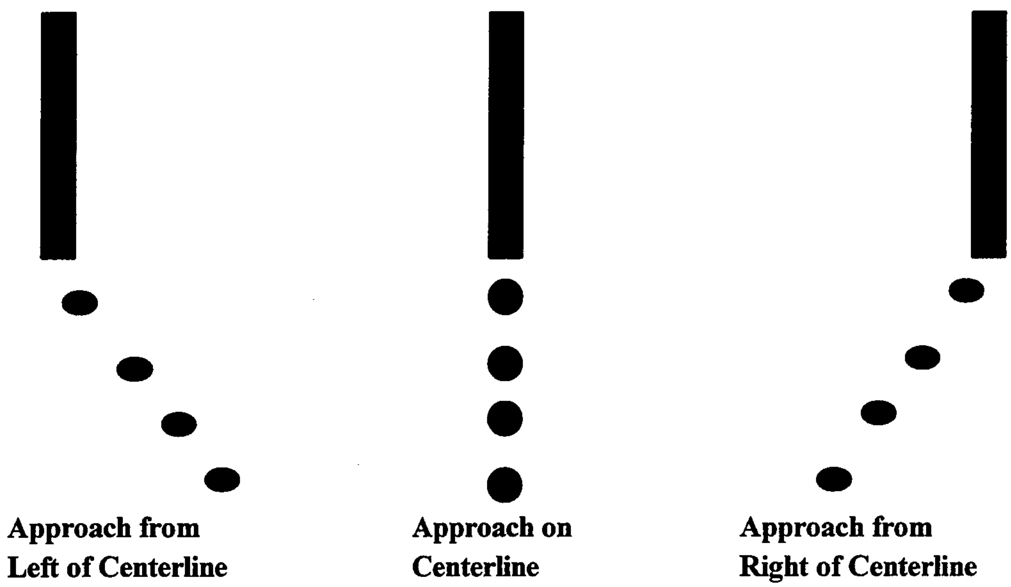

Figure 4 When the Approaching Helicopter Is Off Course, the Vertical Light Pipe Forms an Angle with the Extended Line-Up Lights Which Provides an Easily Interpreted Line-Up Cue.

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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.

6.2 Color

The color of the cold cathode lights was selected to maximize the ability of the eye to detect the light (references 8 and 10). The lights used at the NationsBank Southside heliport were estimated to be in the 530-540 nanometer wavelength range. The color was the closest available off-the-shelf color to a recommended blue-green color with a wavelength of 525 nanometers. As shown in figure 5, a wavelength of 525 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 almost unique, even in an urban environment. The spectral luminous efficiency, shown as the vertical axis in figure 5, is the reciprocal of the relative amounts of energy required to produce equal perceived luminance. Although the wavelength of 530-540 nanometers used in this evaluation met many of the design goals (that is, it was unique in color and it was visible to both the rods and cones), follow-on evaluations should use lights with a laboratory-verified color close to 525 nanometers.

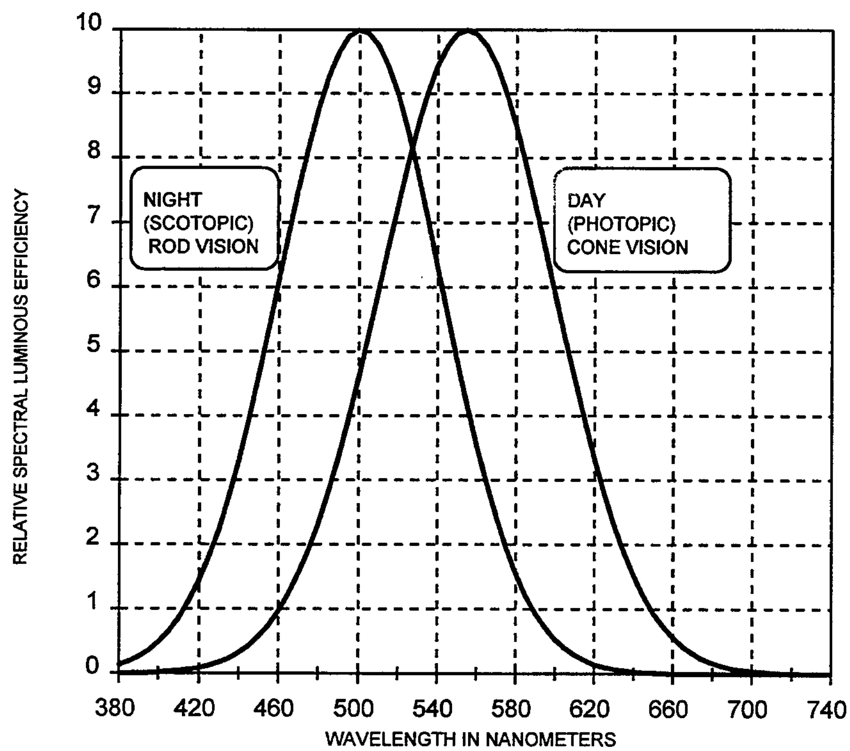

Figure 5. The Rods and the Cones of the Eye Are Equally Effective When Viewing Light with a Wavelength of Approximately 525 Nanometers

The color of the light pipe is determined by light source and any filter that may be installed. In this case, the light pipe provided by the manufacturer produces a slightly blue-green hue that was compatible with the color of the cold cathode lights.

6.3 Cues Provided by the Prototype Lighting System

The relative design strengths of the cues provided by various components are indicated in table 2.

Table 2 The Elements of the Prototype Lighting System Provide a Broad Range of Effective Cues to the Pilot

Prototype Lighting	*CUES*				
	Acquisition	*Lineup*	*Closure Rate*	*Touchdown*	*Glideslope*
Light Pipe	s	s	w		
Perimeter	s		m	m	
Glideslope Indicators		w			s
Perimeter Light Extensions	s	m	m	s	
Centerline Lights	s	m			
Centerline Light Extensions	s	s			w
Surface Flood Lights			w	m	
EL Pad Lights			w	m	
s = strong cue m = medium cue w = weak cue					

7.0 RESULTS

The promise of evaluating the prototype lighting system by large numbers of commercial pilots was not realized. Due to the physical constraints of the heliports used during Operation Heli-STAR, the heliport located at NationsBank Southside was selected for the prototype. Due to the long summer days and a limited night schedule, night traffic was minimal at all heliports. When the amount of cargo to be moved by air did not meet original estimates, the schedule was re-evaluated and the night flights to the NationsBank Southside location were eliminated. Security flights in the early morning, a very few night cargo flights, and a few dedicated evaluation flights were the only opportunities to evaluate the prototype lighting system. Pilot first impressions were all favorable, with the easily identifiable lights mentioned most. Video and still photography was obtained and the system was removed and shipped to Washington, DC for further evaluation.

The installation proved valuable, however, in that a semi-permanent installation, suitable for re-use, was built, improvements were made, and many parameters were identified for further evaluation in simulation and flight testing.

Based on the Operation Heli-STAR installation, the prototype system was modified slightly for installation in Washington, DC. Incandescent flood lights have not been used in the modified prototype. The cold cathode lights provide sufficient illumination, making the floodlights unnecessary. (This is fortunate since surface flood lights are often difficult to install without presenting a serious obstruction hazard.) The electroluminescent lights, as configured in the prototype, did not provide useful acquisition, closure rate, or lineup cues, but did provide a good, low profile outline of the wooden landing pad at Nations Bank South. Since the installation in Washington does not have a similar requirement to outline a landing pad, the EL lights were not used.

8.0 CONCLUSIONS

The following conclusions were reached through non-quantitative analysis:

- The prototype system has great potential to provide the required lighting cues and to meet most of the basic premises of this evaluation. That is, the lights appear to be suitable for VFR and perhaps IFR (although the issue of approach lights still raises many questions). They appear to be cost effective and they can be arranged to fit typical heliport sites.

- The acquisition cues provided by the prototype lighting system are very strong and appear to be suitable for most heliports. The color and characteristics of these lights were unique to the well-lit city environment and they were easily identified in the midst of a variety of typical city lights. These unique characteristics also improved the ease with which the pilot maintained visual contact with the heliport environment and significantly increased the amount of information provided to the pilot as compared to conventional incandescent heliport lights.

- The line-up cues are very strong and intuitive. However, the use of a vertically mounted light pipe may not be suitable for all heliports sites. If there are no obstacles already present at the proposed heliport site, the heliport designer should avoid adding one in the form of a light pipe.

- In clear weather, the cold cathode lights provide ample translational cues to support the transition to a hover, the hover itself, and landing tasks, without the use of additional floodlights. (No data were available in anything other than clear weather.)

- Separate parking was not required at the NationsBank Southside heliport. The helicopters landed on the pad and parked there to unload and load cargo. Other locations will require a separate pad for landing and parking and will require the integration of taxi lights into the lighting system.

- A demonstration-evaluation such as this requires a much longer evaluation time than allowed by Operation Heli-STAR and the Olympics.

- From many angles, this evaluation has shown that eight lights do not adequately differentiate a circular FATO from a square or rectangular FATO (see figure 3).

- The tests to date have revealed that simulation will not be able to capture correctly the characteristics that make these lights unique.

- Simulation will be useful in evaluating and optimizing the geometry of the proposed lighting systems.

9.0 SOME RECOMMENDATIONS FOR FURTHER WORK

The limited demonstration-evaluation conducted during Operation Heli-STAR also provided valuable insight into future evaluations and refinements of this lighting system. Some questions to be answered during follow-on evaluations are listed for each lighting component.

9.1 Light Pipe

How short can the light pipe be, yet still provide a useful line-up cue? Unless there is only one way in and one way out of the heliport, the height of the pipe determines the distance from the pad that it can be placed. The pipe must be placed so as to remain below the approach and departure surface, as defined by the Heliport Design Advisory Circular, and it must not pose a risk to flight operations.

How much is gained by adding a second vertical light pipe below and in front of elevated pads such as those on the tops of buildings? This pipe could be a different color (perhaps red) to indicate low altitude and to differentiate it from the ground level lights and the upwind light pipe.

What is the minimum length of the extended line-up lights in front of the light pipe, and is there a relationship between this length and the height of the light pipe? This is also an important factor in placing the array on elevated helipads or pads in close proximity to buildings.

How far from the pad can the light pipe be placed and still provide a useful line-up cue? If the pipe can be placed far enough from the pad, and still be useful, the pipe can be attached to adjacent buildings or existing obstacles that are out of the approach and departure paths.

Can light pipes be used to replace existing runway approach lighting? The light pipes can be placed horizontally, perpendicular to the runway, in place of rows of incandescent bulbs.

Can horizontal light pipes be used as lead-in lights? Light pipes can be arranged to form an arrow or a "V." *Will light pipes be cost effective? Are there lower cost solutions?*

How well does the light from the light pipe penetrate weather? Is it equal to, better than, or worse than conventional incandescent lights?

9.2 Cold Cathode Lights

What are the optimum and the minimum useful length and spacing for the wing bars?

What is the optimum and minimum number of lights required for the array? Does the number of lights vary depending on ambient lighting and visibility conditions?

Can cold cathode lights be used to provide easily identifiable "lead-in" lights to lead the pilot to the heliport from a point that is farther away from the heliport than the existing visibility? If so, what is the best configuration for these lead-in lights? The unique color and character of these lights make them easily identifiable in the midst of a sea of city lights. They have possibilities for not just identifying the heliport, but also for visually identifying a complex path leading to the heliport.

Can a line of cold cathode lights spaced at specific intervals be used as a closure rate cue? As the helicopter approaches the heliport, the lights of the wing bars separate from what appears to be a solid line of lights into individual lights with apparently greater distance between the lights. Various light spacings should be investigated to determine if a usable closure rate cue is presented to the pilot.

How well does the light from the cold cathode lights penetrate weather? Is it equal to, better than, or worse than conventional incandescent light? Since blue light penetrates fog (that is, there is less absorption than with red light), the blue-green cold cathode lights should perform better in fog than incandescent amber lights. This must be confirmed quantitatively.

How well do the cold cathode lights perform in the presence of snow, ice, and frost? These lights are more efficient because they do not "waste" energy in the generation of heat. This may be a serious disadvantage in cold climates. *Will temperature-activated heaters be required? Should these lights only be used in mild climates?* These questions need to be investigated.

9.3 FATO Edge Lighting

What is the significance of being able to differentiate between a circular FATO and a square or rectangular FATO? If it is significant, how many edge lights does this require? Figure 6 with 12 lights clearly shows a circular FATO. By comparison, the 8 lights in figure 3 do NOT clearly define the circular FATO.

9.4 Simulation

What is the role of simulation in developing lighting concepts or developing specific designs at a heliport? Many of the configuration modifications suggested above can be evaluated through the initial use of simulation. Conclusions reached in simulation can be verified in flight test. However, some of the differences in the color and character of various lighting technologies are difficult or impossible to replicate in a simulator.

REFERENCES

1. Anonymous; National Airspace System (NAS) Requirements, NAS-SR-1000; FAA, Washington DC; 1984.

2. Anonymous; FAA Memorandum; NAS Change Proposal (NCP) 12485; FAA, Washington DC; February 2, 1990.

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

4. Fisher, S., McConkey, E., Peisen, D., Sampson, W., and Judkiewicz, A., Editors; Operation Heli-STAR - Summary and Major Findings; prepared for the FAA, Washington DC, by Science Applications International Corporation, Arlington VA; Report No. DOT/FAA/ND-97/9; September 1997.

5. Anonymous; Heliport Design, Advisory Circular 150/5390-2A; Federal Aviation Administration, Washington DC; January 20, 1994.

6. Gilstrap, J.B. and Richards, R.B.; NAVTOLAND Program Report, Development of Visual Landing Aid Requirements, Task 2 - Initial Analysis of Display Requirements, prepared for the United States Navy, Naval Air Engineering Center, Lakehurst, NJ, by Pacer Systems, Inc., Billerica MA; May, 1976.

7. Kimberlin, R.D., Sims, J. P., and Bailey, T.E.; Heliport Lighting systems for GPS Approaches, Lighting Technologies, prepared for the Federal Aviation Administration by the University of Tennessee Space Institute, Tullahoma TN 37388; under contact to Science Applications International Corporation, Arlington VA; May 1, 1995.

8. Kimberlin, R., Sims, P., Wright, S.H., and Ernst, C.; Test Plan for the Evaluation of the Effects of Heliport Lighting System Color on Pilots' Night Adaptation; prepared for the Federal Aviation Administration by the University of Tennessee Space Institute, Tullahoma, TN under contact to Science Applications International Corporation, Arlington VA; January 31, 1996.

9. Hoh, Roger, H.; The Effects of Degraded Visual Cueing and Divided Attention on Obstruction Avoidance in Rotorcraft; prepared for the Starmark Corp., Arlington VA and Systems Control Technology Inc., Arlington VA, under contract to the FAA December, 1990.

10. Kaufman, J. E., editor; IES Lighting Handbook, The Standard Lighting Guide, Fourth Edition; Illuminating Engineering Society, New York NY.