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FogEye Sensor System: Low Visibility Landing Test (Phase-IV Report)

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)
= 1.1 short tons

VOLUME (APPROXIMATE)

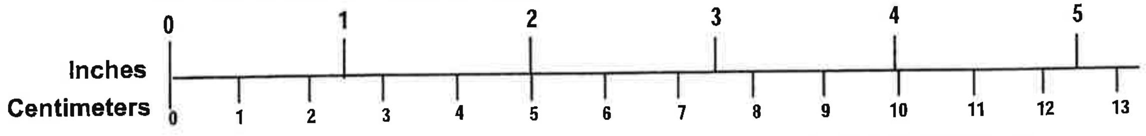
1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)

1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

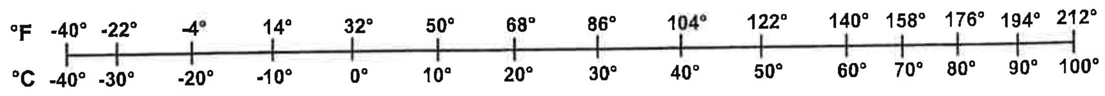
TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 6/17/98

PREFACE

FogEye technology employs radiation in the solar-blind region of the ultraviolet spectrum to operate sensors and systems that have favorable atmospheric characteristics during all aviation weather conditions. Congress requested the FAA to evaluate the feasibility of applying this FogEye technology to aviation-related problems. The FAA's Office of Surface Technology Assessment (AND-520) assumed responsibility for this investigation and requested the support of the Volpe Center.

The FogEye Sensors were provided by Norris Electro Optical Systems Corporation.

This evaluation has thus far extended over a two-year period, 2002 and 2003, in response to Congressional Directives for each of the two years. The first year involved evaluation of the characteristics of FogEye technology and an assessment of the application of the technology as a sensor that would aid in runway incursion prevention. The first half of 2003 was devoted to evaluating an aircraft presence detection sensor, Safety Sentry, at a commercial airport. The later half was directed toward assessing a second application – as an aid during low visibility landings. Limited static tower tests were conducted, concurrent with dynamic flight tests. This report addresses the flight tests.

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Executive Summary

The potential of FogEye solar blind UV technology to contribute to safe and swift throughput operations at airports has been demonstrated. One application, use of FogEye (Safety Sentry), as an aircraft surface detection sensor has been successfully operationally tested at a commercial airport[1]. Another application for FogEye technology is as an aid during low visibility landings. A Phase III effort during FY 2003 was directed toward static tower evaluation during fog. The landing aid hardware consisted of a FogEye imaging sensor and UV augmented runway edge lights[2]. A Phase IV effort during FY 2003 was conducted to concurrently flight test FogEye UV imaging sensor and augmented runway lights at a commercial airport. This report describes these tests, and presents an analysis of the results.

The Phase IV test consisted of:

- Integrating the FogEye Sensor System with the Head Up Display (HUD) of a Head Up Guidance System (HUGS),
- Conducting flight tests at the Greenbrier Valley Airport,
- Recording the performance of FogEye as an Integrity Monitor, and
- Compiling quantitative databases to allow for digital refinement of automatic camera gain control and intra-frame dynamic range compression.

Over a period of 3 days, 21 test flights were flown in an instrumented Cessna 402. The weather conditions were clear for all flights. Observations show that using the FogEye Sensor System the pilot could pick up the augmented UV runway lights at distances beyond normal visual range. Observations also show that approach light discernment range depended on FogEye gain settings.

The results of the tests were favorable and demonstrated the fundamental principle of operation for the FogEye UV Sensor System's use as a low visibility landing aid. Flight test recordings demonstrated that cross checks between the actual touchdown zone and the equivalent guidance vector signal location were achieved. Further test in fog/low visibility conditions with the FogEye Sensor System is recommended.

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[1] Clark, K., "FogEye Sensor Evaluation Phase-II", December 2003

[2] Clark, K., "FogEye UV Camera System Phase-III", February2004

1.0 INTRODUCTION

1.1 Background

The goal of the work reported here is to improve our capability for safely landing under low visibility conditions. Given that modern flight control systems can make completely blind ILS landings, why is there any need for any other systems? Why is it important for the pilot to make contact with the ground before reaching the decision height? The answers have to do with ILS reliability and human factors:

1. Certification for blind landings is very costly. The validity of the ILS signals and avionics equipment must be continually verified. Substantial pilot training may also be necessary, for example, to make a missed approach when ILS validity is lost.

2. The concept of a decision height permits the pilot to verify that following the ILS has placed him in the correct position for landing while giving the leeway for a safe missed approach if ground contact is not achieved.

3. Under low visibility conditions the pilot's first contact with the ground is by seeing the approach lights. Seeing the well-defined pattern of the approach lights accomplished two purposes: a) it verifies that the ILS equipment is operating correctly and b) it gives the pilot a sense of his spatial location with respect to the runway. The second purpose could be also achieved by projecting an ideal view of the runway lights on a HUD, based on the measured location and attitude of the aircraft. Thus, the first purpose is probably more fundamental than the second. Modern terminal guidance systems are more complicated than traditional ILS systems and hence have even greater requirements for validation.

Norris Electro Optical Systems Corp has conducted dynamic measurements of the ability of solar blind UV technology to see through fog. These tests, on an airport surface, demonstrated that a FogEye imaging sensor could detect a very low power UV source at a distance of 2,800 feet under 700 feet visibility conditions[3]. Congress requested that the FAA evaluate the FogEye Sensor System as a potential landing aid during low visibility conditions.

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[3] NEOS, "FogEye Dynamic Surface Tests"; Video Recording; August 1996

2.0 TEST OBJECTIVES AND METHODLOLOGY

2.1 Test Objectives

2.1.1 General Test Objectives

In order to determine the capabilities of the FogEye Sensor System dynamic recordings of analog and digital images during approach and landings were required. This data was used for:

a. Quantifying camera gain settings and providing a quantitative data base for refinement of digital image processing techniques.

b. Evaluating the operational effectiveness of the FogEye Sensor System by comparing FogEye's actual touchdown zone location with the location of the primary guidance signal.

c. Quantifying the FogEye sensor characteristics in clear weather and postulating performance in fog.

The evaluation status of the FogEye Sensor System is presented in Table 2-1. The tests described herein were conducted during clear weather with a FogEye analog Demonstration Model. A more specific enumeration of the flight test objectives follow. The end result of these objectives are the accumulation of a data base that will allow for refinement of robust automatic gain and digital processing techniques.

Table 2-1. FogEye UV Camera System Evaluation Status

Capability of Technology	Analog Demo Model
Contractor Runway Tests	☒ fog
Volpe Center Tower Tests[4]	☒ fog
Operational Evaluation	
Volpe Center Flight Tests	☒ clear

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[4] Clark, "FogEye UV Camera System: Phase-III Report", February 2004

2.12 Specific Flight Test Objectives

1. Evaluate operational effectiveness of the FogEye Sensor System's ability to integrate the locations of the landing zone lights on a HUD with the location of the guidance vector signal and to observe the dynamics of the aircraft flight vector relative to the landing zone light locations.
2. Obtain dynamic recordings of digital and analog imaging to enable:
    a. Determination of approach, decision height, and landing state camera gains.
    b. Integration for long range detection.
    c. Intra-frame gain variation for wider dynamic range.
    d. Determination of the location of the nearest four runway edge lights to enable extrapolation to the locations of more distant runway edge lights.
    e. Characterization of an optical attenuator.
    f. Plotting of camera gain vs. detection range during clear weather to determine gain margin available to compensate for light attenuation during fog.
    g. Display of digital (stroke scan) imagery on the HUD vs. analog (raster scan) imagery.
    h. Digital signal processing of the blob intensities to allow for: use of blob intensity profiling and centroiding techniques to isolate adjacent blob locations that appear to "run together"; summing of actual blob intensities per frame to determine magnitude of sensor AGC control signal; and dynamic blob volume and intensity thresholding to isolate blobs and pull out from accompanying, self generating, random background.
3. Validate solar blind operation of the camera; i.e., absence of background noise in imagery of airport light locations.
4. Evaluate performance of UV-augmented lights
    a. Field of view and alignment variations
    b. Adequate intensity
    c. Not distracting to the visible eye.

2.2 Test Methodology

2.2.1 Purpose Per Phase

The evaluation program has been divided into phases that incrementally build up to an assessment of the FogEye Sensor System capability.

Phase III (2003) – Baseline the technology characteristics of the analog Demonstration Model at the Volpe Weather Test Facility (WTF) @ OANGB;

Phase IV (2003) – Record flight data at Greenbrier and subsequently refine hardware and software performance of the analog Demonstration Model

2.2.2 Phase IV Test Description

The flight tests were conducted with a Cessna 402 flight test aircraft that flew low level approaches to Manassas Regional Airport, VA and the Greenbrier Valley Airport, Lewisburg, WV. Landings were also conducted at the Greenbrier Airport. A FogEye Sensor System consisting of a UV imaging camera and related equipment were installed in the fully instrumented aircraft. UV augmented lights were installed on the runway at the Greenbrier Airport immediately adjacent to existing lights. The tests were conducted during late December 2003 and early January 2004. Clear weather prevailed during the tests. The tests were originally scheduled for earlier in the year, during the peak fog interval. However continued delays were experienced by the flight test aircraft operator in gaining release of the aircraft from its annual inspection.

Results of the Phase III effort are reported in a separate document noted earlier. This report describes Phase IV and also provides a supplement to the Phase III report on additional results that have been realized relative to the Phase III objectives. Phase IV involves the recording of dynamic flight performance parameters at Greenbrier Valley Airport. The recordings will contain data sufficient to exercise the hardware optical characteristics and image processing capabilities during bench tests as if operating under a total flight conditions.

The duration of the recordings are from five miles from the touchdown point until the aircraft has slowed to runway exit speed. Recordings were obtained from multiple approach and landing sequences under varying circumstances. The data recorded includes the composite image on the HUD, the individual video output of the FogEye Sensor System, visibility and time. The recordings are synchronized to enable the flight scenario to be reproduced during bench playback. The initial purpose of the recordings is to allow for an assessment of the effectiveness of (1) landing light hardware modifications, (2) UV sensor hardware modifications, and (3) signal processing of the UV imagery, in reducing landing light blooming and aiding in the isolation of the locations of each of the lights.

2.2.2.1Test Hardware

A block diagram of the FogEye Sensor System and instrumentation is provided in Figure 2.2.1. Photos of the airborne test hardware are provided in Figure 2.2.2. The layout of the UV augmented runway edge and threshold lights is provided in Figure 2.2.3. Twenty-four ultraviolet runway edge lights and four ultraviolet threshold lights were placed around on the runway as shown in Figure 2.2.3. Locations for two of the twelve lights on the left side of the runway were in the middle of taxiway intersections and hence were not deployed. The field of view of each of the lights on the right side of the runway was reduced, relative to the field of view of the lights on the left side of the runway. The alignment angle set for the lights at 200 ft and 400 ft on the right side proved to be too canted to the left and hence they were not detectable. Otherwise, the intensity of each of the right side lights was less than the intensity of each counterpart on the left side. However, the difference was not as great as was expected. The cause was traced to internal reflections within the lamps that caused radiation patterns wider than anticipated. A more effective runway light radiation pattern will result. Several of the lights were designed to provide no visible output. The design proved to be effective.

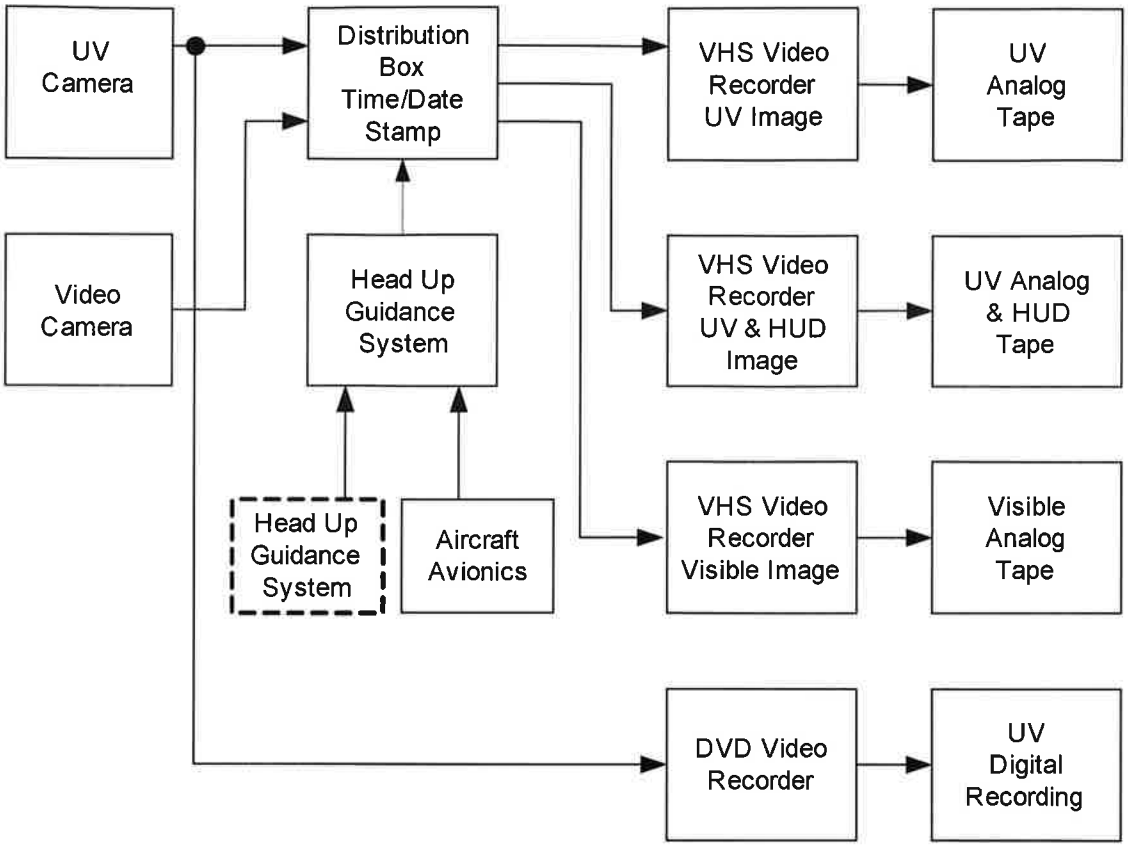

Figure 2.2.1 FogEye Sensor System and Instrumentation Block Diagram

Test Aircraft

Figure 2.2.2-a

Sensor Installed in Aircraft

Figure 2.2.2-b

HUD

Figure 2.2.2-c

Aircraft Instrumentation

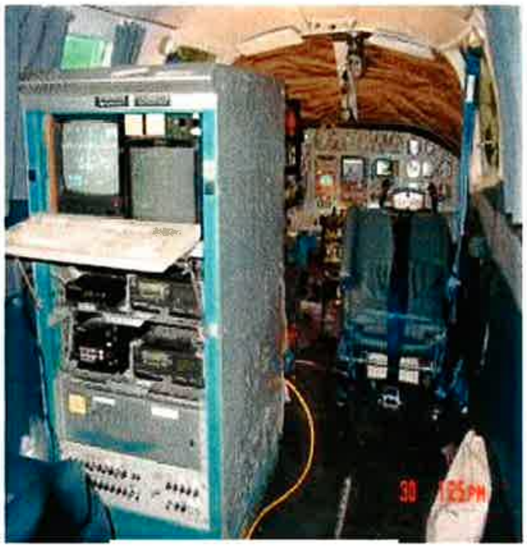

Figure 2.2.2-d

Figure 2.2.2 Flight Test Hardware

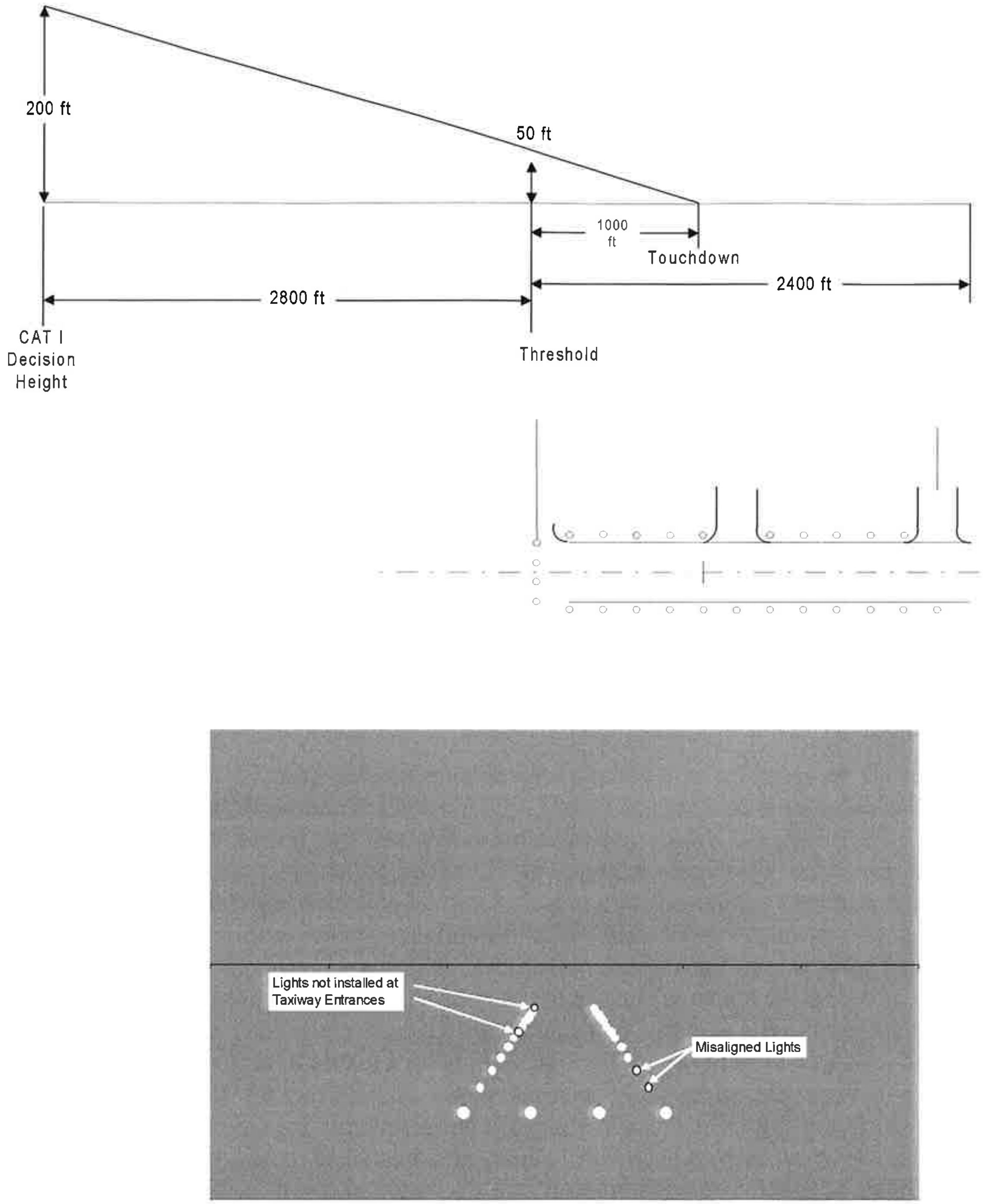

Figure 2.2.3 Placement of UV Augmented Lights

3.0 TEST DATA

A total of 21 flight test sorties were conducted. A breakdown of these flights is shown in Table 3-1. The gain settings for the FogEye Sensor System's camera were manually set prior to each approach cycle. As the flight testing progress results of the difference gain settings were characterized as very weak images, crisp images, or blooming images. Refer to Table 3-2.

The camera gain settings were set by adjusting the intensifier voltage value and the pulse width value. The intensifier value could range from 1000, the lowest gain setting, to 0, the highest gain setting. The intensifier gain can also be changed by varying the time duration during which the intensifier voltage value is applied. This pulse width can be varied from 2000 msec microseconds to 16000 msec microseconds. The pulse width and intensifier value are used for fine tuning and significant for adjustment for range and sensitivity. In addition and for documentation of parameters, optimum gain settings were established.

Post flight analyses of the intensifier gain and companion pulse width settings for the UV detector shown in Figure 4.2-1a provide baseline sensor data in two areas: a static baseline gain bias value about which an AGC voltage might vary, and a measure of maximum detection range for a given intensifier voltage value during different visibility conditions. In the first instance, crisp or lightly blooming images were obtained over intensifier values ranging from 550 to 750, with a constant pulse width value of 2000 microseconds. These values will enable implementation of automatic gain control, by varying the pulse width value, as described in paragraph 4.2. An intensifier value of 350 was employed during maximum detection range tests, as indicated by a light detection parameter value of 3404.

The column labeled DVD time reference value indicates the time reference on the UV digital recording, obtained as described in Figure 2.2.1. The VCR time reference value is the time annotation on the UV analog tape that was recorded as also shown in Figure 2.2.1. The first light detection time is the time annotation on the UV analog tape when a UV image was first detected on a display. The first light detection barometer column values are the barometer readings corresponding to the time at which detection of the UV image first occurred. The barometric reading at runway ground level was 2288. Subtracting this ground level reading from the barometric values provides a rough indication of the altitude at which the detection occurred. If we assume that the aircraft is approaching the runway at a 3-degree glide slope we can solve a trigonometric relationship to obtain a rough indication of the range from a runway at which the detection occurred. If, for example, the barometer read 3404, subtracting a value of 2288, leaves a value of 1116. Assuming a 3-degree glide slope, the distance from the airport can be calculated to be 21,462 feet. We assumed a value of 21,500 feet when we were calculating detection range in fog as shown in Figure 4.1.1b. A companion calculation to establish additional camera gain available employed a gain setting of 350, as discussed earlier, and utilized in Figure 4.1.1a.

Table 3-1. Flight Test Log

Location	Date	No. of Flights	Type
Manassas Regional Airport, VA	1/03/04	7	Approach & fly over
Greenbrier Valley Airport, WV	1/06/04	10	Approach & fly over
Greenbrier Valley Airport, WV	1/07/04	4	(2) Flyovers (2) Landings

Table 3-2. Log of Flight Test Results

Light Locations	Intensifier Value	Pulse Width Value	DVD Time Reference	VCR Time Reference	1st Light Detection Time	1st Light Detection Barometer	Notes
			01-06-04 Tuesday AM				
Full Set 12+4th	650	2000 usec	00.22	10:57	10:57:21	2704	100-50 ft; very good detection; short turn range
Full Set 12+4TH	650	1000 usec	08:00	11:01	11:01:30	2752	100-50 ft; very good detection; short turn range
Full Set 12+4TH	650	4000 usec	14:25	11:05	11:05:32	2600	100-50 ft; fuzzy detection; short turn range
			01-06-04 Tuesday PM				
Full Set 12 + 4TH	850	2000 usec	07:02	16:06	16:06:39	2632	100-50ft; crisp detection; very good turn range
Full Set 12 + 4TH	750	2000 usec	15:05	16:14	16:14:50	2772	100-50ft; crisp detection; very good turn range
Full Set 12 + 4TH	650	2000 usec	20:10	16:19	16:19:43	2628	100-50ft; very light bloom; good turn range
Full Set 12 + 4TH	550	2000 usec	25:20	16:24	16:24:56	2968	100-50ft; light bloom; very short turn range
Full Set 12 + 4TH	450	2000 usec	00:30	16:31	16:31:24	3252	100-50ft; bloom; short turn range
Full Set 12 + 4TH	350	2000 usec	08:05	16:38	16:38:57	3404	100-50ft; heavy bloom; short turn range
Full Set 12 + 4TH	250	2000 usec	14:30	16:45	16:45:54	2772	Landing; extra heavy bloom; very short turn range
			01-07-04 Wednesday PM				
Full Set 9 + 2 TH	650	2000 usec		11:01	11:01:19	3064	100-50ft; crisp detection; good turn range
Full Set 9 + 2 TH	550	2000 usec		11:11	11:11:19	3224	Landing; light bloom detection; good turn range
Full Set 9 + 2 TH	750	4000 usec		11:34	11:34:19	2920	100-50ft; crisp detection; good turn range
Full Set 9 + 2 TH	750	8000 usec		11:46	11:46:09	2972	Landing; light bloom detection; good turn range

3.1 Flight Recordings

Emphasis was placed on recording of the locations of the UV augmented lights at three key points: airport detection, 200 ft decision height, and directly over threshold. Light images at these points are shown in Figures 3.1-1 through 3.1-3. Each UV image is accompanied by a visible image of the same scene. The airport detection range of about 21,5000-ft figures 3.1.1 was achieved in clear weather. The equivalent detection range for 700 ft fog has been calculated in section 4.1. Figures 3.1.2 show the locations of the UV-augmented lights from a view at 200 ft decision height and directly over threshold. Note the view is skewed due to aircrafts crab angle during approach. This crabbing was to counter cross-wind gusts of 15-16 knots. The relative weak intensities of the runway light outlines are thought to be due to a mismatch in the input gain levels of the raster-scanned images. Table 3-3 provides the time designations on each of the tapes for the designated still shots. In addition, portions of tapes are available that present one or two minutes of continuous recordings. The sequences and the time designations are so labeled in the table.

Table 3-3. Tape Settings

Type of Recording	Date of Tape	Start Time	Stop Time	Event Title
2a Overhead Camera Video	01/06/04	16:06:48	16:07:14	Approach & Fly Over
2a UV/HUD Video	01/06/04	16:06:48	16:07:14	Approach & Fly Over
2b Overhead Camera Video	01/07/04	11:01:57	11:02:30	Approach & Fly Over w/Gusts
2b UV/HUD Video	01/07/04	11:01:57	11:02:30	Approach & Fly Over w/Gusts
2c Overhead Camera Video	01/76/04	11:11:53	11:13:00	Approach & Landing
2c UV/HUD Video	01/07/04	11:11:53	11:13:00	Approach & Landing
3a Overhead Camera Video	01/06/04	16:06:54	16:06:54	200 Ft Height
3a UV/HUD Video	01/06/04	16:06:54	16:06:54	200 Ft Height
3b Overhead Camera Video	01/06/04	16:07:06	16:07:06	50 Ft Height
3b UV/HUD Video	01/06/04	16:07:06	16:07:06	50 Ft Height
3c Overhead Camera Video	01/07/04	11:12:54	11:12:54	Touchdown
3c UV/HUD Video	01/07/04	11:12:54	11:12:54	Touchdown
4 Overhead Camera Video	01/07/04	11:11:37	11;12;53	Detection Range
4 UV Video	01/07/04	11:11:37	11;12;53	Detection Range

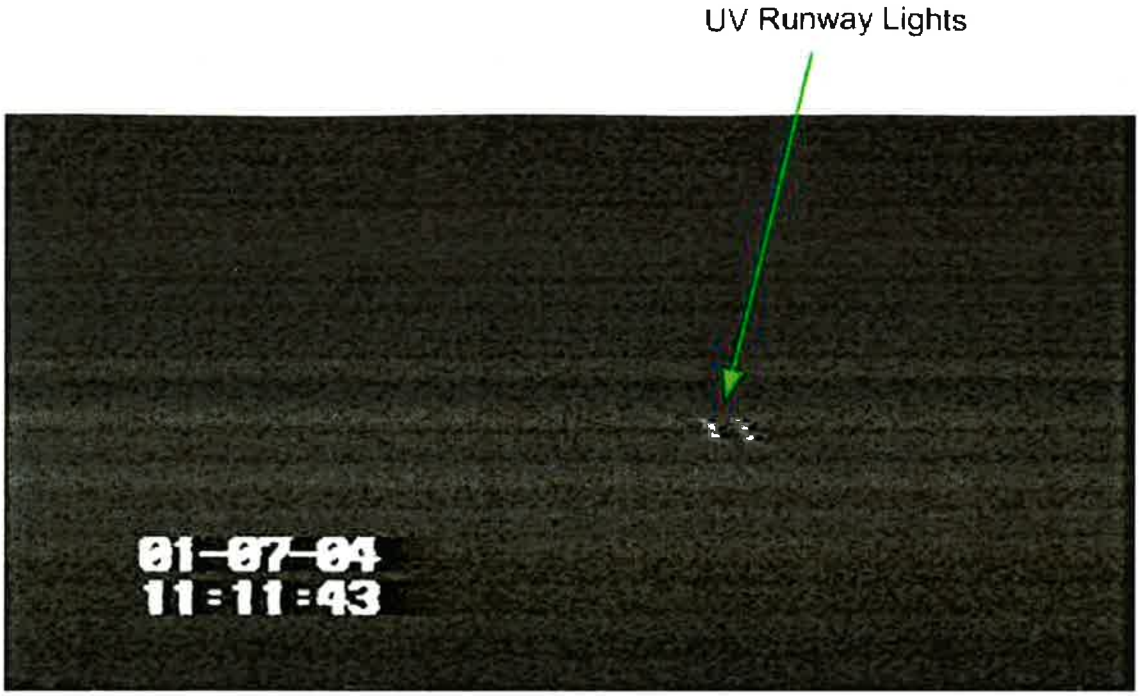

Figure 3.1-1a - Image of UV Augmented Runway Light Location at 21,500 Ft

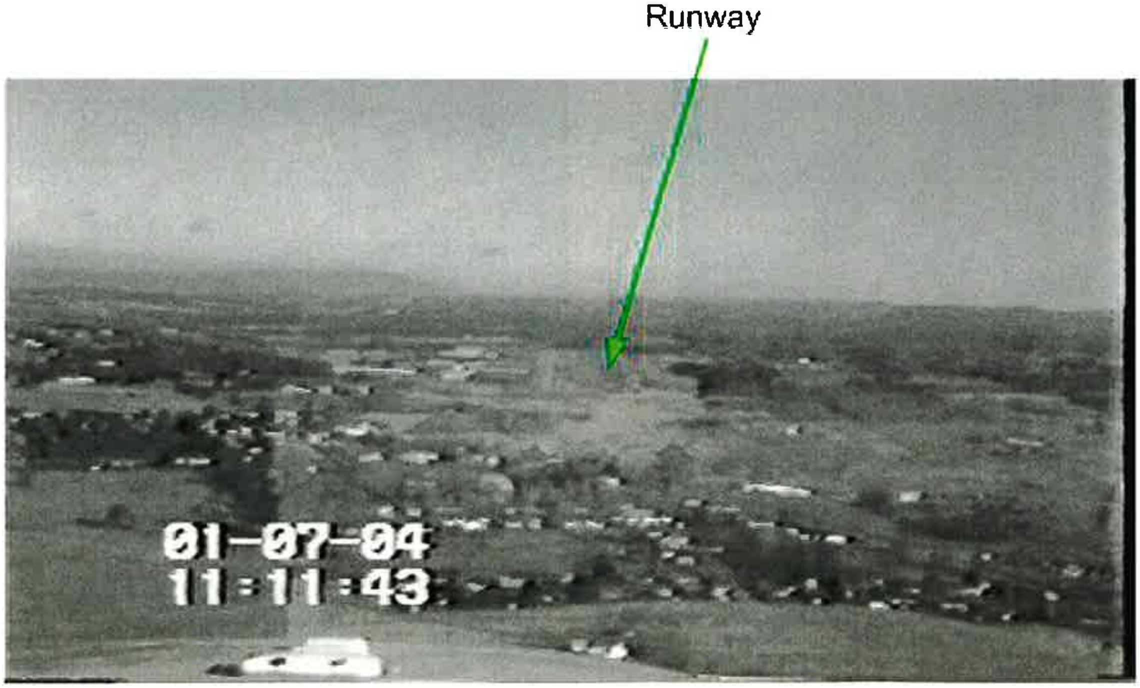

Figure 3.1-1b - Visible Camera Pilot's View of the Airport Region from 21,000 Ft Distance

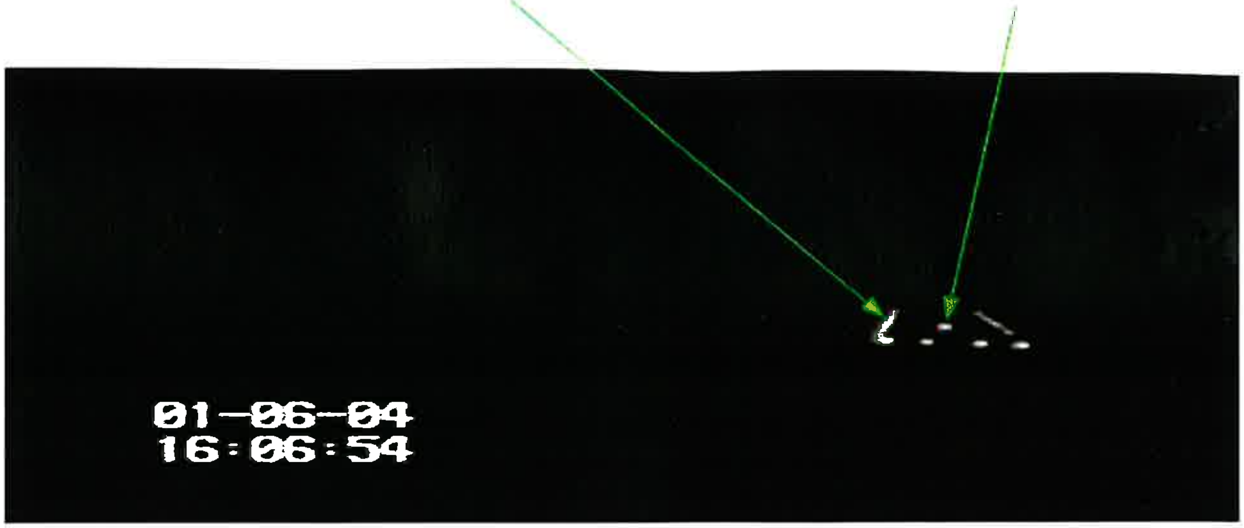

Figure 3.1-2a – Outline of UV Augmented Runway Lights

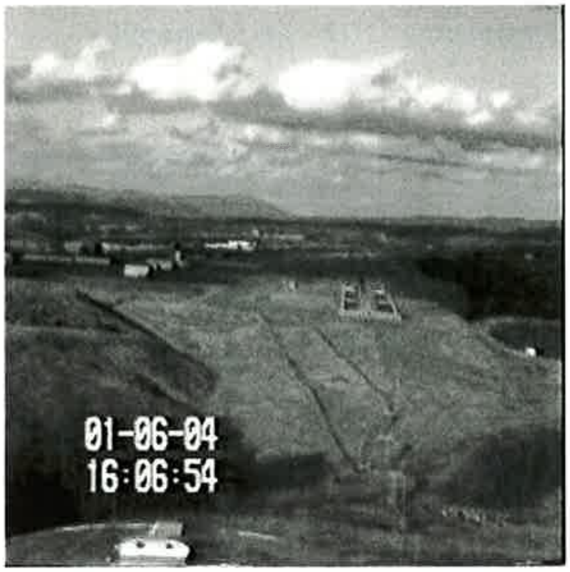

Figure 3.1-2b - Visible Camera - Pilot's View from 200 Ft Decision Height

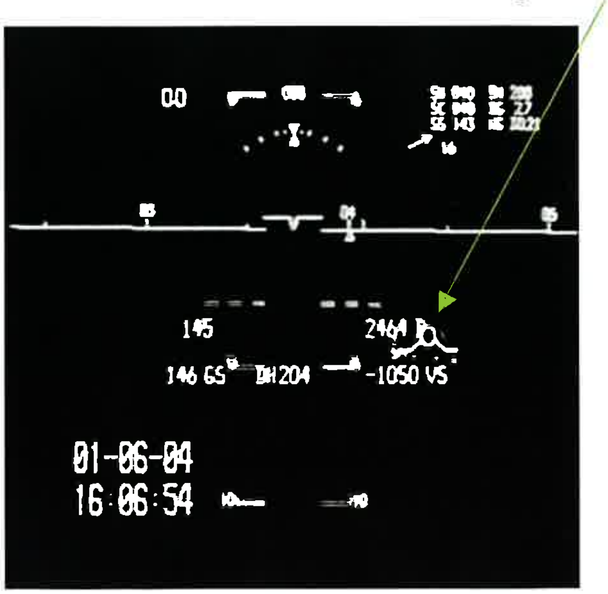

Figure 3.1-2c – UV Light Image Superimposed Over Flight Control Vector Location

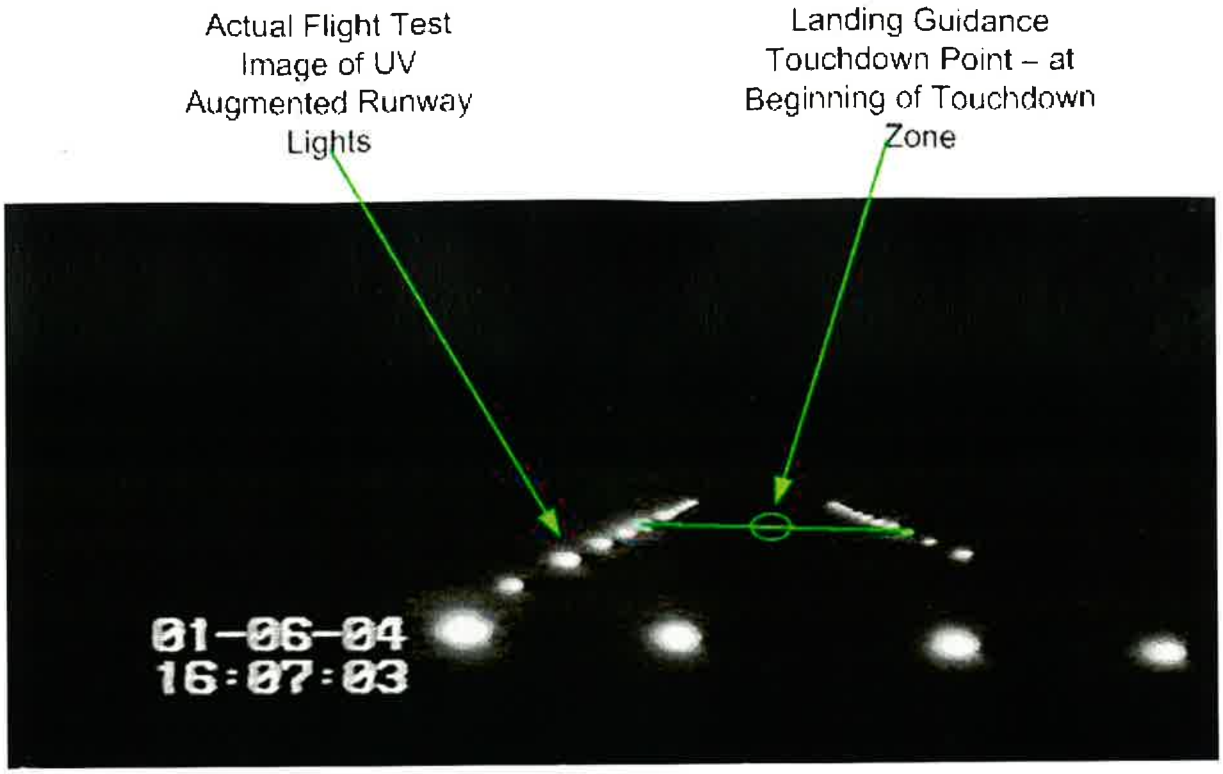

Figure 3.1-3a – UV Augmented Light Locations Outline Touchdown Zone

Figure 3.1-3b - Visible Camera - Pilot's View at Threshold Crossover

Figure 3.1-3c – UV Light Image Superimposed Over Flight Control Vector & Other Symbology

4.0 DATA ANALYSES

The flight tests were originally scheduled to be conducted during the peak season for fog at the Greenbrier Airport. However, the availability of the flight test aircraft was delayed numerous times due to failures in meeting the aircraft's annual inspection requirements. These series of schedule slippages, and time constraints, caused the flight tests to be conducted during clear weather. The results have therefore been analytically extrapolated to predict performance during low visibility conditions. These extrapolations are forming a basis for sensor adaptations that are being incorporated prior to actual flight tests in fog.

4.1 Projected Performance in Fog

Table 4-1 depicts the projected performance in Fog. The optimum camera gain setting for the clear weather test is shown in Figure 4.1-1a. The gain setting is compared to the overall gain of the system. The actual gain setting of 6,500 is modified by the duration of this voltage (i.e. electronic shutter ratio) that is applied to the camera in order to achieve the desired gain. The static gain setting was accompanied by a 2,000 micro-second pulse duration. These factors combined to indicate that a camera gain factor of 616 was still available and could be used to detect weaker signals. The actual operating point during the clear weather test is shown in Figure 4.1-1b. The figure also depicts the additional atmospheric attenuation that would be experienced during a 700 ft fog, and at a much shorter distance. The plot shows that an additional attenuation of 298 can be expected. The ratio of the attenuation expected vs. the gain available indicates a favorable factor of two in performance margin. These results are consistent with earlier contractor tests that indicated a UV camera could detect UV lights at distances of 2,800 to 3,200 ft during 690 ft fog conditions[5].

Table 4-1

	Visibility	Camera Gain			Detection Range - Feet	Atmospheric Attenuation
		Level	Electronic Shutter	Net		
Actual Results	**Clear: 32,800 ft**	**6,500**	**2,000**		**21,500**	300×10^{-12}
Projected Performance in Fog	**700 ft**	**500,000**	**16,000**		**2,400**	6×10^{-12}
Delta		**77**	**8**	**616**		**298**

Potential Gain: 616 ≅ 2X
Projected Attenuation: 298

$$\frac{616}{298} \cong 2X$$

Camera Gain Margin of 2 Available for Fog Penetration

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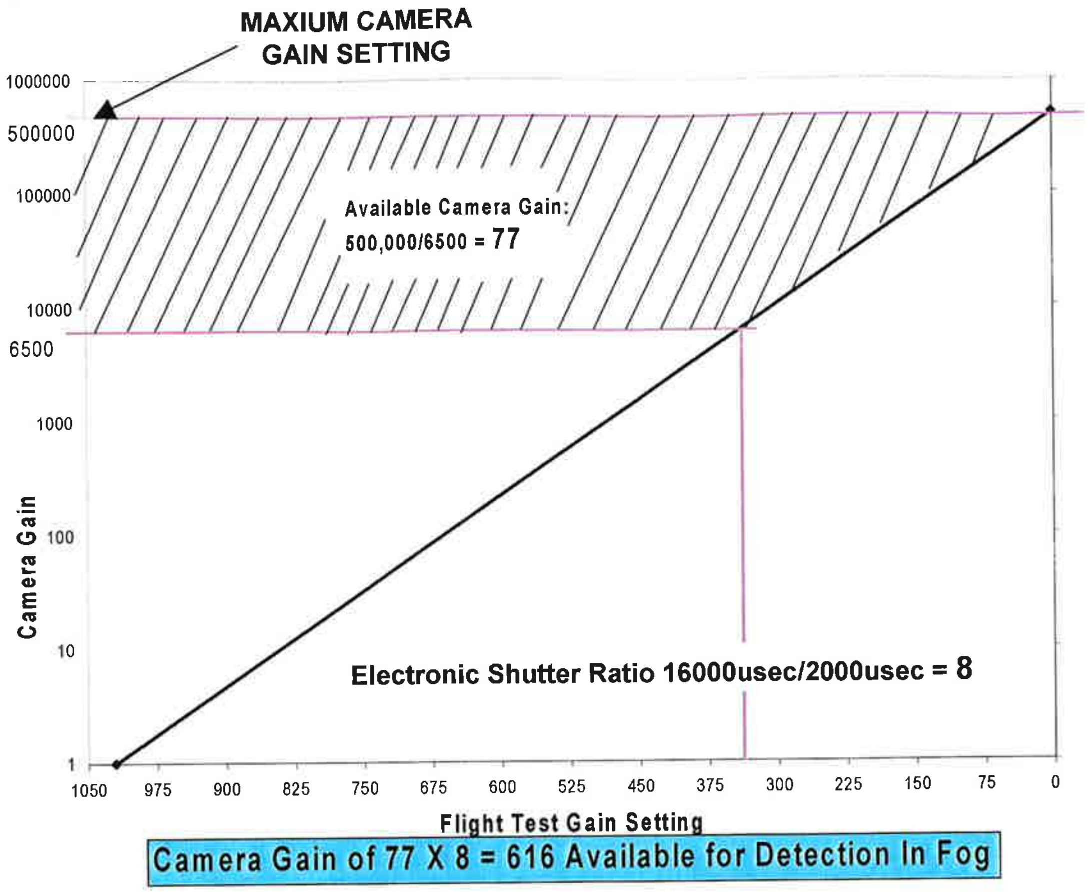
[5] NEOS, "FogEye Dynamic Surface Tests"; Video Recording; August 1996



Camera Gain of 77 X 8 = 616 Available for Detection In Fog

Figure 4.1.1a – Flight Test Camera Gain for Clear Weather

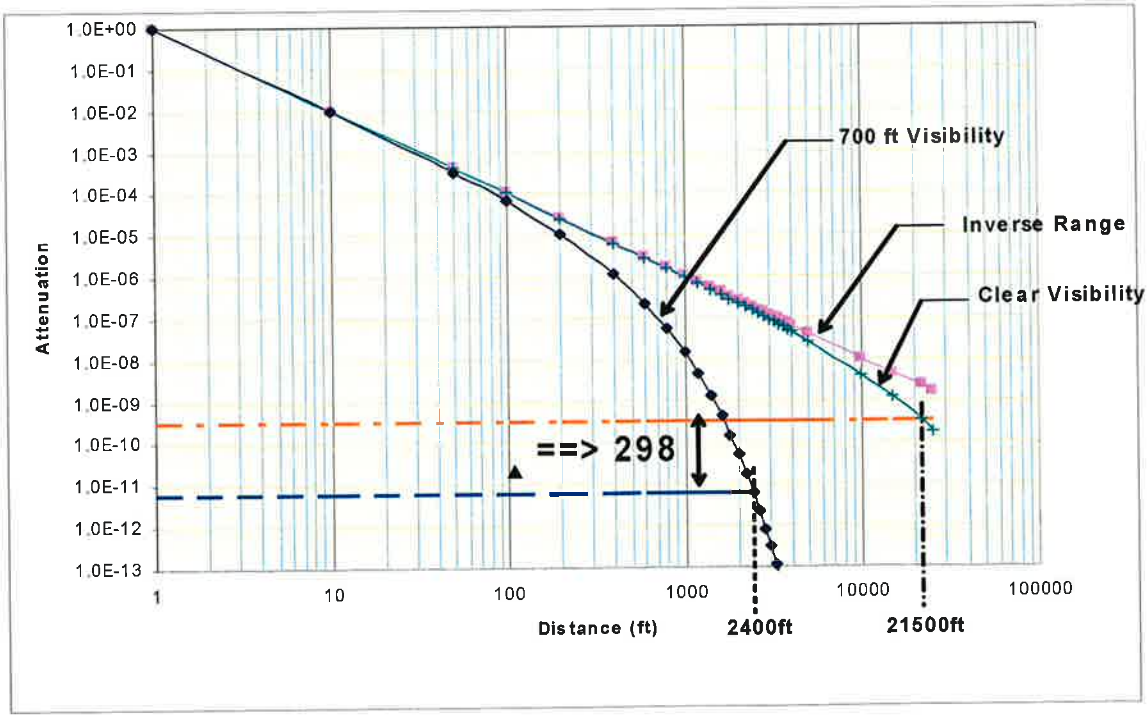


Figure 4.1.1b – Additional Camera Gain of 298 Required for Detection in Fog

4.2 Projected Image Enhancement

The flight tests were conducted with a FogEye Sensor, Demonstration Model camera that operates in an analog signal mode. Refer to Figure 4.2-1a. The camera reads out in a RS170 analog format. This signal was transferred directly to the HUD electronics. The HUD in the flight test aircraft had a raster scan capability and hence directly accommodated the RS170 format. This mechanization was ideal for these flight tests. The camera was operated in a manual gain mode during flight by a NEOS video engineer who continually monitored the displayed analog signal level. Also, intentionally, no signal enhancements were introduced. The engineer was therefore able to determine optimum gain settings throughout the approach and landing sequence during clear weather conditions. Thus image quality vs. gain settings were obtained for all 21 approaches. In some instances, the gain was set intentionally high to artificially introduce blooming between adjacent lights and to introduce random background noise or halo, about the light locations. A quantitative data base was thus established. It will now allow for implementation of automatic camera gain control and for intra-frame dynamic range compression techniques.

An example of digital video processing is shown in Figure 4.2-2. In this instance, analog camera imagery was digitized. The digital imaging was then processed to isolate the light locations. A box was then placed around each location to indicate its size and position has been determined. The X-Y tags of each of these boxes are then formatted and transmitted to a stroke scan HUD.

Figure 4.2-1a – Analog Camera Design

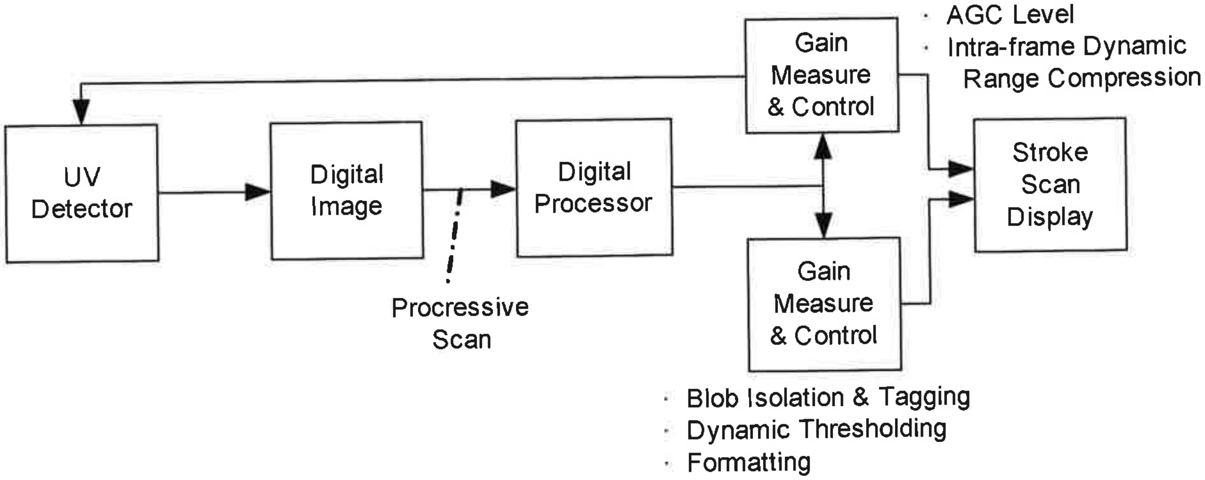
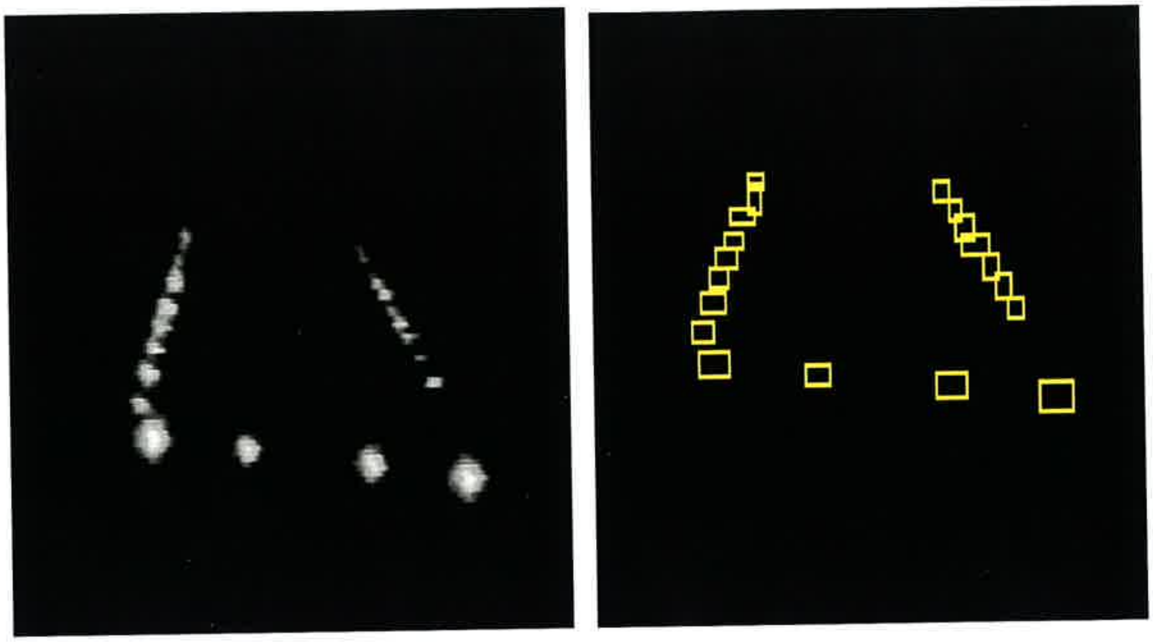


Figure 4.2-1b – Digital Camera Design



Direct Analog Video

Real Time Digital Image

Figure 4.2-2a

Figure 4.2-2b

Figure 4.2.2a – Digital Processing of Analog Video

5.0 TEST RESULTS

Observations and data from the FogEye Sensor System indicate the flight tests were successful. The ability to distinguish the runway at a distance beyond visual range demonstrated the fundamental principle of operation of the FogEye Sensor System as a low visibility landing aid.

Other observations:

- The demonstration used analog displays for the FogEye Sensor that were not easy to see when combined with the computer graphics of the HUD. The raster-scanned runway light image that was superimposed over the stroke-scanned alpha-numeric displayed on the HUD was weak in intensity. This could have been caused by improper gain adjustments in the aircraft's HUD.

- Two of the four augmented threshold lights failed between the 01/06/04 tests and the 01/07/04 flights. The failures were tracked to a defective commercial grade relay that has since been replaced by a military grade relay. The prevailing airport temperature during these tests was 8°F.

- The impact of changing the field of view of the augmented lights on the right side of the runway was not as pronounced as was anticipated. The cause has been attributed to improper surface preparation.

6.0 CONCLUSIONS

The FogEye Sensor System, as tested in VMC conditions, provided the pilot visual reference to the runway threshold and touchdown area beyond visual range.

Flight test recordings demonstrated that cross checks between the actual touchdown zone location and the equivalent guidance vector signal location were achieved. During one approach, cross wind gusts that reached 29 knots were experienced. The pilot had to introduce a considerable crab angle in order to hold the aircraft on a vector to the touchdown zone. Variation of the displayed location of the aircraft flight vector, within and without the touchdown zone boundaries dramatically indicated the difficulty the pilot was experiencing in maintaining a desired vector to the touchdown point.

In a practical system the UV signals must be processed to display the detected lights with the same kind of graphics used for other HUD elements. The other technical issue to be solved for a practical system is to have sufficient camera dynamic range to detect a very weak signal as well as the very strong signals when the aircraft gets close to the UV lights. This problem is the same issue pilots have with transitioning from seeing nothing to experiencing the full glare from bright landing lights. The greater inherent dynamic range for the FogEye Sensor System compared to the human eye stems from two features: a) the absence of background light and b) the capability for detecting single photons.

Follow-up test in fog/low visibility conditions with the FogEye Sensor System is recommended.