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Steven R. Schreiber

Date 21 April 1993

NIGHT VISION GOGGLE (NVG)

AND

HELICOPTER SHIPBOARD NVG COMPATIBILITY

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Steven R. Schreiber

May 1993

DEDICATION

This thesis is dedicated to

my wife Lauren,

my daughter Nicole,

and my son Casey

whose support and laughter have

enabled me to live my dreams

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I would like to thank the United States Navy for providing me with the opportunities to expand my knowledge and provide for my family while having fun at one of the most exciting jobs in the world, a U.S. Navy Test Pilot. I would also like to thank Mr. Bob Richards for his guidance and patience and my committee members, Dr. Ted Paludan and Dr. Ralph Kimberlin, for their comments and assistance.

DISCLAIMER

The information presented in this thesis is the sole opinion of the author and in no way reflects the views of the Naval Air Warfare Center Aircraft Division, Naval Air Systems Command, or the United States Navy.

ABSTRACT

Night Vision Goggle (NVG) and helicopter shipboard NVG compatibility testing required extensive build-up and test procedures development to ensure successful testing. The test process began with the test team becoming familiar with what NVG's were, how they operate, and what they provide the pilot. With this baseline of information, NVG compatible cockpit development and testing commenced with the design of an NVG interior and exterior lighting kit for the SH-60F helicopter. A U.S. Navy Fleet requirement was later identified for NVG compatible shipboard flight decks in support of multi-service helicopter flight operations. Flight testing was then conducted between 1987 and 1990 aboard three U.S. Navy amphibious aviation capable ships with an NVG compatible blue lighting package. These NVG shipboard operations resulted in an emergent requirement for small ship flight deck NVG compatibility. This resulted in the shipboard helicopter NVG compatibility testing with the use of the Elevated Fixed Landing Platform (EFP) at the Naval Air Warfare Center, Lakehurst, NJ. The EFP is a duplicate in size, markings, and lighting of an actual U.S. Navy Frigate flight deck. The EFP enabled engineers to develop an NVG compatible flight deck lighting package, which was then flight tested with the NVG compatible SH-60F. Flight testing included an evaluation of a variety of flight deck lighting matrices to qualitatively

assess the degradation in NVG resolution performance with non-compatible lighting. Testing was also conducted to determine an optimum deck lighting configuration for launch and recovery operations. The optimum configuration for the pilots with a non-NVG compatible flight deck was all deck lighting off. However, due to the lack of lighting, the unaided (no NVGs) flight deck personnel could not safely operate on the flight deck. The final step, testing aboard an actual U.S. Navy Frigate equipped with an NVG compatible flight deck lighting package, was then conducted. These shipboard tests corroborated the Fleet requirement for NVG compatible flight deck lighting and this thesis concludes that the use of NVGs, in an NVG compatible lighting environment, improves the aircrews' situational awareness and enhances the overall safety of shipboard operations.

Based on these conclusions, future challenges for industry and the Developmental Test and Evaluation community have been identified. These challenges include the use of modern simulator technologies to assist in the development of fully compatible Fleet shipboard deck lighting packages; low-light NVG cameras for use by the ship's Captain to monitor the safe conduct of NVG flight deck operations; the development of NVG compatible glideslope and azimuth landing aids; NVGs with increased field-of-view and visor displays; lighter weight NVGs with improved low-light sensitivity; and improved NVG crash survivability for both helicopter and fixed-wing operations.

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LIST OF ABBREVIATIONS

AFCS . . . . . Automatic Flight Control Systems
ATEF . . . . . Aircraft Test and Evaluation Facility
CD . . . . . .Clear Deck landings
COMNAVSURFPAC . . . . Commander, Naval Surface Pacific Fleet
CSAR . . . . . Combat Search and Rescue
DI . . . . . .Dynamic Interface
DLQ . . . . . Deck Landing Qualification
ECP . . . . . .Engineering Change Proposal
EFP . . . . . .Elevated Fixed Landing Platform
EL . . . . . .Electro-Luminescent
FD . . . . . .Free Deck Landing
FFG . . . . . Guided Missile Frigate
FOV . . . . . .Field Of View
GFE . . . . . Government Furnished Equipment
GSI . . . . . .Glide Slope Indicator
HCO . . . . . Helicopter Control Officer
HRS . . . . . .Horizontal Reference System
IMC . . . . . .Instrument Meteorological Conditions
ITT . . . . . International Telephone and Telegraph
LSE . . . . . .Landing Signalman Enlisted
LSO . . . . . .Landing Safety Officer
NATC . . . . . Naval Air Test Center
NAWCAD . . . . . .Naval Air Warfare Center Aircraft Division
NVD . . . . . Night Vision Device
NVG . . . . . Night Vision Goggle
NVIS . . . . . Night Vision Imaging System
RA . . . . . Recovery Assist Landing
RAST . . . . . Recovery Assist Secure and Traverse
RSD . . . . . Rapid Securing Device
SOP . . . . . .Standard Operating Procedure
TERF . . . . . .Terrain Following Flight
VLA . . . . . Visual Landing Aids
VMC . . . . . .Visual Meteorological Conditions
WOD . . . . . .Wind-Over-Deck

CHAPTER I

INTRODUCTION

1.1 BACKGROUND

Since 1988, the author has been an operator and instructor on the use of Night Vision Goggles (NVGs). Also, from December 1990 through May of 1993, he has been a technical evaluator and engineering test pilot for the utilization of NVGs in the H-60 and H-53 helicopters and their shipboard compatibility. These aircraft are designed to operate during day or night, visual or instrument meteorological conditions (VMC or IMC), and from landbased or shipboard environments. With the current global military climate and Third World threats, nighttime flight operations significantly improve the chance of surprise and reduce the probability of detection and weapons engagement by hostile forces. Therefore, the use of NVGs by aircrews maximizes their operational effectiveness (1).

Two separate U.S. Navy Fleet requirements were the key elements in the development of NVG and helicopter shipboard NVG compatibility testing. The first requirement was to develop a SH-60F helicopter NVG cockpit modification kit to enable NVG familiarization and mission training in support of the Combat Search and Rescue (CSAR) and Special Warfare

support missions. The second requirement was for NVG compatible shipboard flight decks to support multi-service night NVG operations.

1.2 SUMMARY

This thesis summarizes the development, implementation, and testing of NVGs and a helicopter shipboard NVG compatible lighting package. Initially, the thesis discusses NVGs and details how they operate and what they provide the pilot. The process involved in the development and testing of the SH-60F NVG cockpit modification kit is then outlined. Once the basics of what NVGs are and how they operate are understood, and an NVG compatible helicopter cockpit is described, the thesis then discusses the use of the shore-based Elevated Fixed Landing Platform (EFP) to develop and test an NVG compatible shipboard flight deck lighting package. Actual shipboard helicopter NVG compatibility testing aboard several U.S. Navy ships is then detailed. Based on these tests, the author's conclusions and specific recommendations are presented. The thesis concludes with several specific challenges to industry and the developmental test and evaluation community related to NVGs and shipboard NVG operations.

CHAPTER II

NIGHT VISION GOGGLES

2.1 OVERVIEW

Throughout history, man has been striving to see in the dark. Fire was man's first tool to illuminate the night. With the development of electricity came the light bulb, and current technologies now enable the use of image intensification tubes. In the 1960's, the U.S. military overcame battlefield darkness with searchlights, these were simple; however, the light source would identify the U.S. forces to the enemy. Simple near-infrared searchlights and viewers were then developed in the late 1960's and enabled friendly forces to view the battlefield without visible light. Nevertheless, this technology was soon available to the enemy and once again U.S. forces were identifying themselves to their enemies. Finally, the image intensification tube was developed and provided the user with the capability to see in reduced light conditions without a traceable light signature.

2.2 NVG SYSTEM DESCRIPTION

NVGs are an electro-optical viewing system placed in front of the eyes that provide indirect viewing of objects, similar to a television image, in a monochromatic green. Aviation NVGs consist of a set of two image intensification tubes mounted to the aviator's helmet.

As illustrated in figure 1, light from the night sky, such as the moon, star light, and artificial or man-made light sources, or reflected light from any of these sources enters an image intensification tube that amplifies and focuses the light onto a photocathode which is sensitive to both visible (to the naked eye) and near-infrared light. The particles of light that strike the photocathode cause the release of electrons. These electrons are then accelerated by an electric field through a microchannel plate that produces secondary electron emissions and multiplies the number of electrons that pass through it by as much as 25,000 times. The electrons then strike a phosphor screen that emits green light proportional to the number and velocity of electrons that strike it. The light produced by the phosphor screen is then viewable by the unaided human eye.

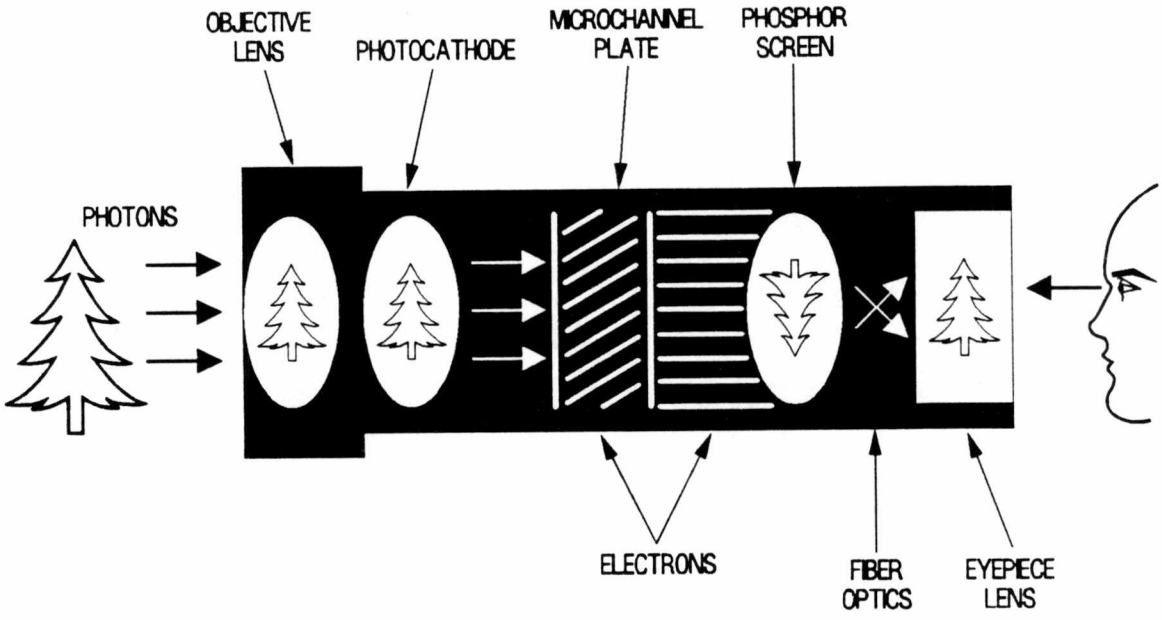


Figure 1. Image Intensification Tube

Adapted from: Marine Aviation Weapons and Tactics Squadron One, ***Helicopter NVG Manual***, Marine Corps Air Station Yuma, Arizona, Fall 1990.

2.3 TYPES OF NVGs

The U.S. military uses two primary types of NVGs, the AN/PVS-5 NVGs, manufactured by the Litton Corporation (Electro-Optics Division) and the AN/AVS-6 NVGs, manufactured by both the International Telephone and Telegraph (ITT) and the Varian Corporations. The primary difference between these two systems is the amount of light amplification produced in the image intensification tubes; this is referred to as the gain. The gain is the ratio of light taken in through the objective lens, to the light delivered out through the eyepiece lens. The image intensifier tube technology is referred to in terms of first, second, or third generation systems. First generation systems were commonly used in Vietnam by snipers with their starlight scopes. However, this technology is now outdated and advances in night vision device (NVD) technologies have produced the second generation tubes (AN/PVS-5's), and most recently the third generation tubes (AN/AVS-6's). The second generation devices were the first system small enough to be worn by pilots and the third generation tubes are a further improvement in both size and low-light level performance. A comparison of the sensitivity of these most recent image intensification tubes with respect to wavelength is presented in figure 2.

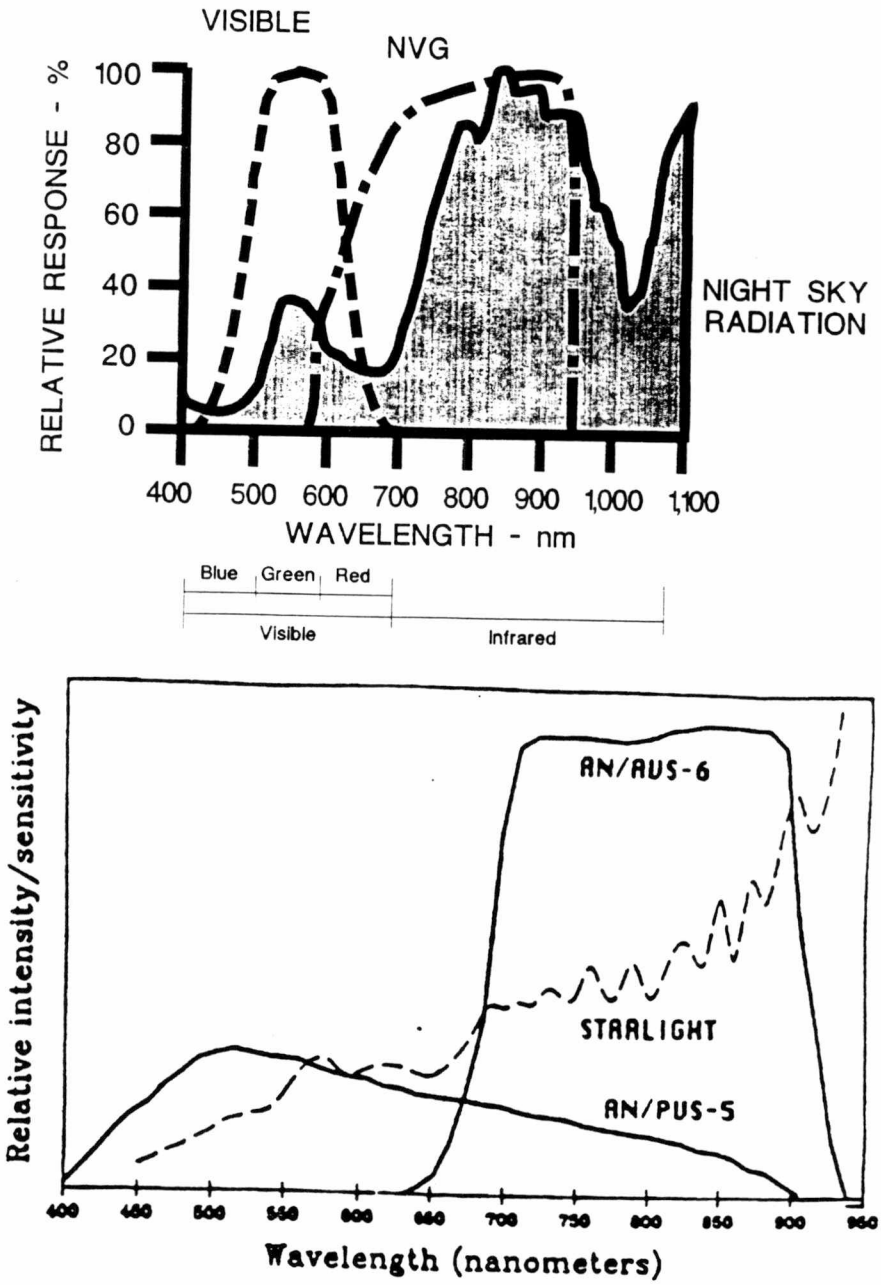


Figure 2. Comparison of AN/PVS-5 and AN/AVS-6 Sensitivities

Adapted from: Marine Aviation Weapons and Tactics Squadron One, *Helicopter NVG Manual*, Marine Corps Air Station Yuma, Arizona, Fall 1990.

2.3.1 AN/PVS-5 NVGs

AN/PVS-5 NVGs were originally designed for U.S. military ground forces and first used in aviation in the early 1970's. These devices were never designed or qualified for aviation use. However, with the operational requirement to conduct tactical military flights at night, U.S. Army and Marine Corps pilots adapted these devices for helicopter aviation use. These NVGs, as depicted in figure 3, weigh twenty-eight ounces and are a full-face binocular design with a heavy counter-weight on the back of the helmet. This design requires the pilot to focus one lens inside the cockpit on the flight instruments, and the other lens outside on the flight environment, causing significant eye strain and pilot fatigue. The AN/PVS-5's have a gain of 10,000:1, a range of focus from ten inches to infinity, a forty degree field of view (FOV), and can produce a visual acuity of 20:50 when optimally focused (1). A more detailed description of the system characteristics of the AN/PVS-5 NVGs is presented in table 1.

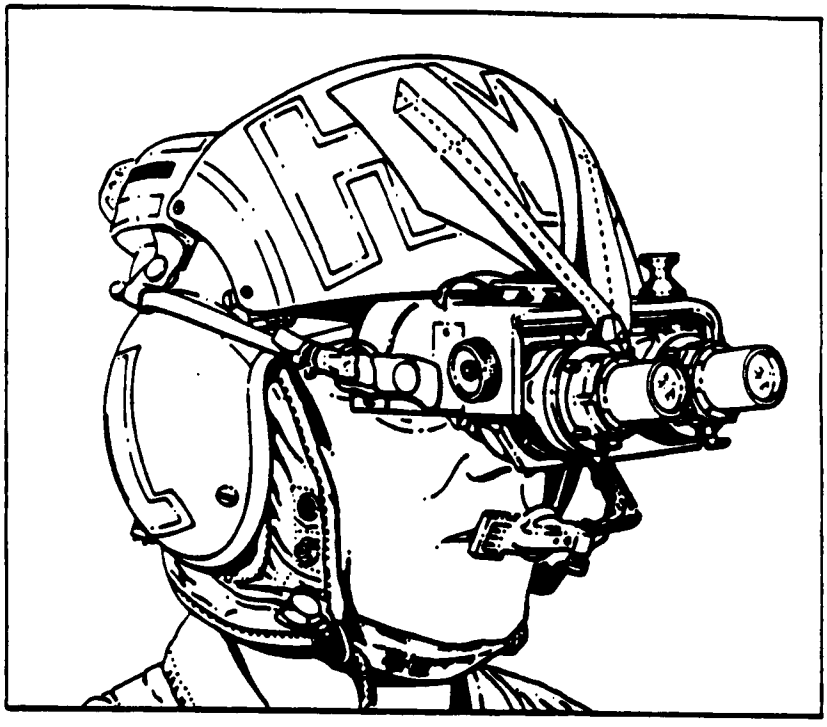


Figure 3. AN/PVS-5 NVGs

Source: Marine Aviation Weapons and Tactics Squadron One, *Helicopter NVG Manual*, Marine Corps Air Station Yuma, Arizona, Fall 1990.

Table 1. Comparison of NVG System Characteristics

NVG Type	AN/PVS-5	AN/AVS-6
Gain	10,000:1	25,000:1
Resolution	20/50	20/40
Photocathode Type	S-20 Multi-alkali	Gallium Arsenide
Magnification	1:1	1:1
Field of View	40 Degrees	40 Degrees
Focus Range	10 inches to Infinity	10 inches to Infinity
Diopter Adjustment	+2 to -6	+2 to -6
Inter-Pupillary Distance Range	51 - 72 mm	51 - 72 mm
Eyepiece Brightness	0.5 mLux	1.0 mLux
Weight	28 ounces	16 ounces
Automatic Gain Control	Yes	Yes

Source: Marine Aviation Weapons and Tactics Squadron One, ***Helicopter NVG Manual***, Marine Corps Air Station Yuma, Arizona, Fall 1990.

2.3.2 AN/AVS-6 NVGs

The AN/AVS-6 NVGs were the first night vision system specifically designed and qualified for U.S. military aviation use. These NVGs, as depicted in figure 4, weigh sixteen ounces and have a lightweight battery pack that acts as a counterweight for the helmet-mounted goggle assembly. Power for the operation of the NVGs is provided by either two 3.0 volt lithium-sulphur dioxide batteries, two 2.7 volt mercury batteries, or four 1.5 volt AA alkaline batteries (1). When the battery power is low, a small red light illuminates on the helmet assembly to alert the user. Each of these types of batteries has a service life that is affected by the environmental temperature, as is detailed in table 2.

The AN/AVS-6 NVGs have an improved low-light level performance over the AN/PVS-5 goggles and can operate down to clear starlight. The cockpit instruments are viewed with the naked eye below and around the NVGs, while the external environment is viewed through the NVGs. The image intensification tubes on are sensitive to light in the 625 to 950 nanometer (orange, red, and infrared) portion of the light spectrum. They have a gain of 25,000:1, a range of focus from ten inches to infinity, a forty degree FOV, and can produce a visual acuity of 20:40 when optimally focused (1). A more detailed description of the system characteristics of the AN/AVS-6 NVGs is presented in table 1.

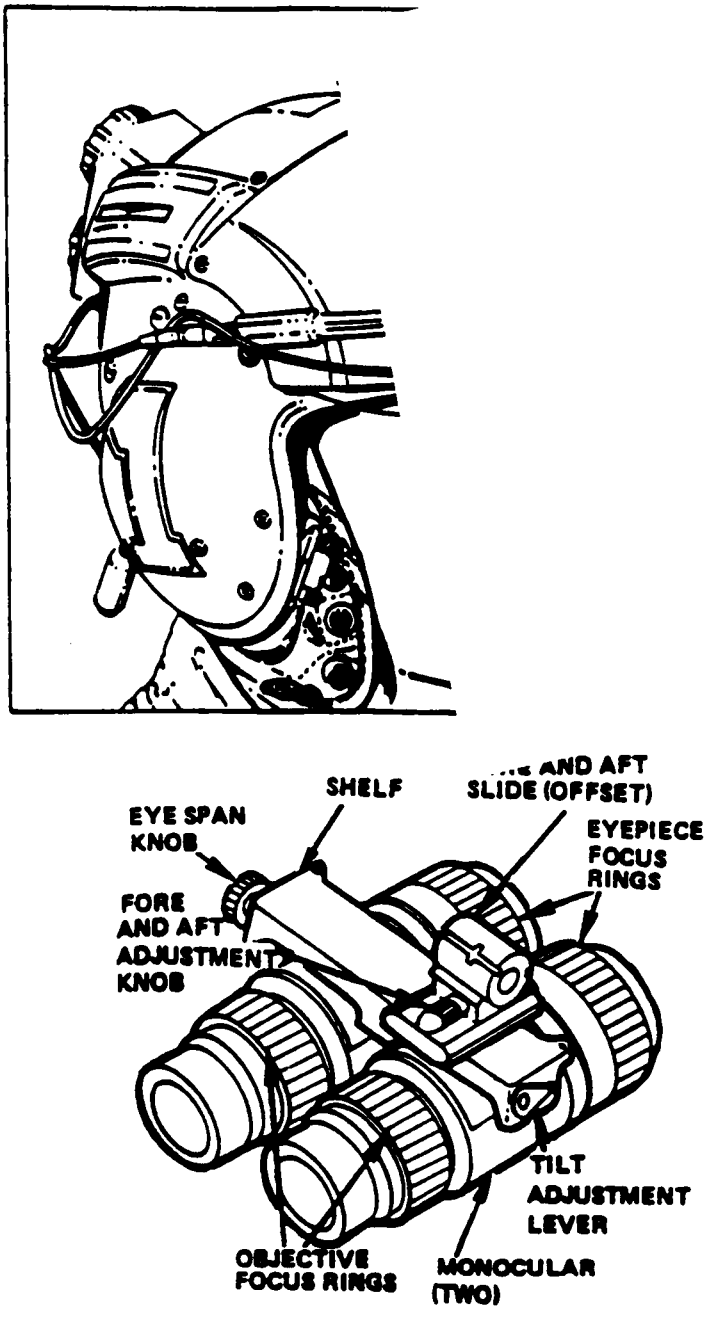


Figure 4. AN/AVS-6 NVGs

Source: Marine Aviation Weapons and Tactics Squadron One, *Helicopter NVG Manual*, Marine Corps Air Station Yuma, Arizona, Fall 1990.

Table 2. AN/AVS-6 Battery Service Life

	Hours of Service Life (min/max)		
Temperature (°F)	Mercury	Lithium	AA Alkaline
100	6/12	13/16	10/22
70	6/12	13/16	10/22
0	0/1.6	9/12	5/10
-20	0/0	5/8	1/3

Adapted from: Marine Aviation Weapons and Tactics Squadron One, ***Helicopter NVG Manual***, Marine Corps Air Station Yuma, Arizona, Fall 1990.

2.4 FIELD OF VIEW

One of the most significant problems encountered when using NVGs is the restricted field of view (FOV). A person with normal vision has a FOV, under daylight conditions, of 188 degrees (1). When operating with NVGs, the maximum FOV attainable is 40 degrees, if the goggles are focused properly. This reduced FOV necessitates a significant compensation in visual scan by the user and often results in eye and neck fatigue.

2.5 VISUAL ACUITY

When operating on NVGs, the visual acuity (resolution) is noticeably reduced. The NVGs cannot turn night into day; however, they far exceed the naked eye's performance at night. The naked human eye has an optimum daylight visual acuity of 20:20. The best visual acuity the naked eye can provide at night is between 20:200 and 20:400. An operator with normal daylight vision of 20:20, with or without eyeglasses, can achieve a visual acuity of 20:40 with AN/AVS-6 NVGs (1). This performance leaves no doubt that the use of NVGs significantly improves the user's night operational capabilities.

2.6 DEPTH PERCEPTION

Depth perception when utilizing NVGs is a topic which is still being researched by experts (1). The naked eyes have binocular or three-dimensional depth perception; the eyes use the triangulation of retinal points to provide this three-dimensional image. Nevertheless, binocular depth perception is limited at night and dependent upon the ambient night sky illumination. Also, binocular depth perception has a limited useable range of approximately 30 feet. With NVGs, this binocular depth perception is limited. However, monocular cues such as relative object size, height, and object overlap are used to judge depth. Relative object size and height, when compared to objects nearby, assumes that the larger an object is, the closer it is in a given visual scene. Object overlap assumes that if an object is obscured in a given scene, the obscured object is further away. As NVG users gain experience in the night environment, they begin to develop monocular depth perception skills through the NVGs. Through the use of these monocular cues, a skilled user can utilize NVG depth perception for the safe conduct of NVG flight operations.

2.7 DARK ADAPTION

NVGs do not require dark adaption for their use. The eyepiece lens of the goggles is sufficiently bright to activate the eye's daylight visual system. Also, full dark adaption after de-goggling takes an average of only three minutes (1). Seventy-five percent of this dark adaption occurs within the first 30 seconds of de-goggling, if previously dark adapted (1). The NVGs are also designed with a built-in protection against bursts of bright light, such as a weapons firing flash or lightning. This protection causes the goggles to degain from the input of bright light and they fully recover within one to three seconds. It takes the human eye, if unaided by NVGs, up to thirty minutes to re-adapt to the dark after a weapons firing flash (1).

CHAPTER III

DEVELOPMENT OF AN NVG COCKPIT MODIFICATION KIT

3.1 BACKGROUND

In order for the aircrews to use NVGs, the aircraft must have NVG compatible internal and external lighting. Aircraft lighting that is not NVG compatible will significantly hinder the operation of the NVGs; non-compatible light sources cause the goggles to degain and the user's visual acuity through the NVGs is reduced. Therefore, aircraft that are used for NVG operations must either be designed as NVG compatible or modified to meet the requirements for NVG use.

3.2 NVG COMPATIBLE INTERNAL AND EXTERNAL AIRCRAFT LIGHTING

For effective NVG operations, the interior of the aircraft must be modified for NVG compatibility. The most critical area requiring compatibility is the cockpit. Flight critical instruments and gauges must be visible in the NVG environment and therefore, compatible. The pilots must be able to locate and activate switches and they must be able to read maps, when not aided by NVGs. The interior lighting has to be designed to minimize glare and reflections within the cockpit. Also, the aircrew in the cabin of the aircraft must be able to

see the external environment without interfering with the operation of the NVGs. Once the interior is modified, the exterior aircraft lighting must then be modified to be NVG compatible. The primary items that should be NVG compatible are the spotlight, the position lights, the main rotor tips and the formation lights.

Some of the common problem areas for designers are the master warning panel, the caution and advisory panel, the fire warning T-handles, the radar altimeter low-height warning light, and Government Furnished Equipment (GFE), such as transponders and countermeasures control boxes.

Solutions to the task of making an aircraft's internal and external lighting NVG compatible are limited due to the sensitivity of the goggles to light within the 625 to 950 nanometer wavelengths. However, NVG compatible lightbulbs and glass filters, in the blue and green light spectrum, are the most common solutions to the compatibility issues. NVG compatible green bulbs are inserted into the fire warning T-handles to replace the non-compatible red bulbs; white instrument floodlights are replaced with NVG blue or green lights; and NVG compatible green instrument bezel lighting is installed on flight instruments. Also, NVG compatible blue or green glass filters are often installed over non-compatible light sources.

The SH-60F helicopter NVG cockpit modification kit utilizes several of these designs. The multi-colored aircraft

performance displays and the aircrew station warning, caution, and advisory panels were all covered with NVG blue filtered glass (3). An example of the SH-60F's multi-colored non-NVG compatible cockpit displays is presented in figure 5. The non-compatible red engine fire T-handle bulbs were all replaced by NVG compatible green bulbs. The lower console pushbuttons on the Automatic Flight Control Systems (AFCS) control box were modified with NVG compatible green glass filters to eliminate the significant glare and reflections they caused. The Radar Altimeter had to be modified with the addition of a switch box, mounted on the instrument panel, which enabled the selection of red or an NVG compatible green low-height warning light. The instrument panel glareshield flood lights were replaced with NVG compatible floodlight covers. These floodlights illuminated all of the primary flight instruments and eliminated the requirement to install individual instrument bezel lights, significantly reducing the cost of the kit. Also, the aircraft external spotlight was modified with an NVG compatible lens cover (3 through 7).

Although these modifications were effective, the best solution to the problem of providing an NVG compatible aircraft is to design the aircraft, from the start, to be NVG compatible. Military aircraft contracts and specifications must specify, in detail, what is required to be NVG compatible

Figure 5. **SH-60F Multi-Colored Non-NVG Compatible Cockpit Displays**

Source: Schreiber, S, ***SH-60F NVG and Shipboard NVG Dynamic Interface Compatibility Testing***, Technical Report to U.S. Navy Test Pilot School, 44th Annual Symposium, April 25, 1992.



in the aircraft. Military Specification MIL-L-85762A (2) is the first positive step taken to provide this guidance to aircraft designers. Also, experienced engineers and pilots must be included in the planning and design of NVG aircraft to reduce the long-term costs; contract modifications and Engineering Change Proposals (ECPs) for production aircraft result in an increase in the procurement costs. A good example of this process at work is the design and manufacture of the HH-60H helicopter. This aircraft was designed, from the ground up, as an NVG aircraft with its internal and external lighting. An example of this fully NVG compatible HH-60H is presented in figure 6. This photograph was taken using an NVG lens and as can be seen, there is no blooming from non-NVG compatible lights. However, the SH-60F helicopter is an example of an aircraft requiring post-production modification. As displayed in the NVG photograph of the SH-60F in figure 7, there are multiple internal and external aircraft light sources that are not NVG compatible, causing significant blooming. The NVG cockpit modification kit for the SH-60F, detailed in the previous paragraph, is only an interim solution for NVG compatibility. The cockpit is not fully NVG compatible and many of the non-compatible lighting components have to be secured for NVG operations. Due to the costs required to fully modify the aircraft, incorporation of the NVG ECPs has already been delayed for over three years (3 through 7).

Figure 6. **Fully NVG Compatible HH-60H Helicopter as Seen Through an NVG Lens**

Source: Schreiber, S, ***SH-60F NVG and Shipboard NVG Dynamic Interface Compatibility Testing***, Technical Report to U.S. Navy Test Pilot School, 44th Annual Symposium, April 25, 1992.

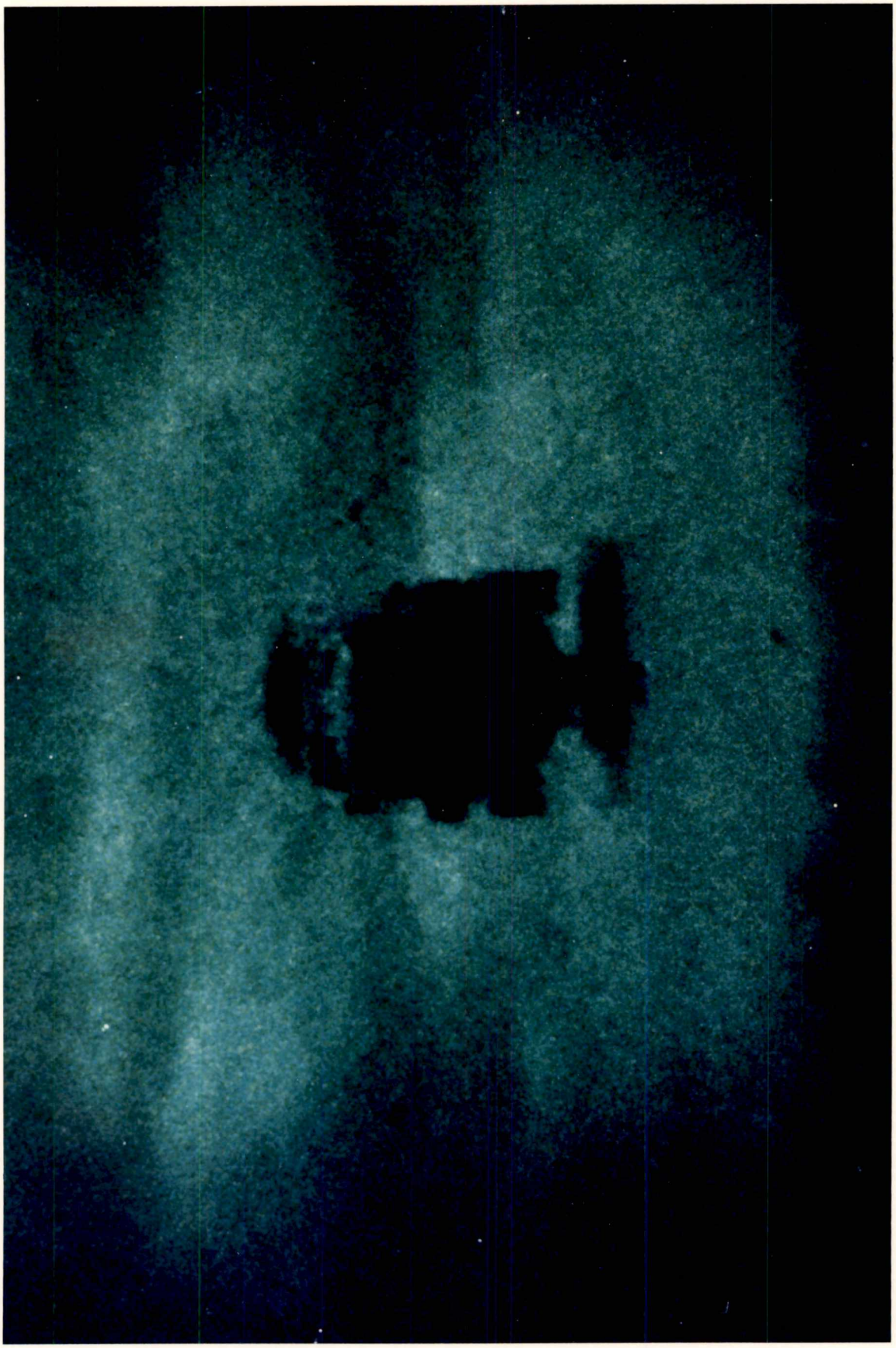
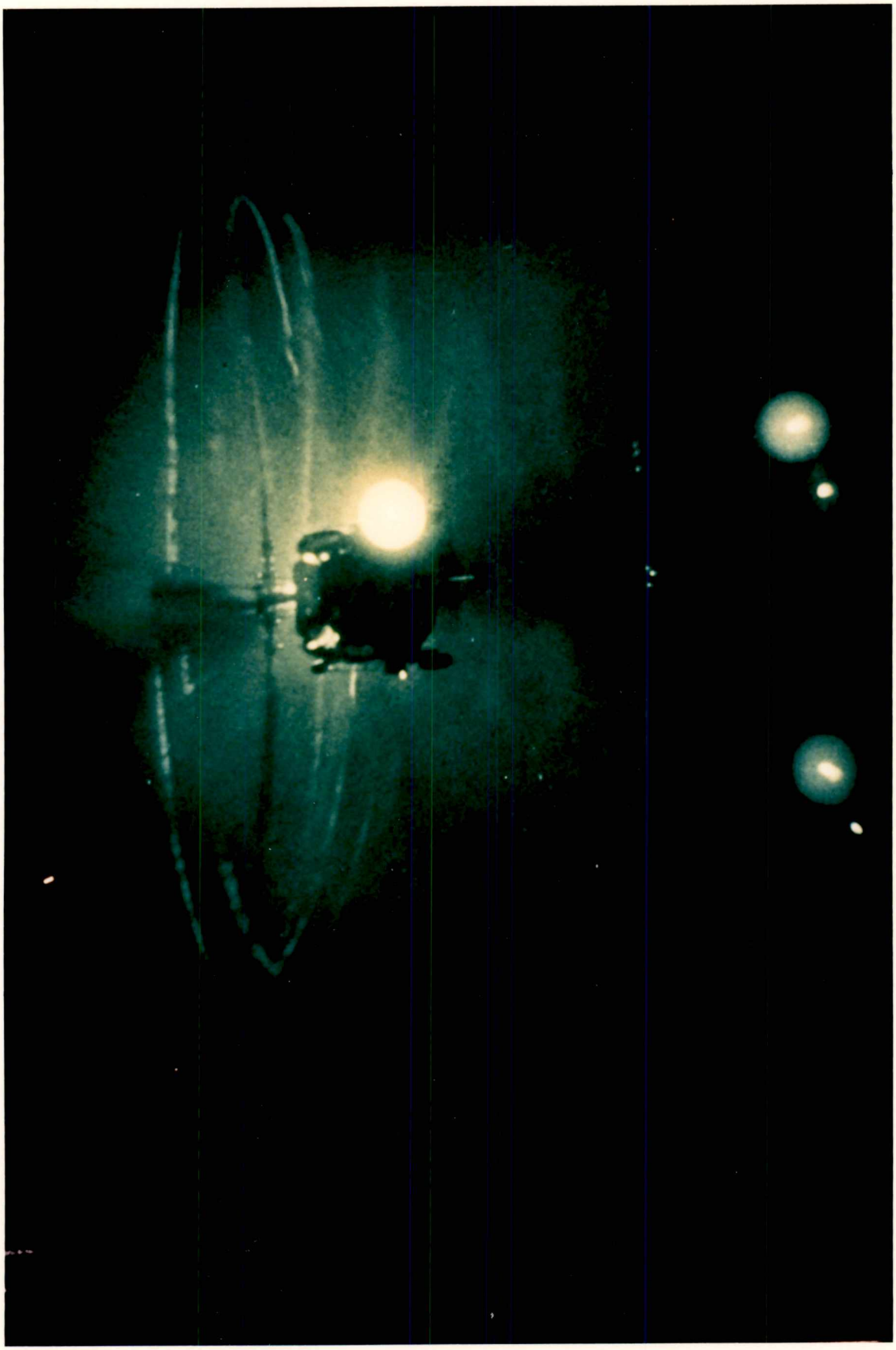


Figure 7. **Non-NVG Compatible SH-60F Helicopter as Seen Through an NVG Lens with Blooming of Non-Compatible Internal and External Light Sources**

Source: Schreiber, S, ***SH-60F NVG and Shipboard NVG Dynamic Interface Compatibility Testing***, Technical Report to U.S. Navy Test Pilot School, 44th Annual Symposium, April 25, 1992.



3.3 GROUND TESTING FOR AN NVG COMPATIBLE COCKPIT

Prior to conducting flight testing of an aircraft to determine if the lighting is suitable for NVG operations, ground tests must first be completed. This testing must be conducted in an environment which provides controlled, repeatable conditions. The ground tests to determine NVG compatibility for the SH-60F helicopter were conducted in the Aircraft Test and Evaluation Facility (ATEF) hangar at Patuxent River, Maryland (3 through 6). This facility provided an environment in which the light level could be precisely controlled to determine the adequacy of the NVG modifications to the cockpit. An NVG bar chart (1), similar to an eye chart, was used to ensure that the goggles were focused properly prior to commencing the tests. Once the light level illuminance was set on the NVG bar chart to a standard 0.0022 lux, the precise analysis of the degradation in visual acuity through the NVGs due to non-compatible aircraft lighting was conducted. (Lux is a measure of illuminance equal to one lumen per square meter; lumen is a measurement of light equal to the light emitted in a unit solid angle by a uniform point source of one candle intensity.) Also, laboratory evaluations of NVG cockpit light assemblies, displays, and filters were conducted to acquire spectral content, luminance, radiance and transmissivity data.

Bar chart resolution testing was conducted by the pilot first viewing the chart through the NVGs with all of the aircraft's lighting secured. This served as a baseline measurement to use as a comparison during illumination of discrete lighting and display systems or components. Changes in target element recognition to the next larger set of patterns, due to glare and reflections from non-compatible light sources, represented a twelve percent reduction in visual acuity as a result of offending light sources.

The results of the ground testing determined the best available NVG lighting configuration for the SH-60F cockpit to achieve safe NVG flight operations and provide adequate mission performance at night. All of the data collected from this ground testing were evaluated to ensure that the night non-NVG and NVG operations met the performance requirements of Military Specification MIL-L-85762A (2). Once the ground evaluation test and the analysis of test results was completed, progression to subsequent flight testing could occur.

3.4 FLIGHT TESTING OF AN NVG COMPATIBLE COCKPIT

Flight testing of the SH-60F for NVG compatibility was conducted using progressively more difficult flight parameters. The progression to more complex and difficult NVG flight parameters only occurred after evaluation under ideal

flight conditions determined that no deficiencies in the NVG cockpit existed that could endanger the aircrew or the aircraft. This progressive buildup in testing began with an evaluation on a bright night with high ambient illumination. Testing then progressed to low-light level conditions, down to starlight illumination only.

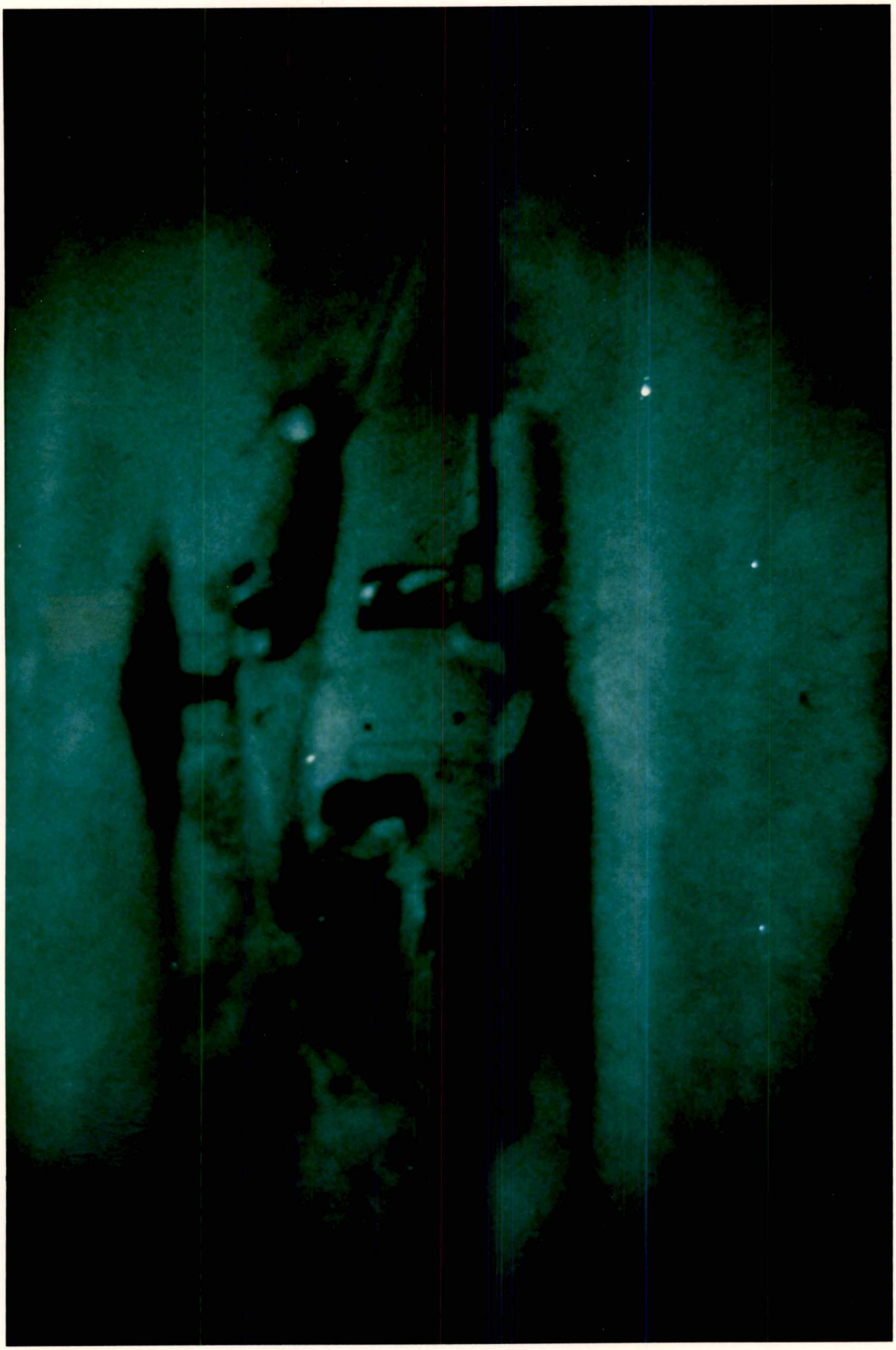
Flight testing evaluated NVG aircraft modifications to crewstation lighting systems to ensure that the readability of instruments, controls, displays, caution, advisory and warning signals was not compromised during NVG-aided flight. The pilots evaluated the cockpit to determine if non-compatible NVG lighting sources created glare and reflections in the cockpit, visible with either the unaided and NVG-aided eye, which degraded external visibility during flight maneuvers. The testing progressed from low airspeed flight operations, such as hovering, pedal turns over a spot, takeoffs, and landings to more difficult mission related operations. These maneuvers included confined area landings, terrain following flight (TERF), and overwater hovering and maneuvering.

Once the SH-60F helicopter's cockpit lighting system had all available NVG modifications in place and flight testing was completed, quantitative bar chart resolution testing results were combined with qualitative flight data and compared to initial resolution testing. This combination of ground and flight test data provided a thorough analysis of the aircraft's NVG mission capabilities and resulted in the

design of an NVG cockpit modification kit which was acceptable for operational use. Figure 8 depicts this NVG compatible SH-60F, with no internal or external non-NVG compatible light blooming present. This same ground and flight test process is used for fully NVG compatible aircraft (HH-60H), as well as for aircraft modified with NVG kits (SH-60F).

Figure 8. **SH-60F Helicopter as Seen Through an NVG Lens with NVG Modification Kit Installed**

Source: Schreiber, S, ***SH-60F NVG and Shipboard NVG Dynamic Interface Compatibility Testing***, Technical Report to U.S. Navy Test Pilot School, 44th Annual Symposium, April 25, 1992.



CHAPTER IV

DEVELOPMENT OF NVG DECK LIGHTING PACKAGE

4.1 BACKGROUND

Once NVG compatible helicopters entered service and aircrews gained experience operating on goggles, a U.S. Navy Fleet requirement for NVG compatible shipboard flight decks was identified for aviation-capable ships. Prior to 1987, standard non-NVG compatible flight deck lighting packages were extensively used for unaided flight operations. The flight deck lights were multi-colored with variable intensities and most often were redundant in order to provide sufficient deck illumination. As NVGs entered Fleet use, ships employed a lights out flight deck lighting scheme to enable NVG operations. By extinguishing all of the flight deck light sources, no non-NVG compatible light was emitted. However, this lights out scheme created significant problems for the flight deck personnel operating during NVG flight operations, because they were unable to safely see what they were doing on the deck. In order to improve the safety of NVG flight deck operations, operators expressed a desire for NVG compatible flight deck lighting which could be used for both NVG-aided and unaided flight operations. The NVG compatible lighting configuration had to provide sufficient NVG compatible flight

deck illumination, such that non-NVG equipped pilots and shipboard flight deck personnel could operate safely during both NVG and non-NVG flight deck operations.

4.2 NVG COMPATIBLE FLIGHT DECK LIGHTING

The ideal NVG compatible shipboard flight deck has all of the ship's lighting converted to NVG compatible light sources which provide adequate NVG-aided and unaided illumination; however, due to cost constraints, this has not yet been achieved. Also, the shipboard lighting package consists of multi-colored lights, with each light color representing various signals and flight deck status. These colors are not all NVG compatible and industry is just beginning to produce NVG compatible reds and yellows. Once the cost of procuring this new technology is reduced, fully NVG compatible flight decks will become a reality.

In order to modify the flight deck to NVG compatible lighting, the primary deck illumination lights had to be modified with the addition of NVG compatible blue filters. These lights included the overhead floodlights, all hangar face lights, and all flight deck surface dustpan floodlights. NVG compatible green electro-luminescent (EL) panel lights were used to modify the deck edge lights, the extended centerline lineup lights, the vertical dropline lineup lights, and the forward and aft lineup lights (8,9). All of these

lights were considered visual landing aids (VLA) for the pilots. The dustpan lights illuminated the lineup lines for deck positioning aids to the pilots. The overhead floodlights also illuminated the lineup lines for the pilots, but they also provided overall flight deck illumination for the deck operating crews. The VLA flight deck components not modified by the addition of NVG blue filters, due to cost or complexity constraints, included the blue hangar corner obstruction lights, the red, yellow, and green Glide Slope Indicator (GSI) and deck status indicator. A summary of shipboard VLA lighting and a description of its use is presented in table 3 and a summary of NVG modified lighting is presented in table 4. After the NVG compatible blue filters and EL panels were designed to replace the existing non-compatible lights, flight testing of this new NVG compatible shipboard lighting package began.

4.3 FLIGHT TESTING OF NVG FLIGHT DECK LIGHTING PACKAGE

The first use of an NVG flight deck lighting package was aboard the helicopter amphibious assault ship USS TARAWA in 1987. Between 1987 and 1990, three more at-sea tests of the lighting package were conducted aboard the amphibious aviation ships the USS PONCE, USS BELLEAU WOOD, and USS WASP (10, 11,

Table 3. Summary of Shipboard VLA lighting Components

Lighting Component	Description and Use
Deck Surface Floodlights (Dustpans)	White light units mounted around the flight deck periphery with red or amber filters; illuminate the outer edge of the flight deck and provide supplemental deck surface textural cues.
Deck Edge Lights	Red lights, flush mounted along the sides and aft periphery of the flight deck; used to define the edge of the flight operations area.
Dropline Lights	A 3 or 6 lamp group of red lights, mounted on a vertical bar located at the aft base of the lineup line; used in conjunction with the lineup lights to provide lineup cues during the approach to the ship.
Lineup Lights	A group of sequentially strobing or non-strobing white lights, all mounted flush with the deck along the lineup line; used with the drop line lights to provide lineup cues during the approach to the ship. Also, used in conjunction with the extended lineup lights to provide lineup and drift cues during hover sequences.
Hangar Face Illumination Floodlights	White dustpan units mounted on the upper corners of the hangar face; used to provide hangar door illumination and to aid the pilots in forward and aft depth perception.

Table 3. (continued)

Lighting Component	Description and Use
Overhead Floodlights	White or amber lights mounted on the upper edge of the hangar face; used to provide flight deck illumination during launch and recovery and maintenance sequences.
Extended Lineup Lights	Groups of sequentially strobing or non-strobing white lights, all mounted flush along the hangar face in line with the lineup lines; used with the lineup lights to provide lineup cues during the approach and hover sequences.
Deck Status Lights	A single set of three lights (red, yellow, and green) mounted on the aft portion of the hangar face; designed to indicate the flight deck operational status.
Glide Slope Indicator (GSI)	A gyro-stabilized 3-color (amber, green, and red) Fresnel lens light unit, mounted on the hangar roof; used to provide approach glide slope deviation cues. Amber is above glide slope, green is on glide slope, and red is below glide slope.
Waveoff Lights	Two flashing red lights, one mounted on either side of the hangar roof or control tower; used to signal the pilots to abort an approach or recovery sequence.

Table 3. (continued)

Lighting Component	Description and Use
Hangar Obstruction Lights	Two non NVG compatible blue lights, mounted on the outboard, top corners of the hangar face; used to define the outermost obstructions to the aircraft on the flight deck.
Navigation Lights	One red light mounted on the port side of the ship's hull, one green light mounted on the starboard side of the hull, and one white light mounted on the ship's stern; used to assist other ships to determine the ship's course and heading.
Masthead Maneuvering and Man Overboard Lights	A vertical sequence of multiple red and white lights located on the ship's mast; used to notify other vessels of the ship's operational status.
Homing Beacon	One very bright white strobing light located on the top of the ship's mast; used to assist other ship's or aircraft in locating the ship.

Table 4. Summary of NVG Modified VLA lighting Components

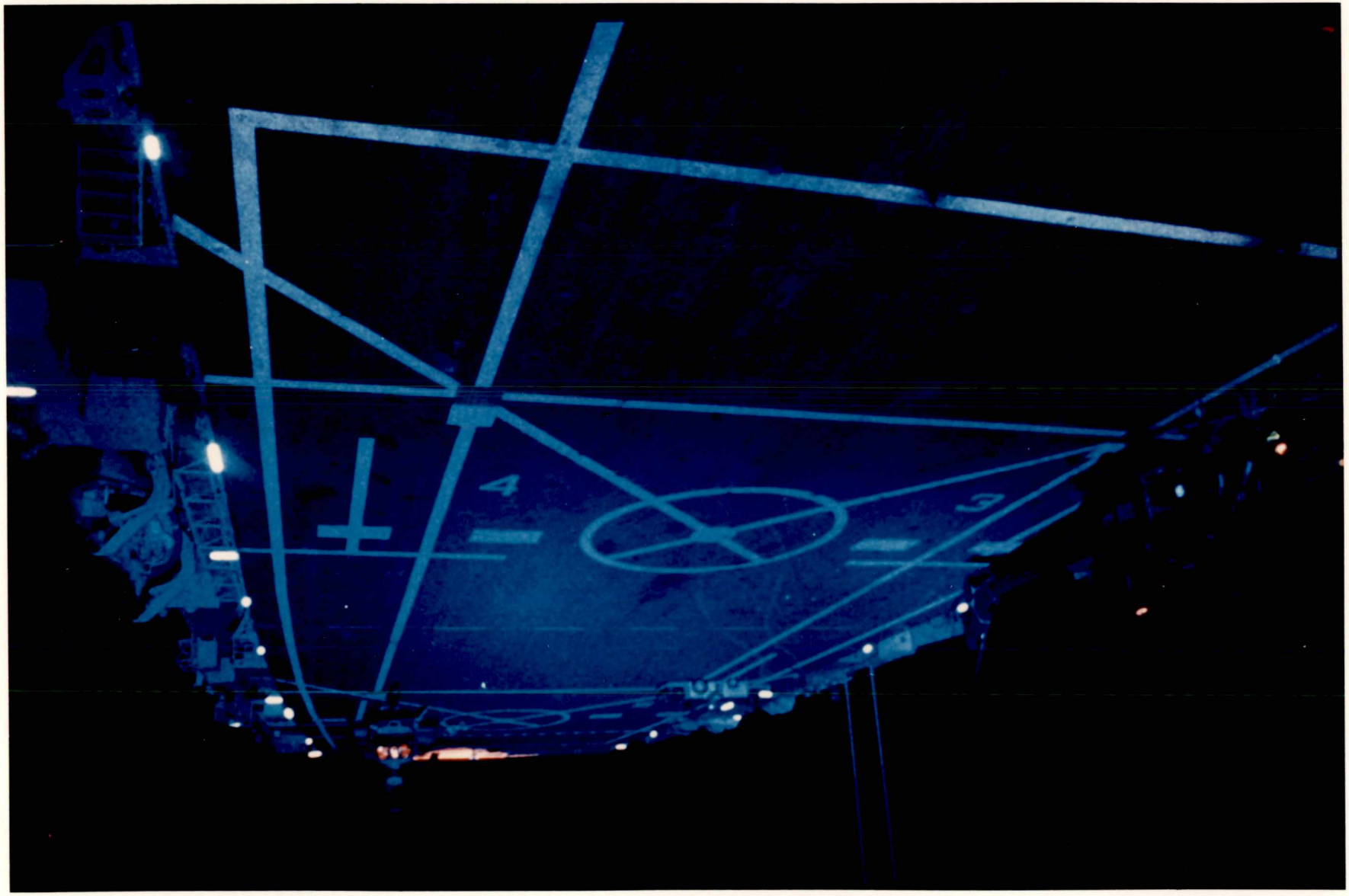
NVG Lighting Component	Description of modification
Deck Surface Floodlights (Dustpans)	The two lamps in each unit were replaced by two "Cool Beam" lamps; the white, red, and amber filters were replaced with NVG compatible blue glass.
Hangar Face Illumination Floodlights	The two lamps in each unit were replaced by two "Cool Beam" lamps; the white, red, and amber filters were replaced with NVG compatible blue glass.
Overhead Floodlights	NVG compatible blue glass filters were installed in each light unit.
Dropline Lights	Four 12 inch long green EL panels were added and mounted on the vertical dropline bar.
Lineup Lights	Four 12 inch long green EL panels were added and mounted above the vertical dropline bar.
Horizontal Reference System Bar (HRS)	This did not require modification, it was originally designed with the green EL panels.
Deck Edge Lights	Four 12 inch long green EL panels were added and mounted (evenly spaced) along the flight deck edge.

12). Figure 9 is a photograph of the USS PONCE's flight deck with the NVG modified blue deck surface and overhead floodlights installed.

The NVG flight deck lighting package for these first three ships was simple and installation of the blue filters only took four to six hours. The only modifications to these ships was the flight deck surface dustpan floodlights and the overhead floodlights. The NVG compatible flight deck lighting package, with the modified flight deck surface dustpan floodlights and the overhead floodlights, provided the aircrews and deck personnel adequate illumination to conduct safe NVG-aided and unaided night flight operations. However, in order to prevent the severe glare caused by non-NVG compatible light sources during flight operations, all non-NVG compatible light sources were required to be secured. The non-compatible lighting included all of the red deck edge lights, the red centerline droplights, the white spot illumination lights, the ship's red and white navigation and masthead lights, the blue hangar corner obstruction lights, the red, amber, and green GSI and deck status indicator. Also, it was determined that the Landing Signalman Enlisted's (LSE's) directing wands had to be modified to prevent blinding the pilots when utilizing NVGs (10, 11, 12). NVG compatible blue lenses or chemlites were inserted into the light wand to eliminate the non-compatible light source.

Figure 9. **USS PONCE (LPD 15) Flight Deck with NVG Modified Blue Deck Surface and Overhead Floodlights Installed**

Source: Schreiber, S, ***SH-60F NVG and Shipboard NVG Dynamic Interface Compatibility Testing***, Technical Report to U.S. Navy Test Pilot School, 44th Annual Symposium, April 25, 1992.



4.3.1 TESTING ABOARD THE USS PONCE

The flight test data obtained from tests aboard the USS PONCE showed that the NVG compatible lighting capability was limited by the existing ship's lighting hardware and the restrictions of the flight deck geometry (12). However, it was determined that NVG compatibility was possible with the use of the NVG compatible flight deck lighting package. Also, the NVG blue light package provided the added benefit of stealth for the ship. If the ship was configured with the blue NVG compatibility kit and all non-compatible light sources were secured, the detectability of the ship without the use of NVGs was significantly reduced.

4.3.2 TESTING ABOARD THE USS BELLEAU WOOD

The USS BELLEAU WOOD tests demonstrated NVG compatibility with the first fully outfitted and qualified ship. The BELLEAU WOOD had the modified flight deck surface dustpan floodlights, overhead floodlights, and green EL flight operations control tower illumination. It also had a fully qualified NVG flight deck crew to assist in the helicopter launch and recovery evolutions during NVG operations. A detailed drawing of the USS BELLEAU WOOD flight deck is presented in figure 10 and a list of general symbols and lighting symbology used on this figure is contained in table 5.

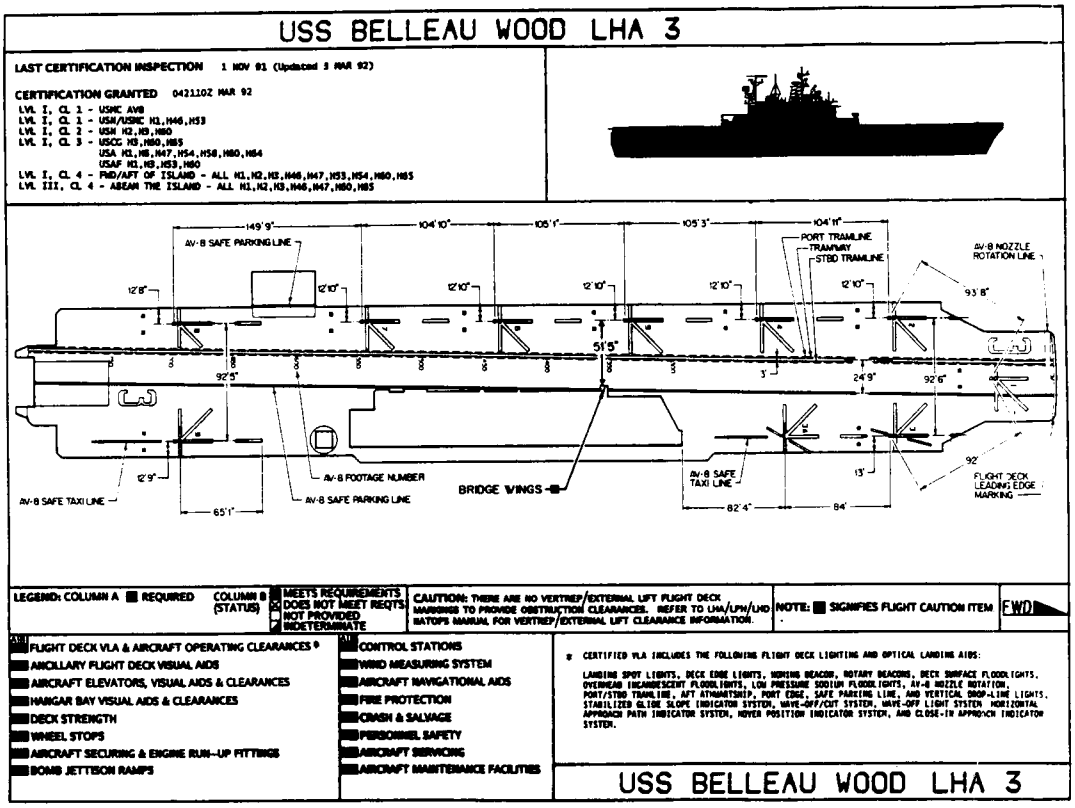
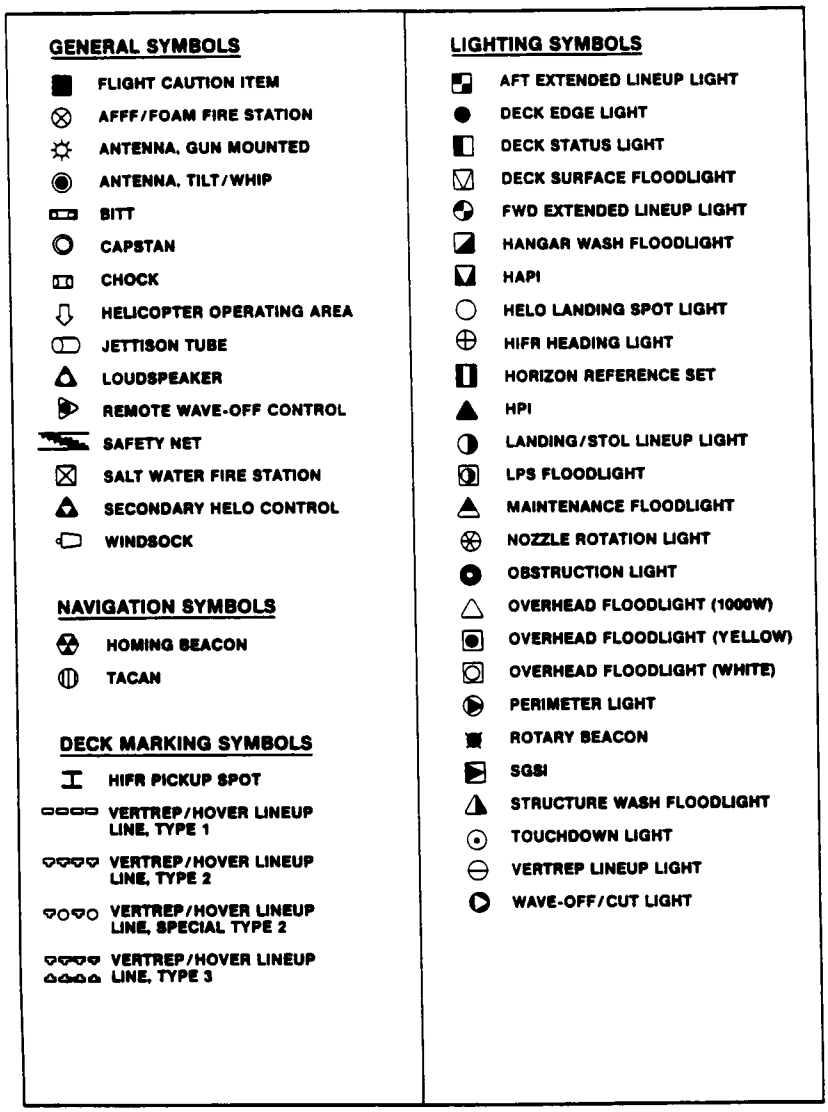


Figure 10. USS BELLEAU WOOD (LHA 3) Flight Deck Drawing

Source: Naval Air Warfare Center Aircraft Division, *Shipboard Aviation Facilities Resume*, Lakehurst, New Jersey, NAEC-ENG-7576, Revision AL, January 1993.

Table 5. General Flight Deck and Lighting Symbols



Source: Naval Air Warfare Center Aircraft Division, *Shipboard Aviation Facilities Resume*, Lakehurst, New Jersey, NAEC-ENG-7576, Revision AL, January 1993.

The pilot workload during NVG-aided and unaided launch and recovery evolutions was evaluated. These tests proved that the pilot workload was reduced when wearing NVGs, due to the improved situational awareness provided by the goggles. The pilots were able to more readily locate the ship and determine its relative aspect to the aircraft. Also, the NVGs provided the pilots with a good horizon when operating around the ship; when unaided, this horizon was minimal. The blue lighting package provided the NVG-aided pilot peripheral vision under and around the goggles; this was not available on ships without the blue light package, when all flight deck lighting was required to be secured. The peripheral vision provided by the blue lights was a significant aid to the pilots on a pitching and rolling deck. On NVGs, the pilots' comfort level and therefore, workload was significantly improved when operating in the normally pitch black night environment around the ship. Due to the reduction in pilot workload when operating on NVGs, this testing determined that there was a need for separate NVG-aided and unaided night launch and recovery flight envelopes.

4.4 SHIPBOARD DEPLOYMENT WITH NVG COMPATIBLE FLIGHT DECKS

These flight tests resulted in the development of a standard amphibious aviation class helicopter support ship NVG flight deck lighting modification package. Also, based on the results of this testing, a U.S. Navy Standard Operating Procedure (SOP) for the use of NVGs aboard all aviation capable ships was developed (13). This policy guidance enabled the safe conduct of NVG flight operations and included the following safety critical requirements (13):

a. The Helicopter Control Officer (HCO), the LSE, and flight deck supervisors will be equipped with NVGs during NVG flight operations in order to safely direct the helicopter to and on the flight deck.

b. The LSE's directing and signalling wands must be NVG compatible to prevent the blinding of pilots by non-compatible light.

c. All shipboard personnel involved in the conduct of NVG flight operations must receive training and orientation in the use of NVGs prior to conducting NVG flight operations. This training must include, as a minimum, information on NVG physiology, environmental considerations, aircrew tendencies on NVGs, LSE

signalling procedures, static flight deck orientation with NVGs, and a flight deck procedural review by all supervisors.

d. LSEs must direct five takeoffs and landings under the direct supervision of a qualified instructor prior to conducting unsupervised NVG flight operations.

e. Mixed NVG and non-NVG flight operations are prohibited to ensure that non-compatible aircraft do not interfere with the safe conduct of flight operations.

f. If there is no visible horizon when unaided by NVGs, NVG flight operations are prohibited unless waived by the operational commander.

g. All non-compatible light sources must be secured prior to conducting NVG flight operations since the ship's lighting and light discipline are critical to NVG performance and therefore, the safe conduct of operations.

CHAPTER V

DEVELOPMENT OF AN NVG COMPATIBLE SMALL DECK

5.1 BACKGROUND

Between 1989 and 1990, once the NVG flight deck lighting package was approved, deployments with the blue NVG compatible lights aboard amphibious aviation class helicopter support ships began. These deployments proved to be highly successful; however, as the U.S. Navy and Marine Corps gained experience in the advantages of NVG operations, an emergent requirement for small deck NVG lighting compatibility was identified. Ships considered to have small flight decks included, but were not limited to, Cruisers, Frigates, and Destroyers.

5.2 ELEVATED FIXED LANDING PLATFORM NVG LIGHTING TESTS

The Elevated Fixed Landing Platform (EFP) facility, located at the Naval Air Warfare Center Aircraft Division, Lakehurst, New Jersey, is a fixed platform that simulates the flight deck and aft hangar face structure of various ship classes. For the NVG lighting tests, the EFP was configured as a Guided Missile Frigate (FFG) class ship; as such, it included all operational FFG 7 class VLA, including a Horizontal Reference System (HRS), deck and hangar face

dustpan floodlighting, and a GSI. The EFP maintains an operable Landing Safety Officer (LSO) station and a fully functional Recovery Assist Secure and Traverse (RAST) hauldown system. Therefore, it provides a realistic land-based RAST system virtually identical to that of a RAST-equipped ship. The EFP does not move, and therefore cannot duplicate shipboard wind or ship motion conditions, but otherwise, it exhibits excellent fidelity for use in pilot and LSO RAST training, maintenance procedural proficiency, and land-based buildup or limited scope evaluations. This realistic shore-based landing platform provided an excellent environment for the development and initial testing of an NVG compatible small deck lighting package. A photograph of the EFP in the FFG 7 configuration is presented in figure 11.

5.3 FLIGHT TESTING OF SMALL DECK NVG LIGHTING PACKAGE

The VLA lighting package on the EFP was modified by the addition of blue NVG compatible glass filters to the overhead floodlights, the hangar face and deck surface floodlights (dustpan lights), the strobing flight deck centerline lineup lights, and the hangar face extended lineup lights. Also, NVG compatible green EL deck edge, vertical drop line, and RAST forward and aft lineup lights were installed; these were similar to the lights on the HRS bar mounted above the hangar.

Figure 11. **Photograph of the Elevated Fixed Landing Platform (EFP) in the FFG 7 Flight Deck Configuration**

Source: Schreiber, S, ***SH-60F NVG and Shipboard NVG Dynamic Interface Compatibility Testing***, Technical Report to U.S. Navy Test Pilot School, 44th Annual Symposium, April 25, 1992.

5.3.1 NON-NVG FLIGHT TEST EVALUATION

Non-NVG test evolutions were conducted first to determine if the NVG compatible lighting configuration provided sufficient NVG compatible flight deck illumination, such that pilots not equipped with NVGs and shipboard flight deck personnel could operate safely during both NVG and non-NVG flight deck operations.

The pilots and flight deck personnel evaluated the lighting configuration for unaided adequacy and compatibility for the approach, hover, landing and departure phases of simulated shipboard operations. Landings were evaluated by first conducting standard non-RAST assisted operations (Clear Deck landings (CD)). After successfully completing these landings without difficulty, RAST assisted landings were conducted. These landings consisted of multiple night recovery assist (RA) (cable assisted hauldown into the jaws of the Rapid Securing Device (RSD)) and free deck (FD) (recovery into the RSD without the use of the hauldown cable) landings.

This evaluation was conducted under multiple, systematically varied, lighting component intensities and conditions. The pilots, LSEs, LSOs, HCOs, RAST hookup men, and other safety observers evaluated the safety and adequacy of each lighting configuration for both NVG and non-NVG equipped helicopter operations. During the non-NVG portions of the evaluation, the pilots and aircrew employed normal unaided vision to conduct all flight evolutions.

The non-NVG test evolutions resulted in the determination of an optimum lighting intensity for the NVG compatible light sources of 100 percent. This intensity provided satisfactory flight deck illumination for all of the flight deck personnel during non-NVG RA, FD, and FD operations. For unaided operations, optimal intensity settings provided adequate flight deck and hangar face illumination for the pilots. Once the unaided testing was completed and optimal lighting intensities were determined, NVG-aided flight operations were conducted.

5.3.2 NVG-AIDED FLIGHT TEST EVALUATION

During the NVG-aided portions of the evaluation, the pilots and aircrew used AN/AVS-6 NVGs. This testing consisted of multiple NVG-aided RA, FD, and CD approach and recovery sequences under the optimal lighting intensities determined during the unaided portion of the tests. This optimal setting of 100 percent was also found to be acceptable for the NVG-aided operations.

The NVG-aided test evolutions at the EFP proved that the pilots, LSEs, LSOs, HCOs, RAST hookup men, and other safety observers could safely conduct both NVG and non-NVG equipped simulated helicopter shipboard operations on a properly illuminated flight deck. Therefore, the goal of this VLA lighting configuration, to eliminate the requirement for

flight deck personnel to also wear NVGs, was achieved. Also, this testing confirmed the findings during the USS BELLEAU WOOD evaluation that the blue lighting provided beneficial peripheral vision cues to the pilots which were not available if all of the lights were secured. These optimistic shore-based flight test results enabled the final phase of testing to be conducted; the small deck helicopter shipboard NVG compatibility evaluation.

5.4 SHIPBOARD TESTING OF SMALL DECK NVG LIGHTING PACKAGE

The at-sea shipboard testing of the small deck NVG lighting package was conducted with a fully NVG compatible HH-60H helicopter. This H-60 NVG compatible shipboard lighting evaluation was conducted aboard the USS RENTZ (FFG 46), an OLIVER HAZARD PERRY (FFG 7) class guided missile frigate. Each FFG 7 class ship has a single helicopter flight deck, located immediately aft of twin hangars (each capable of storing a folded H-60 or equivalent sized aircraft). These class ships also have two complete RAST systems, one to port and the other to starboard. This system enables H-60 launch and recovery operations in adverse weather and sea state conditions. Since shipboard RAST operations are considered the most difficult aircrew and flight deck crew intensive flight operations, this evaluation would determine if the NVG compatible shipboard lighting package was acceptable under high workload at-sea

conditions. A detailed flight deck drawing of the USS RENTZ is presented in figure 12 with an explanation of flight deck symbology in table 5.

5.4.1 SHIPBOARD NVG VLA LIGHTING CONFIGURATION

The primary goal of the testing aboard the USS RENTZ was to evaluate the effectiveness of a prototype shipboard VLA lighting configuration in providing sufficient NVG compatible flight deck illumination, such that non-NVG equipped shipboard flight deck personnel (HCO, LSO, LSE, and RAST hookup men) could operate safely during both NVG and non-NVG helicopter flight operations. The ship was modified with NVG compatible blue glass filters and green EL panels, identical to the configuration developed at the EFP. All of the other non-compatible, standard RAST-equipped FFG 7 class, VLA lighting components employed nominal settings for the non-NVG operations and were secured for the NVG-aided operations.

5.4.2 NON-NVG AT-SEA FLIGHT TEST EVALUATION

The at-sea NVG lighting evaluation was conducted only after the satisfactory conclusion of day and night non-NVG deck landing qualifications (DLQs). The DLQs included both RAST (RA and FD landings) and non-RAST (CD) operations. These helicopter launch and recovery sequences served as a

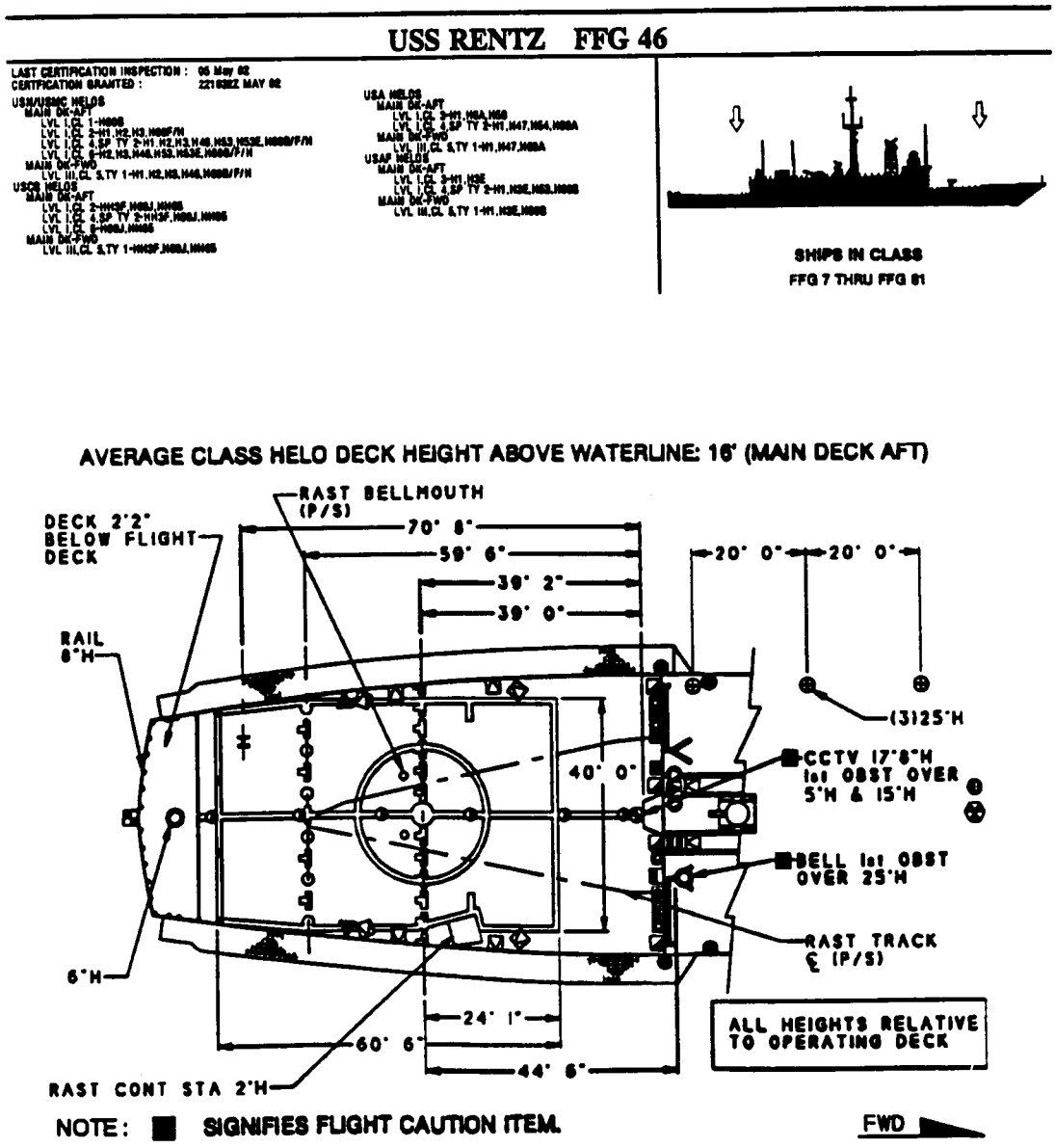


Figure 12. USS RENTZ (FFG 46) Flight Deck Drawing

Source: Naval Air Warfare Center Aircraft Division, *Shipboard Aviation Facilities Resume*, Lakehurst, New Jersey, NAEC-ENG-7576, Revision AL, January 1993.

proficiency buildup for the pilots and flight deck personnel prior to the actual conduct of shipboard NVG landings. Also, since this was the first NVG RAST evaluation conducted in the world, all helicopter launch and recovery sequences were conducted under optimal wind-over-deck (WOD) and ship motion conditions. During the non-NVG portions of the evaluation, the pilots and aircrew employed normal unaided vision to conduct all evolutions. These unaided tests were conducted under multiple, systematically varied, lighting component intensities and conditions. The pilots, LSEs, LSOs, HCOs, RAST hookup men, and other safety observers evaluated the safety and adequacy of each lighting configuration for both NVG and non-NVG equipped helicopter operations. The optimal lighting intensities determined during the unaided portion of the shipboard tests was 100 percent for all of the NVG compatible light sources. This optimal setting of 100 percent was similar to the findings during the EFP evaluation.

5.4.3 NVG-AIDED AT-SEA FLIGHT TEST EVALUATION

Following the conclusion of the day and night unaided DLQ operations, the night unaided and NVG-aided lighting compatibility evaluation was conducted. The pilots and flight deck personnel evaluated the lighting configuration for unaided adequacy and compatibility for the approach, hover,

landing and departure phases of the shipboard operations. NVG-aided landings were then evaluated.

The NVG evaluation began with several approach and waveoff sequences to the flight deck prior to conducting the actual NVG recovery sequences. During these events, the NVG-equipped pilots evaluated the lighting adequacy and cues provided by the NVG compatible flight deck lighting package. After confirmation of the adequacy of the lighting and the intensities required, the NVG recoveries could be conducted. The optimal lighting intensities of 100 percent were also found to be acceptable for the NVG-aided operations.

Actual NVG landings aboard the ship were evaluated by first conducting standard non-RAST assisted clear deck recovery operations. After successfully completing these NVG landings without difficulty, RAST assisted NVG landings were conducted. These landings consisted of multiple night recovery assist (cable assisted hauldown into the jaws of the RSD) and free deck (recovery into the RSD without the use of the hauldown cable) landings.

The NVG-aided test evolutions at the ship proved to be highly successful. The pilots, LSEs, LSOs, HCOs, RAST hookup men, and other safety observers could safely conduct both NVG and non-NVG equipped shipboard operations on this properly illuminated flight deck. Therefore, the goal of this VLA lighting configuration, to eliminate the requirement for flight deck personnel to also wear NVGs, was achieved.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Based upon the discussion in the preceding sections, NVG compatible helicopters and shipboard VLA lighting demonstrates excellent potential to enhance safety in the night shipboard flight environment for NVG operations. The use of NVGs by aircrews reduced the pilot workload in the night environment due to the improved visual acuity provided by NVGs at night. The pilots' situational awareness at night was also improved when using NVGs. This was due to the good horizon cues provided by the goggles and the fact that deck spotting and ship orientation was achieved at much greater distances than when unaided by NVGs.

In the early stages of testing, it was determined that the optimum flight deck lighting configuration for NVG-equipped pilots, on a non-NVG compatible flight deck, was all flight deck lighting secured. However, on a non-NVG compatible flight deck, the flight deck personnel, ship's Captain, and tower controllers were unable to safely monitor the flight operations unless they were also NVG-equipped. This, as well as the significant reduction in peripheral cues for NVG-aided pilots on a pitching and rolling non-NVG compatible darkened

flight deck, seriously reduced the safety of night flight operations. Therefore, the use of NVGs in an NVG compatible aircraft, and in a properly illuminated NVG compatible shipboard VLA lighting environment, significantly enhances the overall safety of night shipboard helicopter flight operations.

6.2 RECOMMENDATIONS

Based on the extensive flight testing and evaluation of NVG compatible shipboard VLA lighting packages and the significant enhancements provided by these lighting configurations to the overall safety of NVG-aided shipboard helicopter flight operations, the author recommends that fully NVG compatible shipboard flight deck lighting be installed on all U.S. Navy ships as soon as possible. Also, based on these conclusions, future challenges and recommendations for industry and the Developmental Test and Evaluation community were identified.

6.2.1 AIRCRAFT SIMULATOR TECHNOLOGIES

These challenges and recommendations include the use of modern aircraft simulator technologies to assist in the development of fully NVG compatible Fleet shipboard flight deck lighting packages. The high visual fidelity of these

modern simulators can be an invaluable tool in designing the flight deck lighting configuration to optimize the illumination and NVG compatibility of the flight deck.

6.2.2 NVG COMPATIBLE AIRCRAFT

These NVG helicopter shipboard compatibility evaluations have proved that the use of NVGs at night significantly enhances the safety of shore-based or at-sea night flight operations by reducing the pilot's workload and improving situational awareness. Therefore, the author recommends that all military, coast guard, and law enforcement aircraft should be equipped with NVG compatible cockpits to enable NVG operations as soon as possible.

6.2.3 LOW-LIGHT NIGHT VISION CAMERAS

It was determined during these shipboard NVG evaluations that the ship's Captain and tower controller required an additional tool to monitor the aircraft and flight deck during NVG operations. Therefore, to correct this problem, the author recommends that low-light, night vision-capable camera systems should be installed on the flight deck to monitor the safe conduct of NVG flight operations.

6.2.4 NVG COMPATIBLE GLIDESLOPE AND AZIMUTH LANDING AIDS

Throughout this evaluation, no NVG compatible glideslope and azimuth landing aids were available due to the cost and technology constraints involved in their development. Nevertheless, due to the enhanced approach and lineup cues these systems provide the pilots, the author recommends that an NVG compatible shipboard glideslope and azimuth landing aid should be designed and installed on all ships as soon as possible. Also, these devices must be useable by both NVG-aided and unaided aircrews.

6.2.5 IMPROVED NVGs

As helicopter and fixed wing aircrews gain experience in the use of NVGs, deficiencies in the NVGs are identified and improvements must be made. These NVG evaluations and the experience gained by the author during these tests resulted in the following recommendations that must be addressed and incorporated as soon as possible: lighter weight NVGs with an improved low-light sensitivity and crash survivability for both helicopter and fixed wing operations must be designed; and NVGs with an increased field of view and flight helmet visor displays for night vision imagery must be designed.

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VITA

Steven R. Schreiber was born in Tucson, Arizona on June 4, 1961. After graduating from the University of Arizona in Tucson, AZ in 1983 with a Bachelor of Science degree in Aerospace Engineering, he joined the Navy to become a pilot. He received his Naval Aviator Wings in helicopters in January 1985 and completed a 3-year tour in CH-53E helicopters at HC-4 in Sigonella, Sicily in 1988. After completing his tour in Sicily, he was a Government Acceptance Pilot for H-53E and H-60 helicopters at the Sikorsky helicopter plant for 18 months before being accepted to Test Pilot School. As the first U.S. military helicopter pilot to attend the British Empire Test Pilot School in England, he graduated in December 1990 and returned to Patuxent River, Maryland for his current tour as an Engineering Test Pilot at the Rotary Wing Aircraft Test Directorate. During this tour he participated in seven major shipboard helicopter NVG compatibility test programs. His first contact with the enhancements provided by NVGs for shipboard flight operations was during this testing, which was his inspiration for this thesis.