To the Graduate Council:

I am submitting herewith a thesis written by David Culbertson entitled "Conceptual Design of a Future Night Vision System for Tactical Jet Aircraft." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of science, with a major in Aviation Systems.

Ralph D. Kimberlin

Dr. Ralph D. Kimberlin, Major Professor

We have read this thesis
and recommend its acceptance:

C. T. Paludan

Dr. C. Ted. Paludan

Frank G. Collins

Dr. Frank G. Collins

R B Richards

Mr. Robert B. Richards

Accepted for the Council:

Cew Minkel

Associate Vice Chancellor
and Dean of The Graduate School

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a Master's Degree at the University of Tennessee, Knoxsville, I agree that the Library shall make it available to borrowers under the rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of the source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his absence, by the Head of Interlibrary services when, in the either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature David Culbertson

Date 20 AUGUST 1994

CONCEPTUAL DESIGN OF A FUTURE NIGHT VISION SYSTEM FOR TACTICAL JET AIRCRAFT

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

David Culbertson

December 1994

DEDICATION

I dedicate this work to

My Parents who taught me to Persevere

My Wife who taught me to Care

My Children who taught me to Love

The Veterans who have fought for our freedom

The Pioneers of Night Vision Devices who lost their lives

ACKNOWLEDGMENTS

I would not have been able to complete this work without the help of several individuals. The F/A-18 Mission Systems flight test engineers gave me tremendous comradery and support during my Flight Test days at Patuxent River. The Patuxent River Base Library staff helped me immensely during my literature search and research. Brian Gillespie at the Night Vision Laboratory at Ft. Belvoir and Lori Bryner from Naval Air Warfare Center at Warminster provided me numerous contacts and more importantly their valuable time. The Vendors; GEC-Marconi, Honeywell, Westinghouse, Texas Instruments and Systems Research Laboratory all provided me with the latest and greatest information. Bob Thompson, a friend and associate at NAVAIR provided last minute technical sanity. The engineers at DCS gave my some inspiration ideas. And finally I would like to acknowledge my family for enduring the process.

ABSTRACT

Night vision system developments have played a crucial role in the warfighting tactics of our armed forces. The ability to see and fight at night have given our military an unprecedented advantage. Passive night vision systems, Forward Looking InfraRed sensors and Night Vision Goggles, have provided the capability to do daytime air combat tactics at night in tactical jet aircraft. Despite opening a whole new way of fighting the enemy, the existing night vision systems have deficiencies that limit their utility.

This paper comments on simple night vision theory, discusses the history of night vision devices, presents the deficiencies and enhancing qualities of existing night vision systems, and outlines basic requirements and specifications for a new night vision design for tactical jets. The proposed conceptual design utilizes the evolving technologies in digital Forward Looking InfraRed (FLIR) systems, advanced image intensifiers, sensor fusion, high speed computer processing, accurate helmet tracking systems and advanced helmet mounted displays. The critical aspect of the design is the integration of two separate sensors through sensor fusion algorithms and high speed processing to provide one improved dynamic image. The proposed night vision design of a forward fuselage mounted dual sensor turret linked to an advanced helmet mounted display through an accurate helmet tracking system should meet all the future night vision requirements.

Much of the information to rate the deficiencies and enhancing qualities of the existing systems is based on personal flight test of the night vision systems in the F/A-18 C/D, F-15E, and AH-64 aircraft. This thesis and all reference material listed are unclassified. In addition, the proposed conceptual design does not compromise company private information.

TABLE OF CONTENTS

LIST OF FIGURES

NOMENCLATURE AND SYMBOLS

AC	Alternating Current
AGARD	Advisory Group for Aerospace Research and Development
ANVIS	Aviator Night Vision Imaging System
AMEL	Active Matrix Electroluminescent
AMLCD	Active Matrix Liquid Crystal Display
ASR	Automatic Scene Reject
ARPA	Advanced Research Project Agency
CAS	Close Air Support
CCD	Charge Coupled Device
CG	Center of Gravity
CRT	Cathode Ray Tube
DC	Direct Current
deg	degree
ECM	Electronic Counter Measures
ESM	Electronic Surveillance Measures
FLIR	Forward Looking InfraRed
FOV	Field Of View
FPA	Focal Plane Array
GaAs	Gallium Arsenide
HMS	Helmet Mounted Sight
HMD	Helmet Mounted Display
HUD	Heads Up Display
I-NIGHTS	Interim Night Integrated Helmet Tracker System
IP	Initial Point

IR	InfraRed
IRST	InfraRed Search and Track
I^2	Image Intensifier
I^2CCD	Image Intensifier Charge Coupled Device
LANTIRN	Low Altitude Navigation and Targeting InfraRed for Night
LOS	Line Of Sight
NATOPS	Naval Air Training Operating Procedures
NAVFLIR	NAVigation Forward Looking InfraRed
NVG	Night Vision Goggle
NVIS	Night Vision Imaging System
MCP	Micro-Channel Plate
mm	Millimeter
PNVS	Pilot Night Vision System
rad	radian
RAE	Royal Aircraft Establishment
UK	United Kingdom
USAARL	United States Army Aeromedical Research Laboratory

INTRODUCTION

Night vision systems have been one of the greatest advancements in the warfighting capabilities of the U. S. Armed Forces in the later half of the twentieth century. These systems have provided the ability to "see-at-night and fight-at-night"[1] by passively capturing infrared electromagnetic energy in different spectrums and providing images for viewing, acting as "windows" to see into the night. The Persian Gulf War in 1991 validated the technology of night vision systems. Ground troops and helicopter aircrew operated extensively with night vision systems, playing a major role in the rapid defeat of Iraq. U.S. Air Force Major General Buster C. Gloson summing up their importance by saying, "Always remember that the Gulf war began, was fought and was won at night."[2] A few U.S. tactical jet aircraft in theater were fortunate to be equipped with night navigation and pilotage systems. The U.S. Air Force F-15E deployed with the Low Altitude Navigation and Targeting InfraRed for Night (LANTIRN) system, which included an external pod that provided an active terrain following radar and a passive NAVigation Forward Looking InfraRed (NAVFLIR) system. The U.S. Marine Corps F/A-18D aircraft deployed with a passive only system, which included a NAVFLIR external pod and combiner style Night Vision Goggles (NVGs). Passive night vision systems; NAVFLIRs and NVGs, have provided the capability to do daytime air combat tactics at night, but have not "turned night into day."[3,4] Despite opening a

---

[1] Richard Tinker and Fredrick H. McFarland Jr., "Enhanced Night Operational Effectiveness Utilizing Multi-Spectral Image Fusion," Texas Instruments, Night Vision '92 Conference and Exhibition. London, United Kingdom, September 1992. p. 1

[2] Mark Tapscott, "At Night: First Look, First Shot Wins," Defense Electronics, April 1992, p. 50.

[3] Bruce D. Nordwall, "New Goggles Improve Night Vision But Do Not Match Daylight Conditions,"Aviation Week & Space Technology, April 10, 1989, p. 86.

[4] Steve Pickering, "Turning Night into Day." Electronics & Power: The Journal of the Institution of Electrical Engineers, 33 (July 1987) 447.

whole new way of fighting the enemy, night vision systems have deficiencies that limit their utility. Future night vision systems will take advantage of evolving technologies in digital Forward Looking InfraRed (FLIR) systems, advanced image intensifiers, sensor fusion, high speed computer processing, accurate helmet tracking systems and advanced helmet mounted displays to fully integrate a greatly enhanced synergistic system. This paper will comment on simple night vision theory, illustrate the history of night vision devices, show the deficiencies and enhancing qualities of existing night vision systems, provide basic requirements and specifications for a new night vision design for tactical jets, and propose a conceptual design to meet these requirements and specifications.

CHAPTER I

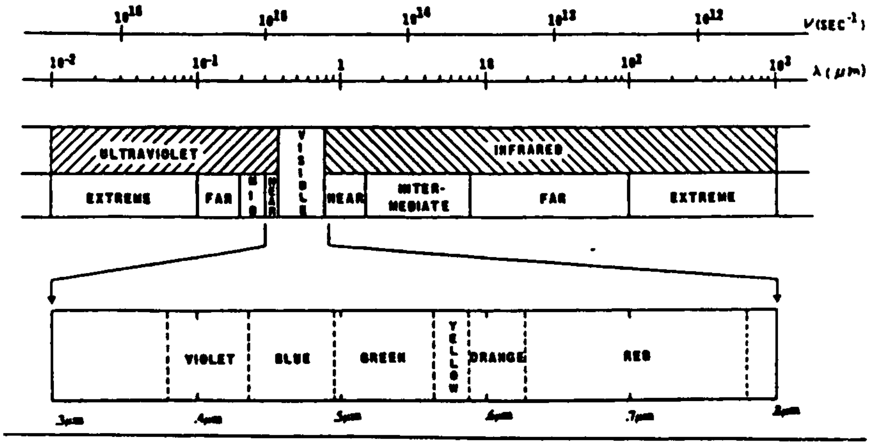
NIGHT VISION SYSTEMS THEORY

ELECTROMAGNETIC SPECTRUM

A simple understanding of electromagnetic energy helps to understand what it takes to develop a passive night sensor that will allow tactical jets to navigate and maneuver in a dynamic environment. Electromagnetic energy is produced by inherent molecular motion and internal energy transfer and behaves in accordance with the laws of reflection, refraction, diffraction, polarization, and velocity of propagation throughout its spectrum. Specific electromagnetic energy is characterized by its frequency and wavelength. The electromagnetic energy spectrum, shown in the appendix, figure 1, includes long electrical oscillations, radio and microwaves, infrared waves, visible light, ultraviolet waves, x-rays, gamma rays and cosmic rays. Passive night sensors need to capture the energy existing in the environment and produce an image that is visually discernible. Unfortunately, only a small portion of the vast spectrum lends itself for passive energy utilization. Millimeter and greater wavelengths require active transmitting devices, such as radars, to capture energy to map terrain features and man-made objects.[5] Below the ultraviolet wavelength, energy is produced from astronomical and atomic reactions and does not have applications for passively imaging at tactical ranges. While, ultraviolet energy does have many passive tactical applications such as mapping oil spills, it is mainly detected as reflected energy from the sun, which precludes it from any night applications.[6] That leaves the infrared (IR) and visible

[5] McGraw-Hill Encyclopedia of Physics, McGraw-Hill Incorporated, 1983, p. 278.
[6] McGraw-Hill Encyclopedia of Physics, p.210.

spectrum shown in figure 1-1, available for passive energy detection at night. The mid and far IR regions are dominated with emitted thermal energy while, the near IR and visible light regions are dominated with reflected and scattered energy.[7] Unique sensors have been developed to capture the energy in these two regions; thermal detectors for mid to far IR and light intensifiers for visible to near IR.



Infrared, Visual and Ultraviolet Spectrum

Figure 1-1

Source: Electronic Warfare and Radar Systems Engineering Handbook, Naval Air Systems Command, Washington D.C., 1st Edition, March 1992, p. 7-1.3.

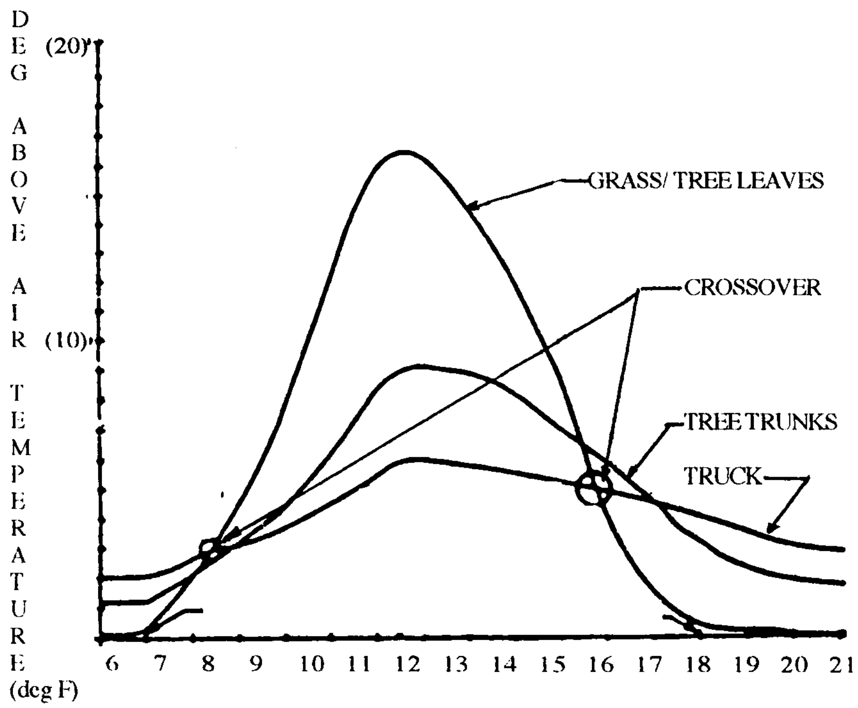
[7] Introduction to Cats Eyes, Training Work Book 171.4, Marine Strike Fighter Squadron One Hundred and One, (November 14, 1991), p. 4.

THERMAL DETECTION THEORY

Forward Looking InfraRed (FLIR) sensors detect variations in thermal radiation about a scene. Variations in the thermal scene are caused by the different temperatures and thermal emissivities of the objects in the scene.[8] In a simplistic view, thermal energy is absorbed during daylight hours and is dissipated during the night hours. Atmospheric conditions, sky conditions, cloud cover, and ambient air temperatures affect the thermal background and the temperature differences. Man-made objects can also increase their thermal signature with an operating engine. Figure 1-2 shows the constantly changing temperature differences of background objects and man-made targets as a function of time of day. This noticeable heating and cooling cycle is referred to as the diurnal cycle.[9] An IR detector is most effective when there are discernible thermal differences between objects. As shown this can occur in both day and night conditions. There are definite crossover points, near the twilight hours, where the background objects change in relation to one another. FLIRs are most challenged during the diurnal crossovers due to the rapidly changing scene and the minimal temperature differences.

[8] Fred Rosell, and George Harvey, The Fundamentals of Thermal Imaging Systems, Naval Research Laboratory Report 8311, (May 1979). pp. 7-8.

[9] Helicopter NVG Manual, Marine Aviation Weapons and Tactics Squadron One, (September 1990), p. 2-18.



Thermal Diurnal Cycle

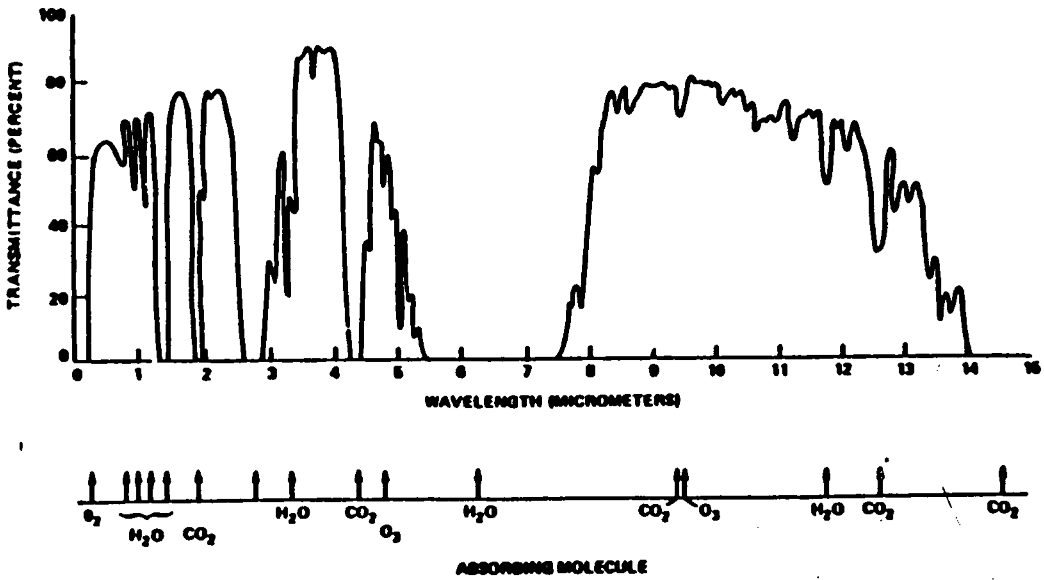
Figure 1-2

Source: Helicopter NVG Manual, Marine Aviation Weapons and Tactics Squadron One, (September 1990) p. 2-18.

Atmospheric conditions greatly affect the transmittance and detection of the thermal scene. As shown in figure 1-3, water molecules are the greatest contributor to absorption of thermal energy and primarily determine the atmospheric "windows" for IR detection. The 3-5 and 8-12 micrometer wavelengths are the most obvious "windows." Aerosols such as salt spray, fog, dust, sand and ashes also affect the performance of an IR detector. Generally, the 3-5 micrometer window is degraded more by hazy conditions and the 8-12 micrometer window is more degraded by humidity.[10]

---

[10] Fred Rosell, and George Harvey, The Fundamentals of Thermal Imaging Systems, p. 21.



Atmospheric Transmittance

Figure 1-3

Source: H.D.V. Böhm, "FLIR, NVG and HMS/D Systems for Helicopter Operation Review", North Atlantic Treaty Organization Advisory Group for Aerospace Research and Development (AGARD) Conference Proceedings, No. 379, (December 1985), 2-12.

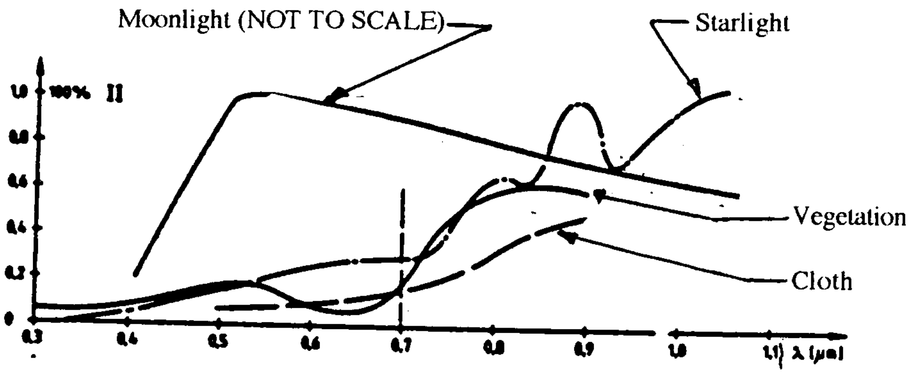
The basic FLIR system consists of several components. A telescopic assembly, employing appropriate transmitting optical elements, collects IR energy from the thermal scene and focuses it on the detector array through a scanner.[11] A scanner moves the image of the scene over each of the detectors in the desired Field of View (FOV). The detectors, which are sensitive to certain bands of IR energy depending on the mission application, convert the thermal differences in the scene

[11] FLIR Performance Handbook, (DCS Corporation 1988) p. 1-4.

radiation to electrical signals. A gimbal mounting system permits accurate pointing of the optics and protects them from jitter. The electrical signals produced by the detectors are then processed through a multiplexer to an electro-optical bus. A display system then converts the electro-optical bus signals into a discernible image for viewing. A picture of a simple FLIR system is shown in the appendix, figure 2.

LIGHT INTENSIFIER THEORY

Light intensifiers simply amplify the existing light registered and display it to the pilot. As shown in figure 1-4, the night sky irradiance and reflected light

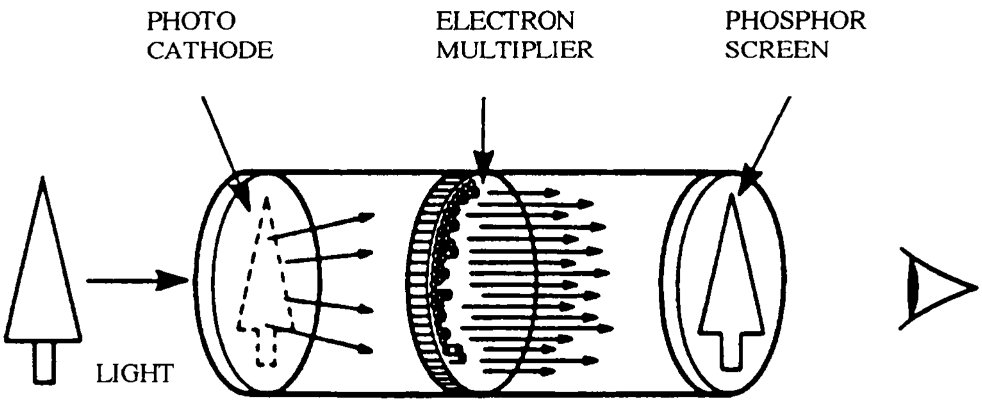


Relative Night Sky Irradiance and Reflections

Figure 1-4

Source: H.D.V. Böhm, "FLIR, NVG and HMS/D Systems for Helicopter Operation Review", North Atlantic Treaty Organization Advisory Group f for Aerospace Research and Development (AGARD) Conference Proceedings, No. 379, (December 1985), 2-9.

from terrain features are enhanced in the near IR spectrum. Light intensifier tubes have been developed for helmet use that operate in this region. Essentially, these tubes work by capturing photons of ambient light and bombarding them against a photocathode, which is sensitive to the appropriate wavelength. The photocathode then emits electrons in proportion to the amount of light striking it. An electron field then accelerates the emitted electrons before they reach a phosphor screen for viewing. The light intensity produced for viewing is proportional to the number and velocity of electrons hitting the phosphor screen.[12] A simple diagram is shown in figure 1-5.



Functional Illustration of Image Intensifier Tube

Figure 1-5

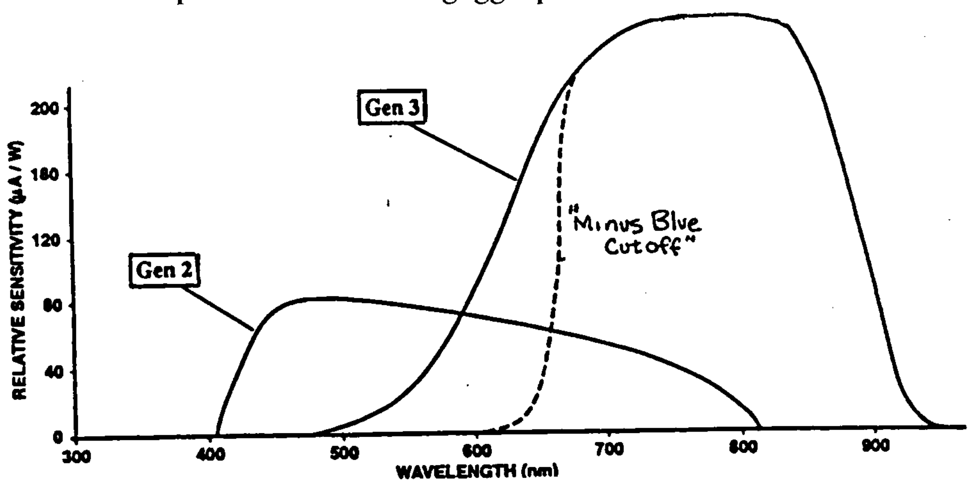
Source: An Integrated Night Vision System for the TF-18 Hornet, PL3741, GEC Avionics Limited, p. 5-7.

NIGHT VISION IMAGING SYSTEM (NVIS) COMPATIBILITY

In order to fly with light intensifiers mounted on the helmet to aid night vision, the aircraft cockpit lighting must be compatible and not adversely affect the Night Vision Goggle performance. The light intensifier devices are sensitive to electromagnetic energy from the 0.5 to 0.9 micrometer wavelengths, which includes much of the visible light spectrum. Therefore, lighting in the cockpit in this region

[12] Robert W. Verona Ph D, "Image Intensifiers: Past and Present" North Atlantic Treaty Organization Advisory Group for Aerospace Research and Development (AGARD) Conference Proceedings No. 379 (December 1985) p. 1-2.

can adversely affect the performance of the goggles to respond to the outside ambient lighting levels. It is much like how the human eye responds to too much interior light inside a car while driving at night. In 1986, a joint military specification, MIL-L-85762, "Lighting, Aircraft, Interior, Night Vision Imaging Compatible," was approved to resolve cockpit lighting problems.[13] Aircraft meeting the requirements of MIL-L-85762 are considered NVIS compatible which means the cockpit lighting colors are all blue-green or below in the visual spectrum. Figure 1-6 shows the typical third generation image intensifier response curve. To further integrate the NVGs into the cockpit and eliminate interference, a dielectric cut-off filter has been incorporated on most modern NVGs that filter out any light below "a minus blue" point. This cutoff at 0.665 micrometers in CATS EYES NVGs allows for some red to be in the cockpit and not affect the goggle performance.[14]



Second and Third Generation Image Intensifier Tube Response

Figure 1-6

Source: Michael R. Swales and Randall W. Cason, "Helicopter Night Vision Goggle Testing in the United Kingdom," Aeroplane and Armament Experimental Establishment, Boscombe Down, United Kingdom, p. 17-3.

---

[13] Clarence E. Rash, and Robert W. Verona Ph D., "Compatibility of Aircraft Cockpit Lighting and Image Intensification Night Imaging Systems," <u>Optical Engineering</u>. 29 (August 1990) 863-869.

[14] Clarence E. Rash, and Robert W. Verona Ph D., pp. 864.

CHAPTER II

NIGHT VISION SYSTEMS HISTORY

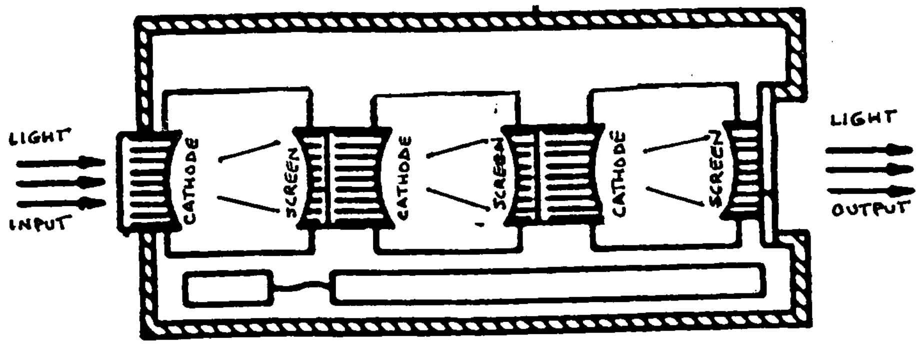
HELICOPTER NIGHT VISION SYSTEMS

Night vision systems used by aviators developed their roots from systems designed for foot soldiers. Historically, aviator night systems have been developed and designed first for helicopters before fixed wing aircraft. The sensitivities in fixed wing aircraft aerodynamics and complications in ejection capability, have made design solutions harder. The image intensifiers have evolved into rugged light weight high performance systems that have allowed the soldier and aviator to see at night. IR technology has proven to be exceptional in finding targets, but limited in mapping the terrain features. IR technology improvements have brought forth night vision systems to enhance night navigation and pilotage. The Apache helicopter has utilized a FLIR system mounted to a rotating turret.

First Generation Image Intensifiers

The US Army first experimented with Night Vision Systems for aviation use in the late 1950s. They first evaluated binocular InfraRed (IR) converter devices that were head mounted. These IR converter devices required an active IR covert landing light to see ahead of the aircraft, which was deemed unsatisfactory in test.[15] In the 1960's, first generation image intensifier (I^2) tubes, shown in figure 2-1, were developed for completely passive imaging. These I^2 tubes utilized a three stage process to accelerate the electrons to the phosphor screen yielding nominal gain of

[15] Albert Efkeman, and Donald Jenkins, "Development of Aviator's Night Vision Imaging System (ANVIS)," Optical Engineering, 20 (March / April 1981) 208.



First Generation Image Intensifier Tubes

Figure 2-1

Source: Helicopter NVG Manual, Marine Aviation Weapons and Tactics Squadron One, (September 1990) p. 2-6.

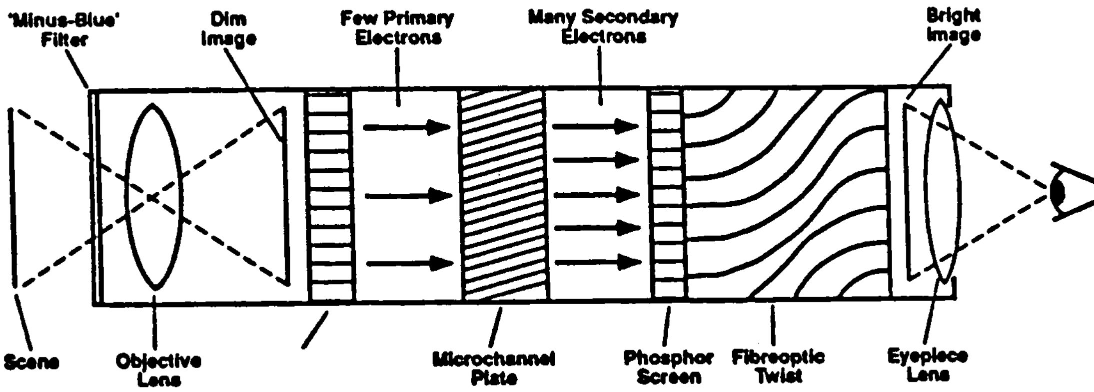
40,000 to 60,000 with a resolution of 30-36 line pairs/mm. However, the major drawbacks were susceptibility to blooming from bright light sources, relatively high voltage requirements(6.75V), and large size (foot long tubes).[16] This technology proved great for starlight rifle scopes but too bulky for helmet mounted aviation use.

Second Generation Image Intensifier Systems

The U.S. Army made a break through in the 1970s by reducing the image intensifier tube in size and weight to allow for helmet mounting. These second generation tubes used a Micro-Channel Plate (MCP) , which consisted of several million fiber optic channels compacted into a 8 mm wafer.[17] The channel walls were

[16] Robert W. Verona Ph D., "Image Intensifiers: Past and Present" p. 1-2.
[17] Robert W. Verona Ph D., "Image Intensifiers: Past and Present," p. 1-2 to 1-3.

tilted about 8 deg and coated with an emissive material that released secondary electrons. This not only accelerated electrons, but multiplied them towards the phosphor screen. The photocathode, S-20 multi-alkali, provided sensitivity of 0.4-0.85 micrometers, just a little out of the visual spectrum to capture some of the night radiance. Diagrams of the second generation devices are shown in figure 2-2. The performance of the second generation I^2 tubes were not as good as the first generation tubes. The nominal gain was only about 20,000 to 30,000 with the resolution of 28 line-pairs/mm, but the tubes were smaller, lighter and had a power requirement of only 2.7 volts. The U.S. Army primarily developed the second generation tubes in the AN/PVS-5 Night Vision Goggles for the foot soldier, but in 1973 the AN/PVS-5's were adopted as interim pilot's aids for night vision. Because the AN/PVS-5's, shown in figure 2-3, were developed only for the foot soldier, they had several misgivings for aviator use including, no look around capability with the enclosed face mask, limited depth of field, excessive weight

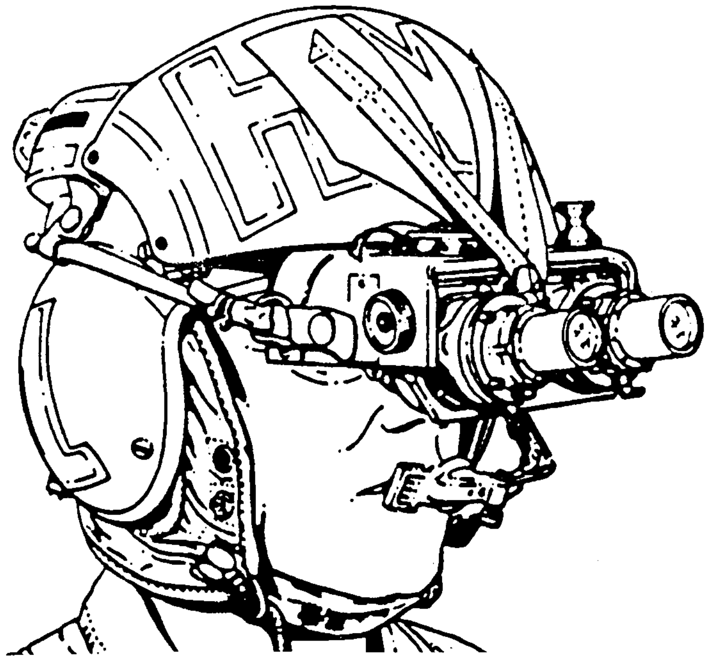


Second Generation Image Intensifier Tubes

Figure 2-2

Source: Michael R. Swales and Randall W. Cason, "Helicopter Night Vision Goggle Testing in the United Kingdom," Aeroplane and Armament Experimental Establishment, Boscombe Down, United Kingdom, p. 17-3.

forward of the head causing neck fatigue and poor response in lighting conditions with less than a quarter moon. However, the U.S. Army tactical helicopter community equipped with modified AN/PVS-5 NVGs did finally possess the capability to perform Nap-of-the-earth flying both day and night, albeit limited. The mission capabilities that opened up from the AN/PVS-5 goggles, along with the severe limitations prompted the U.S. Army to develop Night vision devices explicitly designed for pilots.[18]



Face Mounted AN/PVS-5 Night Vision Goggles

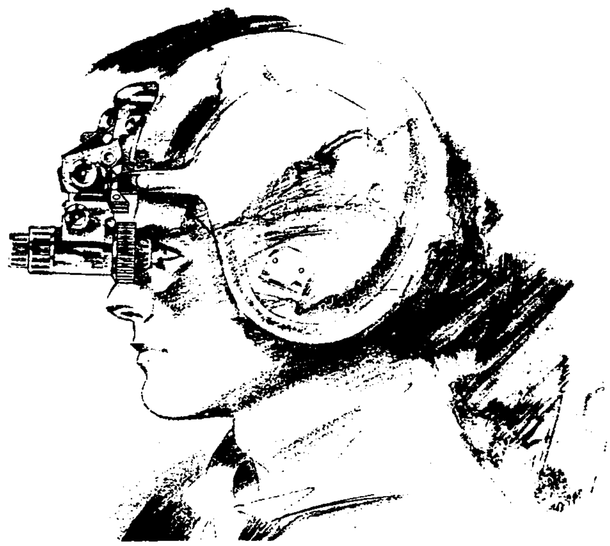
Figure 2-3

Source: Helicopter NVG Manual. Marine Aviation Weapons and Tactics Squadron One, September 1, 1990.

[18] Albert Efkeman, and Donald Jenkins, "Development of Aviator's Night Vision Imaging System (ANVIS)," pp. 208-209.

Third Generation Image Intensifiers Systems

In response to the AN/PVS-5 flight tests, in 1976 the U.S. Army's Night Vision and Electro-Optics Laboratory launched development of the Aviator's Night Vision Imaging System (ANVIS). The ANVIS, AN/AVS-6, goggles used third generation I^2 tubes that improved the resolution and gain of second generation tubes. The newer tubes incorporated Gallium Arsenide (GaAs) as the photocathode, with a sensitivity of 0.55-0.95 micrometers, which provided better response, especially in lower level light conditions. A relative response comparison of second and third generation image intensifier tubes are shown in figure 1-6. The nominal gain was up to 25,000 with a resolution of 36 line pairs/mm while the power requirements were a nominal 3.0 volts.[19] The ANVIS goggles mounted on the helmet, as shown in figure 2-4, had a flip up feature to enable normal unobstructed unaided field of view.



Helmet Mounted ANVIS Goggles

Figure 2-4

Source: Joe Bill Dryden, "Out of the Dark, Through the Glass" Code One, (October 1992), p. 15.

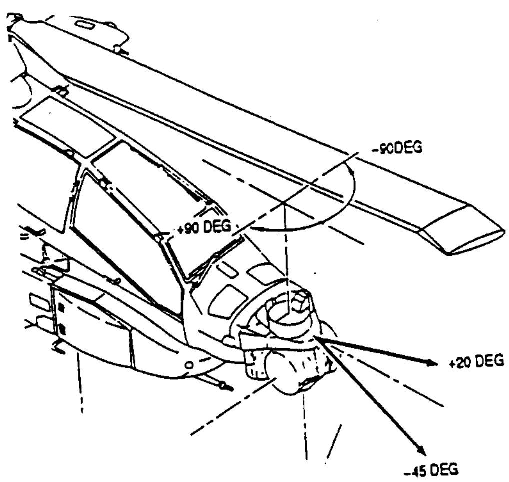
---

[19] Albert Efkeman, and Donald Jenkins, "Development of Aviator's Night Vision Imaging System (ANVIS)," pp. 208-209

With the goggles in the down position the goggles provided 40 deg aided field of view and a much improved look around capability compared to the AN/PVS-5. The ANVIS goggles are still the primary night vision system for many of the U.S. military type aircraft.

Helicopter Infrared Night Vision Systems

In the early 1980's the U.S Army developed the Apache attack helicopter system that included the AN/AAQ-11, Pilot Night Vision Sensor (PNVS) used for visual flight reference, obstacle avoidance, navigation and targeting at night.[20] The PNVS is an 8-12 micrometer FLIR system mounted on a turret device located on the nose of the aircraft, as shown in figure 2-5. The FLIR is linked to the monocular



Apache Helicopter FLIR Turret

Figure 2-5

Source: Todd Brown, "Apache Night Vision Systems." Night Vision "92 Conference and Exhibition. London, United Kingdom, September 3, 1992

[20] Todd Brown, Chief Warrant Officer Three, U.S. Army, "Apache Night Vision Systems." Night Vision '92 Conference and Exhibition. London, United Kingdom, September 1992, p. 1

helmet mounted display by a magnetic helmet tracking system. In the monocular display device, weapons and flight symbology is superimposed with the IR image. Figure 2-6 shows the monocular display attached to a pilots helmet. The

PNVS Monocular Helmet Display

Figure 2-6

Source: Verona, Robert W. Ph D. Human Factors and Safety Considerations of Night Vision Systems Flight. USAARL Report No. 89-12 July 1989.

PNVS provides the pilot with a 30 deg vertical by 40 deg horizontal aided field of view with a field of regard of +/-90 deg in azimuth and +20 deg to -45 deg in elevation. The slew rate of the head tracking FLIR was 120 deg/ sec, approximately 2 rad/sec. The major advantages of the PNVS as noted in a flight evaluation were: 1) not dependent upon ambient light for imaging and 2) integration of FLIR video and flight symbology. The major disadvantages were: 1) slow slew rates inconsistent with rapid head movement, 2) restricted unaided field of view due to the monocular device, 3) distracting display that was not consistent with the visual scene requiring some interpretation and 4) eye strain due to the left eye focused at infinity and adapted to ambient lighting conditions and the right eye focused and adapted to the monocular device display.[21] These combined disadvantages contribute to disorientation and require extensive training to physiologically overcome. Sixty two percent of the total flight training in the Apache Aviator qualification course is devoted to PNVS flying.[22] The greatest contribution to pilot drop out rate is the inability to adapt to the PNVS system.

TACTICAL JET NIGHT VISION SYSTEMS

Night vision system development for tactical jet aircraft followed that of helicopters. U.S. Navy / U.S. Marine Corps night attack aircraft have utilized helmet mounted image intensifiers in conjunction with aircraft mounted FLIRs. Historically, U.S Air Force night attack aircraft have relied on active transmitting terrain following radars. In order to increase situational awareness during low level night strike missions, the U.S. Air Force has added a navigation FLIR capability to its F-15E and F-16C aircraft. Additionally, the U.S. Air Force has evaluated FLIR only systems similar the Apache PNVS.

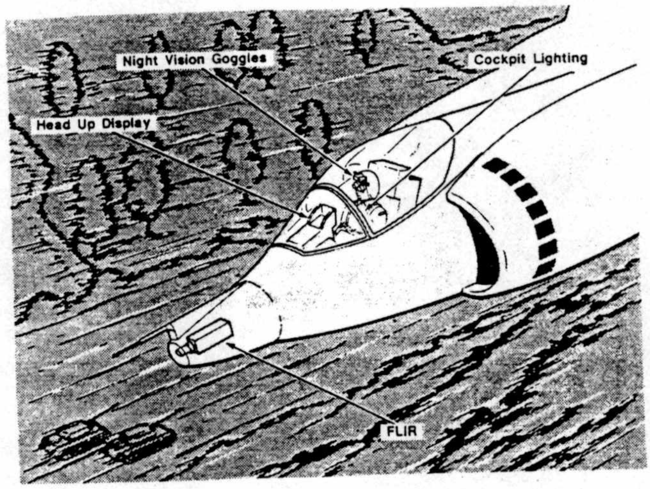
Night Vision System Development for Tactical Jets

In the late 1970's, the tactical jet community saw the emerging requirement to use night vision systems to perform day time tactics at night. The Royal Aircraft Establishment (RAE) in Fainborough, United Kingdom (UK) launched the Night Bird program, which initially consisted of flight tests in two seat Jaguar and Hunter

[21] David Culbertson. "Notes on Qualitative Flight Evaluation of the AH-64 Apache Aircraft." November 1992.

[22] Todd Brown, Chief Warrant Officer Three, U.S. Army. "Apache Night Vision Systems." p. 12.

jets to assess the feasibility of using the ANVIS goggles in the tactical jet environment. The early Jaguar flight tests results were positive with the final report summary stating that "the pilot could taxi and takeoff from a completely dark airfield, fly and navigate accurately at representative low level heights, find a pre-target IP, find and successfully attack targets using 5 deg dive tip-in and toss attacks and return to unlit airfields and land."[23] This was deemed a major breakthrough in the tactical jet community. The Night Bird testing revealed, after test flying with low light television, fixed FLIRs and NVGs, that the most simple, yet effective, configuration to conduct passive high-speed dynamic low level night flight was a fixed NAVFLIR operating in the 8-12 micrometer IR wavelength and helmet mounted NVGs operating in the 0.6-0.9 near IR wavelength.[24] This configuration, shown in figure 2-7, combined a high resolution image from the NAVFLIR displayed on the Heads



Night Bird Configuration

Figure 2-7

Source: Steve Pickering, "Turning Night into Day," Electronics & Power: The Journal of the Institution of Electrical Engineers, 33 (July 1987) 447.

---

[23] G.Peck, Sqn Ldr Royal Air Force, and D.Reech, Flt Lt Royal Air Force, An Assessment of Passive Night Goggles for Strike Ground Attack Operations at Night, Royal Aircraft Establishment Technical Memorandum EFD 811. October 1981. p. i.

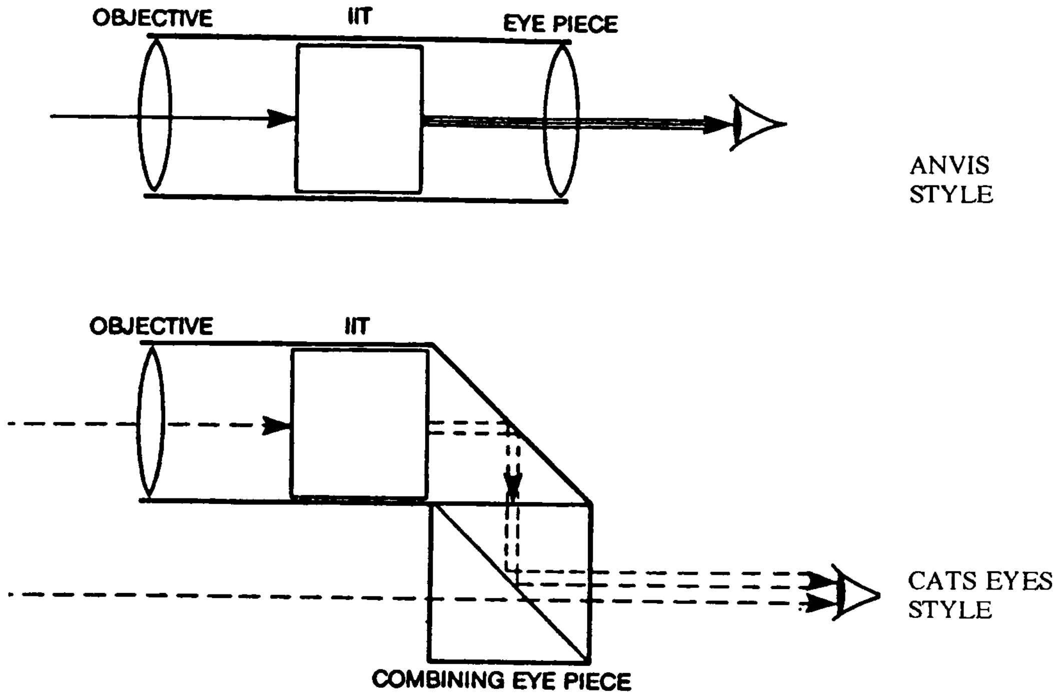
[24] Steve Pickering, p. 447.

Up Display (HUD) and a lower definition image from the NVGs for look-around capability. Further tests revealed more technical information including NVG cockpit compatibility. The RAE concluded, in two seat Hunter flight tests, that ANVIS style "look-through" Night Vision Goggles severely degraded HUD imagery, making it incompatible with holographic HUDs. ANVIS goggles also restricted peripheral vision for cockpit monitoring and were not wind blast and ejection compatible.

CATS EYES Night Vision Goggle Development

In response to the Night Bird flight tests, GEC Avionics Limited of England launched into development of the CATS EYES combiner style NVGs.[25] A pictorial comparison of the "look-through" style ANVIS and combiner style CATS EYES NVGs are shown in figure 2-8. The combiner style NVGs were designed to be compatible with raster holographic HUDs and allowed better unaided unobstructed peripheral vision for cockpit monitoring. The CATS EYES design ensured capability with chemical and biological survival gear and personnel eyeglasses. Direct viewing of the HUD through the combiner instead of through the I^2 tubes was possible with limited loss in transmissivity. Quite often the I^2 image and the IR image conflicted, and were confusing when viewed together. A feature was added to improve integration of the CATS EYES NVGs and the HUD IR image. This pilot selectable feature, Automatic Scene Reject (ASR), immediately turned off the I^2 image on the combiners of the NVGs when the pilot field of view coincided with the HUD field of view, enabling the pilot to view the IR image on the HUD through the combiners. The I^2 image immediately returned when out of the HUD field of view.

[25] An Integrated Night Vision System for the TF-18 Hornet. PL3741. GEC Avionics Limited. p. 5-1

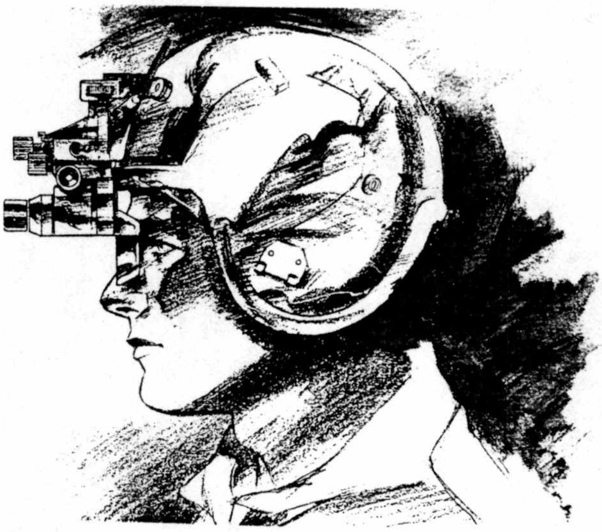


Pictorial Illustration of ANVIS Style vs. CATS EYES Style Goggles

Figure 2-8

Source: An Integrated Night Vision System for the TF-18 Hornet, PL3741, GEC Avionics Limited, p. 5-7.

The ASR feature was incorporated in the AV-8B but not in the F/A-18 C/D. Also, the CATS EYES NVGs were equipped with a quick release mechanism to allow for rapid removal in case of ejection. A picture of the CATS EYES mounted on a helmet are shown in figure 2-9.



Helmet Mounted CATS EYES Goggles

Figure 2-9

Source: Joe Bill Dryden, "Out of the Dark, Through the Glass" Code One, (October 1992), p. 14.

Project Cheap Night

The United Kingdom Night Bird passive night attack concept was further evaluated in the Navy's "Project Cheap Night" in 1984.[26] A two seat TA-7C airplane was configured with a fixed FLIR pod, a raster HUD and NVGs. The program proved to be successful in demonstrating an excellent night low level flying capability, using off-the shelf technology. The combination of the helmet mounted NVGs operating in the visual to near IR spectrum and the raster HUD image of the fixed FLIR, operating in the far IR spectrum, provided complementary capabilities confirming the Night Bird findings. The outstanding results of Cheap Night

[26] Brendan M. Greenly Jr., "Navy, USMC Push Development of Night-Attack Capability," Aviation Week & Space Technology, July 7,1986, p. 99.

launched the U.S. Marine Corps and U.S. Navy into the night attack programs for the AV-8B and F/A-18.

Continued Night Vision Development

The U.S. Navy continued to test and evaluate night vision systems to validate the feasibility of implementing into production aircraft. The U.S. Navy evaluated the capability of inserting the results of Night Bird and Cheap Night into its night attack workhorse, the A-6E Intruder. The production A-6E navigated its way at night with the help of a highly trained Bombardier/Navigator and a terrain clearance radar. Project Quick Night was developed to investigate the feasibility of inserting this passive night vision system into the A-6E.[27] Previous night vision testing has shown the complication of making the cockpit compatible for the helmet mounted Image Intensifiers. The Quick Night A-6E was equipped with CATS EYES NVGs and used the production detection and ranging set (targeting FLIR) as a NAVFLIR. The Quick Night tests also revealed compatibility and integration problems, but showed that the system offered definite advantages. The U.S. Navy continued night vision development with the Real Night attack project.[28] A test bed A-6E was equipped with a pod mounted NAVFLIR, two raster HUDs, CATS EYES NVGs, and a NVIS compatible cockpit. The night attack test bed was introduced to evaluate Night Vision systems as they developed.

Night Attack Production Programs

The U.S. Marine Corps were the first to field a production night vision system in a tactical jet with the AV-8B. The AV-8B completed operational testing in

[27] Brendan Greenly Jr., "Navy, USMC Push Development of Night-Attack Capability," p. 99.
[28] Brendan Greenly Jr., "Navy, USMC Push Development of Night-Attack Capability," p. 101.

1988 and was fielded in 1989. It was equipped with CATS EYES NVGs, a raster holographic HUD which displayed a collimated image of the fixed NAVFLIR, a color digital moving map display and a NVIS compatible cockpit. The U.S. Navy and U.S. Marine Corps F/A-18 followed shortly with a similar integration scheme for all the F/A-18C (Single seat) and F/A-18D (two seat) production deliveries of 1989 and subsequent. The U.S. Marine Corps F/A-18D's replaced the aging all-weather A-6E bomber and proved to be invaluable assets in the Persian Gulf War, not only for fighter support and night strike, but for locating mobile targets and directing close air support (CAS) strikes day and night.[29] Once the flexibility and capability of the F/A-18D was discovered it became the primary night forward air controller platform for CAS.

LANTIRN Program

The U. S. Air Force did not follow the same path of the U.S Navy in incorporating night vision systems into tactical jets. The F-15E and F-16 aircraft improved on the night attack terrain following radar systems of the F-111 and B-1 by integrating the LANTIRN system. The F-111 and B-1 could hug the earth at night with a terrain following radar and coupled flight control system and target weapons with a targeting FLIR and LASER designator. The LANTIRN system provides that capability plus the ability to "see" into the night. The LANTIRN system consists of a navigation pod, the AAQ-13, and a targeting pod, the AAQ-14.[30] The navigation pod contains a 8-12 micrometer NAVFLIR and Ku band terrain following radar, while the targeting pod is a 8-12 micrometer slewable targeting FLIR with two fields

[29] "Night Vision Systems Yield Payoff in Persian Gulf War." Aviation Week & Space Technology, February 3, 1992, p. 42.

[30] LANTRIN FIRE CONTROL SYSTEM , System Description Document OR 17, 280-1, Martin Marietta Corporation, November 1983.

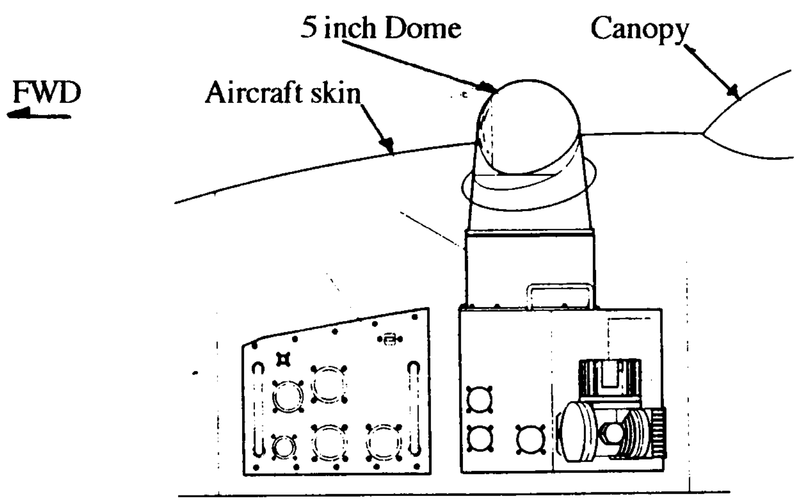
of view and self designating laser. The NAVFLIR is displayed on the wide field of view HUD along with steering commands from the terrain following radar and weapons and flight symbology. The 28 deg azimuth by 21 deg elevation IR image on the HUD gives the pilot a "window" into the night. To expand the "window", the NAVFLIR can be snap-looked up or down 9 deg and left or right by 25 deg from center and slaved to look-into-turn by 6 deg. These momentary snap-look and look-into-turn features allow the pilot the capability to effectively expand the field of view and see in the direction of the turn. As designed this feature seems to be enhancing but, the total field of regard of the expanded "window" is still limited to only a 50 deg cone in front of the aircraft.

Falcon Eye FLIR Program

The U.S. Air Force has looked at additional infrared imaging night vision systems to provide night warfare enhancement. General Dynamics developed a program called Falcon Eye for the F-16 that incorporated a prototype turret mounted FLIR slaved to a head tracking helmet mounted display.[31] A 5 inch diameter turret mounted on the forward fuselage of a two seat F-16B was used for prototype testing. The single turret had two optical fields of view, Wide-22.5 deg by 30 deg(1:1 magnification) and Narrow-4 deg by 5 deg (5.6 magnification). The gimbaled turret allowed for a total field of regard of +/-150 deg in azimuth and +60 deg/-20 deg elevation, which is almost the same field of regard of the pilot in the cockpit. The flight test program proved quite successful and showed the utility of a helmet mounted FLIR system to improve situational awareness over an essentially fixed field of view FLIR. Larry Lydick, Engineering Project Manager for General Dynamics,

[31] Dan Rock, et al. "Falcon Eye Forward-Looking Infra-Red (FLIR) System." Proceedings of the International Society for Optical Engineering (SPIE), Volume 782, Infrared Sensors and Sensor Fusion, May 1987, p. 38-45.

envisioned the Falcon Eye as the follow on to NVGs because it merged the navigation, situation awareness and targeting into one sensor and one display.[32] Figure 2-10 shows a pictorial representation of the Falcon Eye system. The flight demonstration tests proved to be effective, but the concept has not been incorporated into production.



Pictorial Illustration of the Falcon Eye FLIR

Figure 2-10

Source: Dan Rock, et al. "Falcon Eye Forward-Looking Infra-Red (FLIR) System," Proceedings of the International Society for Optical Engineering, 782 (May 1987), 43.

Falcon Knight Program

The U.S. Air Force and General Dynamics have most recently looked at the development of a dual turret mounted FLIR system by WESTINGHOUSE, called

[32] Larry N. Lydick, "Building the System," Code One, (January, 1989), p. 19.

the Falcon Knight. The concept of Falcon Knight is similar to Falcon Eye in that the FLIR turret is located on the nose of the aircraft not on a weapons station and is linked to a helmet mounted display for expanded field of regard. The Falcon Knight adds a dedicated targeting FLIR to the dual turret Line of Sight (LOS) system, allowing separate targeting from navigation and pilotage if desired.[33] The advancement technology of the Falcon Knight is the integration of the two independent LOS turrets through an optical multiplexer into a single FLIR system with one detector. The greatest feature of the Falcon Knight System is the second generation digital 480x4 focal plane array detector. The digital detector not only refines the resolution of the FLIR system but operates at a 60 Hz rate allowing 30 signals for targeting and 30 signals for pilotage a second. Flight tests have been similarly quite successful. The test pilots liked the refined FLIR image and preferred the independent dual LOS approach but did not like the azimuth field of regard restrictions (+/- 90 deg) caused by the side by side installation of the turrets. The Air Force is still evaluating the cost effectiveness of incorporating the Falcon Eye on the F-16 for the CAS mission.

NIGHT VISION HELMET HISTORY

Helmets have developed from leather caps in the early days of aviation to ejection protective gear supporting oxygen masks. Lately, this simple head gear has grown into an essential tool for effective weapons employment, by supporting night vision displays, flight symbology and target designation cueing. Technology for helmet trackers and helmet displays have grown from the early 1970's. Early visor projected target designation cueing on helmet mounted displays were flown on the

---

[33] R.A. Hale et al., "Falcon Knight Dual Line-of-Sight Flir," 1994 IRIS PASSIVE SENSORS MEETING, March 1994. p. 3.

F-4. The Kaiser "Agile Eye" flew in the mid 1980's with a Cathode Ray Tubes (CRT) stroke display and an AC magnetic tracking system. Intensifier tubes have since been strapped on to provide night vision imagery and miniature CRTs have been integrated to display weapons symbology and FLIR imagery. The joint Interim Night Integrated Helmet Tracker System (I-NIGHTS) program was conceived to integrate into one ejection compatible helmet: weapons symbology, flight symbology, head tracking, and integrated I^2 imagery. There where many safety concerns expressed prior to the flight evaluation of the I-NIGHTS helmets, which caused the Navy to cancel the program.[34] The technology was not mature enough in 1990 to produce a lightweight day or night ejection safe helmet with good resolution and performance. The Air Force decided to take the I-NIGHTS helmets and continue research and development to help better define the requirements. Technologies now being researched for helmet tracking systems are DC magnetic and optical. A tracking system is fairly simple to design in thought but hard to actually implement. The integration of a helmet tracking system is essential to providing accurate pointing for weapons systems, valid flight symbology and a registered one to one imaged display. Active emissions of some sort, optical or magnetic, are distributed throughout the cockpit area to create a mapped field. The helmet has a receive device affixed to it to register the active emission field. Movement of the helmet is passed to the system computer to align weapons or drive a LOS turret sensor system. Display technologies being researched are folded optics with prisms lenses, CRT projected on the visor and miniature flat panel active matrix displays. The smaller, lighter and more compacted the design, the greater chance the tactical jet aircraft can incorporate it.

[34] David A. Fulghum, "Navy Orders Contractors to Stop Work On Ejectable Night Vision Helmets," Aviation Week & Space Technology, December 3, 1990, p. 67.

CHAPTER III

COMPARISON OF EXISTING NIGHT VISION SYSTEMS

NIGHT ATTACK SYSTEMS COMPARISONS

As discussed in the previous chapter with the history of night vision systems in tactical jet aircraft, there have been four basic approaches to night attack navigation. The first approach, an active terrain following system, was developed to enable tactical jet aircraft to hug the earth contours at night and in bad weather and remain relatively undetected. These night attack systems have proved to be quite effective, especially for low level bad weather, but they have been relatively expensive and have required extensive systems integration efforts. Additionally, the aircrew situational awareness has been limited to a display of radar returns in front of the airplane with no vision of the outside world. Developments in Electronic Counter Measures (ECM) and Electronic Surveillance Measures (ESM) have increased the vulnerability of the active terrain following systems. Simply stated, active systems can be jammed and detected. The second approach, the Night Bird concept with NVGs and a fixed NAVFLIR, is a purely passive approach which has given tactical jets the capability to perform night low level attack missions in relatively clear weather. The Night Bird concept has proven to be not nearly as expensive, in other words, its successor was not called Cheap Night for nothing. The NVGs have provided night vision with an extensive situational awareness around the entire airplane, essentially wherever the pilot can see. While the fixed NAVFLIR has only a limited field of view off the nose, it does provide vision into the night. The NVGs effectiveness depends upon light levels, where the NAVFLIR depends upon the thermal scene. This makes them complementary sensors that expand the mission effectiveness of the airplane. The third approach, the LANTIRN system, is a combination of the first two approaches, without the NVGs. It incorporates an active terrain following radar and a NAVFLIR. The LANTIRN system is still an expensive integration effort but does provide the all-weather attack capability. Night vision situational awareness is limited to the semi-fixed NAVFLIR. The fourth approach, the Falcon Eye and Apache PNVS method, has a turret mounted FLIR slaved to the pilots helmet with the video projected on to a helmet mounted display. The head slaved FLIR provides extensive situational awareness around the airplane in much the way NVGs do, but is completely dependent on the thermal scene to build an image. The Falcon Eye is also limited because it is only a single spectrum sensor. As far as relative expense and integration effort, the helmet slaved FLIR is greater than the Night Bird approach, but less than active terrain following systems. For the purpose of this paper the latter three approaches, systems that provide night vision, will be examined for their enhancing characteristics and deficiencies to provide guidelines for the design of a future night vision system.

NIGHT VISION SYSTEM CHARACTERISTICS

The three night vision approaches; LANTIRN (NAVFLIR only), Night Bird and Falcon Eye, have unique strengths and weaknesses that are shown in the appendix, table 1. For the purposes of this paper, we will disregard the expense as much as possible and focus primarily on system performance and design. Most of the analysis to evaluate the enhancing characteristics and deficiencies is based on personal qualitative flight test conducted on the F/A-18 equipped with NAVFLIR and CATS EYES, the F-15E equipped with a LANTIRN pod, and the AH-64 equipped with the PNVS system.

NIGHT VISION DEFICIENCIES

A summary of the night vision deficiencies are shown in figure 3-1. Detailed discussions are found below in the ensuing paragraphs. Analysis and discussion of deficiencies is based on flight test of night systems in F/A-18 C/D and F-15E aircraft. Much of this analysis is consistent with several sources, including a University of Tennessee thesis by LT Mike Bryan entitled, "Integration of Night Vision Goggles in the A-6E Intruder Airplane."

NIGHT VISION DEFICIENCIES
-Small Field of Regard of NAVFLIRs
-Small Field of Views of all Night Vision Sensors
-Obstructed Unaided Field Of View of CATS EYES
-Excessive Weight and Off Center of Gravity Addition to the Helmet
-NAVFLIR pod weapons carriage and aerodynamic limitations
-NAVFLIR / CATS EYES POD limited pilot vehicle interface
- FLIR image quality

Deficiencies of Night Vision Sensors
Figure 3-1

Small Field of Regard of NAVFLIRs

The small field of regard of the NAVFLIRs on the F/A-18 AND F-15E restricts the night low level maneuvering flight envelope. When the NAVFLIR is the primary night navigation sensor, due to low light levels on the F/A-18 or terrain following radar degradation on the F-15E, real time prediction of flight path during aggressive maneuvering is extremely limited. Additionally, NAVFLIRs provide only a limited target detection and designation capability, since the airplane has to be pointed at a target to locate it. The fixed field of view NAVFLIR on the F/A-18 is primarily used as a supplement to CATS EYES NVGs for low light level nights. The fixed field of view limits situational awareness to a small area immediately off the nose of the aircraft. The LANTIRN NAVFLIR on the F-15E has a slightly larger field of view that can be effectively expanded by the slewable features of snap look and look into turn. These slewable features may enlarge the field of regard, but causes disorientation for two reasons. Since, the HUD is the primary cockpit reference, it provides the pilot with a one to one image of the real world along with real time flight path, attitude, heading and airspeed information. Disorientation can occur, with look-into-turn activated, because the slewed image is not representative of the actual attitude and flight path and, as the snap look is activated it causes the pilot to feel like the airplane is sliding.[35] Therefore, the LANTIRN FLIR is operationally a fixed NAVFLIR except for only the most daring pilots. The LANTIRN system does not incorporate an expansive night vision system so dynamic terrain masking type maneuvers are not permitted. In fact, even with terrain following modes activated, the angle of bank is limited to 60 deg.[36] The field of regard of NAVFLIRs is too small and provides limited utility as presently implemented.

Small Field of View of all Night Vision Sensors

The small field of views (FOVs) of the night vision systems degrade instantaneous situational awareness. Small FOVs require increased scanning of the night vision image, therefore resulting in decreased monitoring of weapons systems and flight instruments. Ideally, if the sensor system field of view was equivalent to the peripheral field of view of the human eye, it would be perfect, but that

[35] David Culbertson, "Notes on Qualitative Flight Evaluation of F-15E," November 1992.
[36] William B. Scott, "LANTRIN Provides Breakthrough In Night Fighting Capabilities," Aviation Week & Space Technology, April 25, 1988, pp. 35.

technology is not possible at this time. Flight tests have determined that 30 deg circular FOV is the minimum required, with more than 40 deg is highly desired for future systems.[37,38] The CATS EYES NVGs have the largest FOV of the discussed systems in this chapter, with a clipped 30 deg, but it still is considered too small.[39] Without additional sensors, the NAVFLIRs limited FOV confines their utility to flights in benign maneuvering environments such as non-mountainous terrain. As implemented, NAVFLIRs only provide terrain avoidance directly in front of the aircraft. Larger FOVs in the night vision systems enable greater aircraft maneuvering ability. The aircrew can more readily process terrain scene changes.

Obstructed Unaided Field of View of CATS EYES

The obstructed unaided FOV of the CATS EYES are much improved over previous NVG designs like the AN/PVS-5s and AN/AVS-6s. However, the CATS EYES still reduce look around and peripheral vision. The CATS EYES restrict approximately 15 % of the view, therefore, limiting the pilot during unaided night flight.[40] Look around and peripheral vision are important for instrument monitoring, sensor management, and weapon system operation.

---

[37] Jon S. Beesley, "Head Steered FLIR Development for Night Attack," Society of Experimental Test Pilots Thirty Third Symposium Proceedings (September 1989) p. 57.

[38] Richard H. Vollmerhausen and Carolyn J. Nash, "Design Criteria for Helicopter Night Pilotage Sensors," U.S. Army CECOM Center for Night Vision and Electro-optics, p. 1.

[39] David Culbertson, "Notes on Flight Evaluations of F/A-18 aircraft equipped with CATS EYES NVGs and NAVFLIR," March 1991.

[40] David Culbertson, "Notes on Flight Evaluations of F/A-18 aircraft equipped with CATS EYES NVGs and NAVFLIR," March 1991.

CATS EYES Increased Weight and Center of Gravity

The increased weight and shifted Center of Gravity (CG) of the mounted CATS EYES NVGs causes fatigue and ejection complications. The CATS EYES add up to 1.8 extra pounds beyond the forward mold line of the helmet. Fatigue and neck strain can be experienced after continuous NVG operations greater than two hours. Increased maneuvering only increases the strain, making the 1.8 lbs feel like almost 15 lb. Ejection with the NVGs still attached to the helmet is prohibited due to possible neck and back injuries. Quick release mechanisms facilitate fast release on controlled ejections, but complicate uncontrolled ejections. A system is being developed that will initiate a local explosion of the bolts retaining the NVGs and release the goggles from the helmet after the ejection handle is pulled. This automatic release method is still only a back up to manually releasing the NVGs. The added weight and shifted CG to the helmet with the NVGs mounted has some serious drawbacks.

External Sensor Pod Limitations

The external sensor pod concept for the NAVFLIRs on the F/A-18 and the F-15E induces limitations on the aircraft operating envelopes. Carrying an external pod, not only increases aerodynamic drag, but occupies a weapons station. The NAVFLIR on the F/A-18 is stowed on the right fuselage station and increases the basic aerodynamic drag to the airplane by approximately 20 %. This increased drag reduces the non-afterburning top speed by close to 3 1/2 % and the fuel efficiency by almost 12 %.[41] The NAVFLIR weapons station is also one of the primary radar

[41] NATOPS Flight Manual Performance Chart-F/A-18 A/B/C/D, A1-F18AC-NFM-200 Naval Air Systems Command, Washington D.C., August 1992, p. 11-382. Configuration Interdiction Load- 2 External Fuel Tanks on Inboard Pylons, NAVFLIR on Right Fuselage Station, 2 Wingtip Sidewinder Missiles, Conditions-Sea Level, 34,000 lbs. Gross Weight (Full Internal), Airspeed 0.85 Mach.

missile weapons stations. Carrying a NAVFLIR, therefore, may compromise some air to air mission applications. Also, the LANTIRN system installed on a F-16C increases drag by approximately 20% at a Mach number of 0.85.[42] Integrating an external sensor pod to a tactical jet increases the aerodynamic drag and reduces useful weapons loads.

Limited Pilot to Vehicle Integration

The pilot to vehicle integration of the two night vision sensors, CATS EYES NVGs and the fixed NAVFLIR, on the F/A-18 is simple and basic to providing a night low level capability, but not integrated to provide a synergistic benefit of two complementary sensors. As implemented, the sensors are rarely used at the same time. Under moderate to high light levels, the NAVFLIR image in the HUD is considered a hindrance for normal night low level maneuvering.[43] In lower light levels the NAVFLIR image does become useful for terrain avoidance while the CATS EYES provide some clearance situational awareness in turns. Despite the transparent combiners of the CATS EYES, most of the NAVFLIR image viewing is accomplished by looking under or around the combiners. Quite often the images produced by the NVGs and the NAVFLIR are opposite in polarity (light or dark shade of green), so combined viewing is confusing. Additionally the sensors have different fields of view and fields of regard. As discovered in flight test, on any given route of flight the thermal scene and the ambient light levels could change drastically. One sensor can not be relied on to see it all. And even with multiple sensors the use of each sensor depends upon the conditions. Constantly changing thermal scenes and ambient light conditions make for heavily concentrated scan

---

[42] R.A. Hale et al., "Falcon Knight Dual Line-of-Sight Flir," p. 17.
[43] David Culbertson, "Notes on Flight Evaluations of F/A-18 aircraft equipped with CATS EYES NVGs and NAVFLIR," March 1991.

patterns just for navigation and terrain avoidance, leaving little time for instrument and weapon system monitoring. The CATS EYES and NAVFLIR approach have provided an outstanding new capability to the tactical jet community, but the lack of integration of the two sensors actually increase the pilot work load.

Image Quality

In general the image quality of the night vision sensors depends on specific variables. For NVGs, the ambient light level determines the resolution of the image. Under optimum full moon light conditions the NVGs can provide a resolution equivalent to a 20/40 visual acuity on the Snell scale, with the visual acuity decreasing with the decreasing light levels; normal unaided night vision approaches 20/200.[44] The NVGs act like the human eye responding to light and therefore present an image that is easily discernible to the human eye. For FLIRs, the thermal scene differences and the ability to detect those differences determine the resolution of the image. Since the human eye does not respond to thermal differences, the image produced by a FLIR is not as discernible to the human eye and require some interpretation. FLIRs are great in finding objects for targeting but not as good at discerning terrain features. A night vision experienced helicopter pilot wrote of the problems of using FLIRs as the sole pilot aid in 1984. He attested that FLIR images were difficult to interpret, hard to predict, not always capable of showing obstacles in terrain, and are generally inferior to ANVIS capability.[45] Since 1984, thermal detector technology has improved, making the image more presentable to the human eye. However, the principles of human eye interpretation still hold true.

---

[44] Robert W. Verona, Human Factors and Safety Considerations of Night Vision Systems Flight, USAARL Report No. 89-12, July 1989, p. 4.

[45] J. Keane, Major, U.S. Marine Corps, "Forward Looking Infrared and Night Vision Goggles: A Pilot's Perspective Related to JVX," Naval Air Development Center Memorandum 09L2, February 16, 1984.

NIGHT VISION SYSTEM ENHANCING QUALITIES

Night vision system enhancements are shown in figure 3-2. Detailed discussions of the enhancing qualities are contained in the ensuing paragraphs.

NIGHT VISION SYSTEM ENHANCING QUALITIES
-CATS EYES and NAVFLIRs are complementary sensors that increase the operational envelope
-Expanded field of regard of Falcon Eye and CATS EYES
-Low aerodynamic drag of CATS EYES and Falcon Eye

Enhancing Qualities of Night Vision Systems

Figure 3-2

Night Bird Complimentary Sensors

The Night Bird approach provides a two sensor complementary night vision system. The sensors, the NAVFLIR and the CATS EYES, operate in the far IR and near IR, respectively. They provide the airplane the capability to perform low level night missions in numerous ambient conditions. Despite the diurnal cycle and changing ambient lighting conditions, there is always at least one sensor on board that can provide clear navigation and targeting through night Visual Meteorological Conditions. The U.S. Army Center for Night Vision and Electro-Optics confirmed the importance of a dual sensor system. "A system which provides both thermal and I^2 imagery will significantly enhance system capability to support a variety of flight tasks under a wide range of environments."[46]

[46] Trang H. Bui and J. Brian Gillispie, "Night Pilotage Sensors Field Assessment," U.S. Army CECOM Center for Night Vision and Electro-Optics, p. 10.

CATS EYES and Falcon Eye Expanded Field of Regard

The fields of regard for the CATS EYES NVGs and the Falcon Eye are virtually unlimited. Since the NVG image is presented on a helmet display, the FOV of the CATS EYES are close to what the pilot can see without the NVGs in daylight. The only difference from what the pilot can see unaided is at the aft azimuth ends where the unaided eye can move left or right to stretch the field of regard, but the NVG aided eye has to rely on where the helmet is actually pointed. A qualitative estimate of the field of regard of the NVGs is roughly +/- 150 deg in azimuth, and limited to airplane structure in elevation. The Falcon Eye is turret mounted on the nose and sees roughly the same footprint as the human eye, depending on actual installation. The large field of regard improves the aircrew's ability to perform aggressive low level navigation and targeting.

Minimal Aerodynamic Drag on the CATS EYES and Falcon Eye

Increased aerodynamic drag can greatly effect the mission by reducing the effective range and endurance of the aircraft. The CATS EYES NVGs induce no extra aerodynamic drag because they are completely internal to the cockpit. The internally mounted Falcon Eye FLIR system includes only a small mold line change to the airframe. The internally mounted FLIR turret on the fuselage of the F-16C increases the aerodynamic drag by 5%, compared to the LANTIRN system which increases the drag by approximately 20%.[47] The minimal aerodynamic drag caused by CATS EYES and Falcon Eye night vision systems is a great improvement over externally mounted systems.

[47] R.A Hale et al., "Falcon Knight Dual Line-of-Sight," p.17.

CHAPTER IV

DESIGN REQUIREMENTS AND SPECIFICATIONS FOR FUTURE NIGHT VISION SYSTEM

DESIGN REQUIREMENTS

Night vision systems are passive devices used to improve pilotage, navigation and situational awareness while performing day time airborne combat tactics at night. Existing night vision systems have greatly enhanced the operational capabilities of tactical jets, but still have outstanding deficiencies that limit and degrade their performance. The future night vision system shall increase the existing capabilities and correct the major design and integration deficiencies.

DESIGN SPECIFICATIONS

Concentrating on the deficiencies and enhancements of the night vision systems noted in the previous chapter, a simplified set of specifications for the future design is outlined below. A more comprehensive list of specifications would be required for an actual design.

SYSTEM

a) DISPLAYED FIELD OF VIEW-(40 deg)

b) FIELD OF REGARD-Azimuth (+/- 150 deg) Elevation (+90 deg / - 20 deg)

c) RESOLUTION- Better image quality of existing NAVFLIRs and better visual acuity of existing CATS EYES-1.0 cycles / milliradian (20/30 vision)

d) MINIMAL DRAG / FLYING QUALITIES DEGRADATIONS- Reduced Drag from existing pod designs. No airspeed restrictions. No angle of bank restrictions.

e) INTEGRATE TWO SENSORS WITH DIFFERENT ELECTROMAGNETIC SPECTRA TO PROVIDE COMPLEMENTARY AND SYNERGISTIC CAPABILITIES- Provide a sensor fused display of both sensors on Helmet Mounted Display. All relevant information from each sensor must be preserved. The system must have the ability to compensate for degradations of one of the sensors. The combined image shall not be degraded over individual images.

f) ABLE TO WITHSTAND SHIPBOARD ENVIRONMENT- Shock, Vibration, Salt Fog, and Electromagnetic Compatibility

g) MAGNIFICATION OF UNITY-1x

h) ALIGNMENT AND POINTING ACCURACY- 1 milliradians

HELMET

i) EJECTION CAPABILITY- Helmet capable of passing wind blast and ejection tests.

j) FOCUS OF HELMET DISPLAY-Infinity

k) A SINGLE HELMET SHELL CONCEPT- Each pilot will be issued one universal helmet for all daytime and night time flying. The helmet will accommodate rapid removable attachments for night time flying.

l) HELMET CENTER OF GRAVITY-Close to the CG of the head without a helmet Comply with all existing technical specifications and memoranda regarding helmet CG for fatigue and ejection compatibility.

m) HELMET WEIGHT (Without Oxygen Mask)-4.2 lbs

n) DISPLAY COLOR- MONOCHROME GREEN for optimum eye response with 16 shades of gray(green).

o) MINIMAL OBSTRUCTION TO UNAIDED FIELD OF VIEW- Less than existing devices. Goal less than 10%.

GROWTH

p) Growth capability to accommodate Infrared Search and Track (IRST) Air-to-Air Functions into sensor when not used for Navigation and Pilotage.

q) Growth capability for interface integration with a targeting FLIR so the Night Vision sensor can hand off position to the targeting FLIR and Vice Versa.

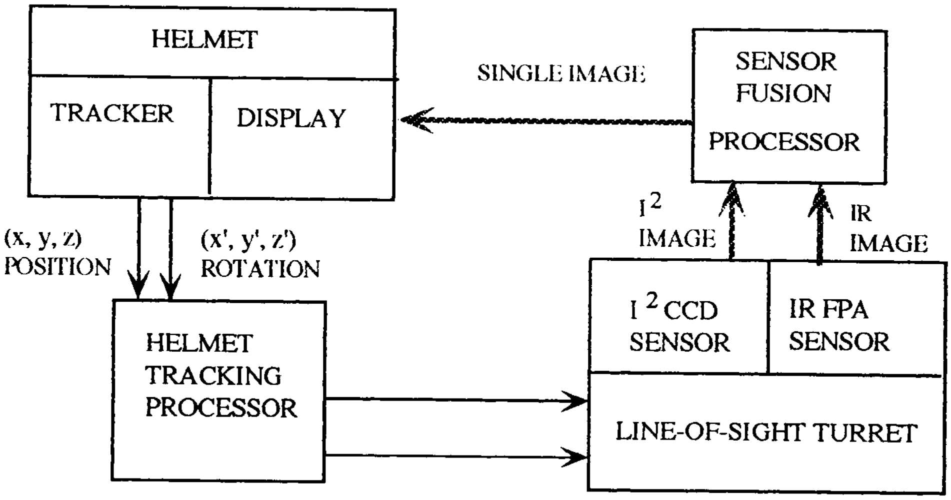
r) Growth to accommodate flight and weapons symbology integrated with the image on the Helmet mounted Display.

CHAPTER V

CONCEPTUAL DESIGN OF A FUTURE NIGHT VISION SYSTEM

OVERALL NIGHT VISION SYSTEM DESIGN DESCRIPTION

This conceptual design does not contain the detailed engineering analysis to verify actual presented specifications. It is merely a concept proposal for a design based on the deficiencies and enhancements of existing night vision systems and the design requirements and specifications outlined in previous chapters. The driving factors to the design are derived as: 1) Dual complementary sensor operation, 2) ejection compatibility; minimal weight and off-center of gravity addition to the helmet, 3) minimal aerodynamic impacts, 4) unlimited field of regard of the sensors and 5) improved resolution, image quality and field of view. This proposed design is not completely an original idea. All the parts of the design have been examined in some fashion or another. What is original is the combining of the individual designs and proposing it for a tactical jet aircraft. Most of the engineering and developmental work with airborne night vision systems have been in the helicopter community. Ejection compatibility has been the main distracter towards tactical jet incorporation. This conceptual night vision system design will incorporate a low aerodynamic profile LOS turret mounted on the forward fuselage of the aircraft. Inside the turret, a dual sensor arrangement will be installed, utilizing the same aperture window for identical fields of view. The dual sensor should be responsive to the 0.6 to 0.95 micrometers and either the 3-5 or 8-12 micrometers "windows" of the electromagnetic spectrum. The dual sensors should provide an image that is fused to enhance the effective resolution in a synergistic way. The image will primarily be presented to the pilot on a helmet mounted display using the latest technologies of Active Matrix Liquid Crystal Displays (AMLCD) or Active Matrix Electroluminescent (AMEL) Display. Removing the sensor and a CRT from the helmet reduces the weight and improves the ejection compatibility. The helmet position will be monitored by an DC magnetic helmet tracker to drive the LOS turret. A functional block diagram of the conceptual design is shown in figure 5-1 and a pictorial diagram is shown in the appendix, figure 3.



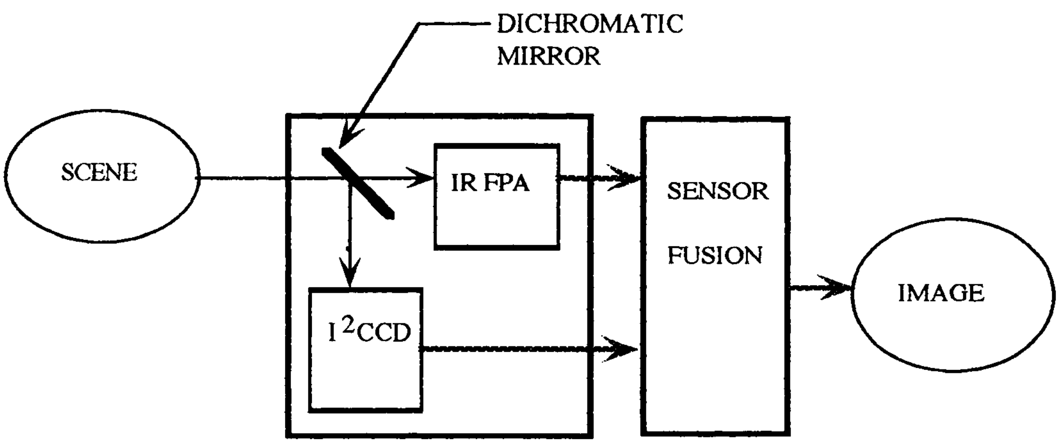
Functional Block Diagram of the Conceptual Night Vision System

Figure 5-1

NIGHT VISION SENSOR SYSTEM

The sensor system for this conceptual design is comprised of an Image Intensifier Charged Coupled Device (I^2CCD) and an IR focal plane array (FPA) infrared detection set encased in a line of sight (LOS) turret. The common aperture of the LOS turret should have an aperture that provides a 40 deg field of view. The turret itself should accommodate an extensive field of regard of

+/- 150 deg in azimuth and + 90 deg and - 20 deg in elevation. The dual sensor assembly should contain a dichromatic type lens that will allow energy through in the desired IR band acting like glass while, energy outside this IR band will be reflected like a mirror. A simple diagram of the dual sensor is shown in figure 5-2. The I^2 Device will be an improved third generation image intensifier that is fiber-optically coupled to the CCD. The CCD converts the image to a pixel array for video bus transmission. The IR system will use a second generation Focal Plane Array detector. The FPA digital signal will be transmitted, along with the I^2CCD, to the video processor along separate video buses. The LOS turret will be driven by the helmet tracking system. The concept of this combined image intensifier and infrared sensor encased in a low profile LOS turret contributes directly and indirectly to achieving the all the driving design factors.



Simple Diagram of the Dual Sensor

Figure 5-2

SENSOR FUSION INTEGRATION

The crux of this conceptual night vision system design is the actual real time fusing of the separate images into one night image. The design objective is to provide the best features of the IR and I^2 sensors into one image that will effectively display better resolution. The two image fusion methods being developed are pixel based and pattern based. Pixel fusion algorithms construct the combined image one pixel at a time, based on mean or variance of the two images.[48] Pattern based algorithms construct the combined image by examining a "glob" or local pattern at one time, attempting to preserve the important spatial patterns of the whole image. An optimum approach would be to combine the two methods by making pixel by pixel comparison and pattern comparisons in the spatial frequency. Until recently, computations required to perform the image fusion algorithms were not possible in real time. The algorithms required 4 billion operations per second when processing on a radio serial video bus with 525 line video from two sources.[49] New high speed 32-bit parallel robust digital processors can now perform the task. The conceptual design will fuse the digital video signals into one image using pixel and pattern based algorithms. The signal will be primarily presented to the helmet mounted display, with a backup selection of the night vision image on a multifunction cockpit display. Sensor fusion of the dual sensors contributes directly to the driving design factors of improved resolution, greater image quality and dual complementary sensor operation. An example of a sensor fused image is shown in the appendix, figure 4.

---

[48] Peter J. Burt, " Pattern Selective Fusion of IR and Visible Images Using Pyramid Transforms, " David Sarnoff Research Center, April 23, 1992, p. 3.

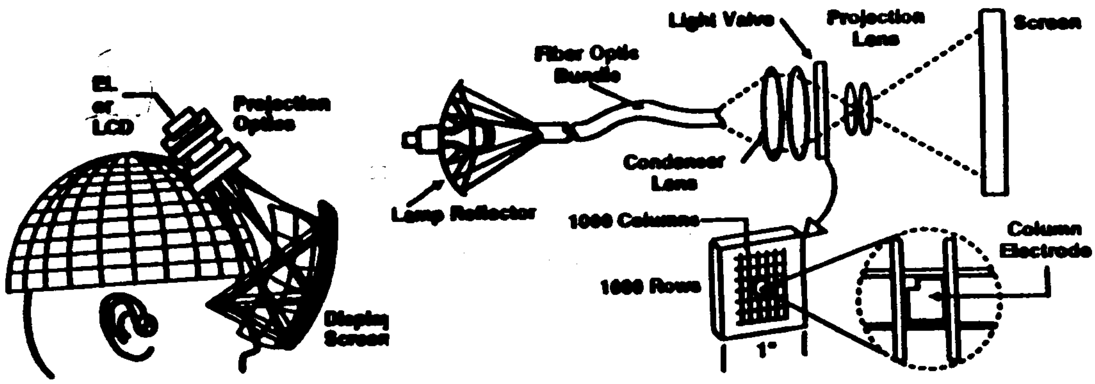
[49] Richard Tinker and Fredrick H. McFarland Jr., " Enhanced Night Operational Effectiveness Utilizing Multi-Spectral Image Fusion," Texas Instruments, Night Vision '92 Conference and Exhibition. London, United Kingdom. September 1992.

HELMET DESIGN

The helmet will consist of a basic helmet shell, fixtures to attach a standard oxygen mask, a detachable night vision display, and the receiving elements of a DC magnetic helmet tracking system. The helmet will be a lightweight crashworthy material that will fit all aircrew with three shell sizes and a form fit liner. The helmet will have three easily interchangeable configurations. First, the basic design will be a standard no-image display helmet with normal visors for wind blast and sun glare protection. Second, the night vision attachment will include the display and wire attachments for fused night imagery. This configuration will also provide a growth capability interface to present weapons and flight symbology and accomplish off-boresight air-to-air and air-to-ground target designations. Third, a growth attachment capability for day only weapons and flight symbology will be incorporated. The design of the helmet to accommodate the display contributes directly to the driving design factor of ejection compatibility.

HELMET DISPLAY DESIGN

Incorporating a helmet mounted sight has made ejection compatibility a complicated task. Wind blast protection, increased size and off-CG helmet weight additions are difficult tasks to overcome in the design. This design proposes removing the sensors and CRT from the helmet to reduce weight. Using AMLCD or AMEL technology for the display instead of a CRT, the weight can be reduced significantly. The image created from sensor fusion will be monochrome green and projected on a visor or a combiner assembly similar to CATS EYES. The use of a visor reduces optics required to present the image and simplifies the wind blast problem but requires a unique perfectly manufactured visor with no distortions or abrasions in the aided field of view. The combiner assembly adds weight and does not address wind blast protection unless a visor is then added to the outside of the combiner assembly. This design will not distinguish between these two display options, nor the choice between AMLCD and AMEL. Further studies would be needed to investigate and analyze the best technical solution. A rough picture of the display technology incorporated on a helmet is shown in figure 5-3. In addition to the weight reductions with AMLCD and AMEL technologies, display resolution should be greatly enhanced. The Advanced Research Project Agency (ARPA) is currently evaluating miniature flat panel displays with AMLCD and AMEL for Night Vision applications.[50] A greater than 1000 x 1000 active array is contained in approximately a one square inch area. The design of the helmet display contributes directly to achieving the driving design factors of ejection compatibility, improved resolution and greater field of view.



Simple Pictorial of a Conceptual Night Vision Display

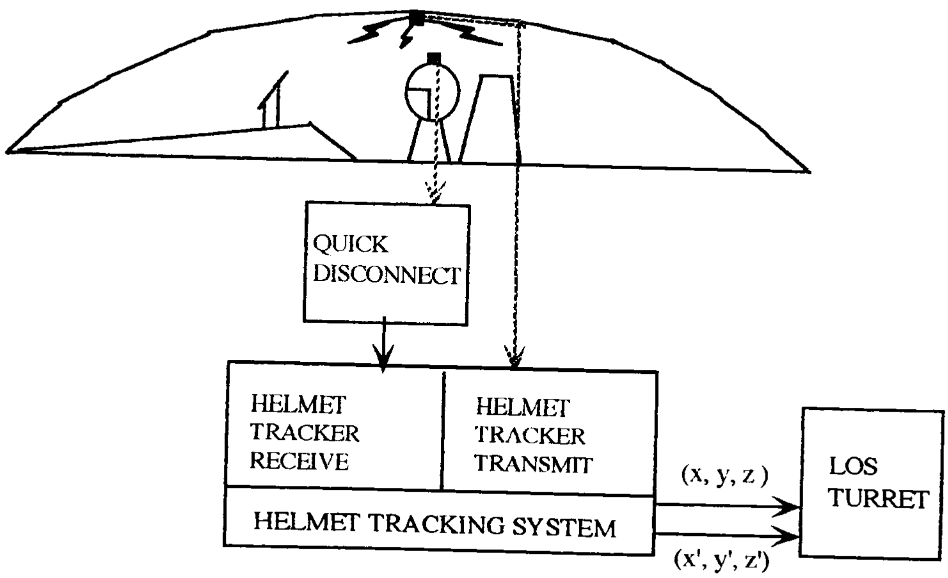
Figure 5-3

Source: "Advanced Helicopter Pilotage," U.S. Army CECOM Center for Night Vision and Electro-Optics. Ft. Belvoir, VA. September 1992.

[50] "Advanced Helicopter Pilotage," U.S. Army CECOM Center for Night Vision and Electro-Optics. Ft.Belvoir, VA, September 1992.

HELMET TRACKING SYSTEM

The conceptual design will include a DC magnetic helmet tracking system to drive the LOS turret and provide for growth capabilities for off boresight weapons designation. The DC magnetic system has been touted as less susceptible to metal disturbances, then previous AC magnetic systems. This allows the cockpit mapping of the electromagnetic field to be valid for a whole fleet of aircraft types, instead of for each individual aircraft. Design features of the helmet tracking system that need to be incorporated are a large motion box with multiple measured parameters for tracking. The pilot will need to move his head to any position including rotation and still have a valid image. A simple pictorial of the helmet tracking design is shown in figure 5-4. The design of the helmet tracker system directly contributes to the driving factor of unlimited field of regard and indirectly contributes to the remainder of the aforementioned driving design factors.



A Simple Helmet Tracking Pictorial

Figure 5-4

OPERATIONAL ANALYSIS OF DESIGN

This conceptual night vision system should provide increased operational utility over existing night vision systems. The operational envelope should be greater due to the dual sensor fusion and expanded field of view and field of regard. Aggressive low altitude terrain masking maneuvering can be accomplished in either low ambient lighting or low thermal detection conditions. Better navigation and situational awareness is realized by the increased resolution, better image quality, and greater field of view and field of regard. The design guarantees ejection compatibility. And of some importance, the design has growth capability to incorporate new functions and features to improve the overall mission of the aircraft weapons systems platform. A qualitative assessment of the conceptual design compared to existing night vision designs is shown in appendix, table 2. An assessment based purely on passive night vision systems is hard to completely evaluate, because some aircraft utilize other means to employ their weapon system at night. An active transmitting terrain following system allows a platform to operate in any environment, but still has limitations such as susceptibility and vulnerability to ESM and ECM and some restrictions to maneuverability. A night attack platform relying entirely on an active terrain following system also lacks the increased situational awareness that night vision provides. The intent of this operational assessment shown in the appendix was not for adding and subtracting of individual "pluses" and "minuses" to obtain an overall rating, but to only compare individual functions This qualitative assessment is very subjective. Each function may not be equally weighted, but an overall feel of the operational effectiveness of the design still can be gleaned. The functions examined are some of the important operational capabilities but surely not a complete list.

CHAPTER VI

CONCLUSIONS

Night vision system developments have played a critical role in the warfighting tactics of our armed forces. The ability to see and fight at night have given our military an unprecedented advantage. Night vision development began first with ground troops and has recently moved into tactical jet aircraft. The two basic devices to provide night vision, thermal detectors (IR) and image intensifiers (I^2), have undergone somewhat separate development paths. The complementary effects of incorporating both types of night vision devices on one weapons platform was realized with the Night Bird flight tests in the early 1980s. The IR and I^2 sensors each have their own distinct advantages and disadvantages, and when incorporated together, significantly increase the operating environment of the aircraft. Technological advances with digital FLIRs, image intensifiers, and high speed computer processors have now permitted the two separate sensor images to be combined into one better image. Advances in helmet tracking and helmet mounted displays should enable the image to be displayed on an ejection compatible helmet for tactical jet aircraft use. The conceptual design presented in this paper incorporates these recent advances in technology to provide a system that should greatly improve on the deficiencies of existing tactical jet night vision systems.

BIBLIOGRAPHY

BIBLIOGRAPHY

"Advanced Helicopter Pilotage," U.S. Army CECOM Center for Night Vision and Electro-Optics. Ft. Belvoir, VA. September 1992.

Beesley, Jon S. "Head Steered FLIR Development for Night Attack." Society of Experimental Test Pilots Thirty Third Symposium Proceedings (1989) 53-61.

Böhm, H.D.V. Dr. "FLIR, NVG and HMS/D Systems for Helicopter Operation Review" North Atlantic Treaty Organization Advisory Group for Aerospace Research and Development (AGARD) Conference Proceedings, No. 379. (December 1985).

Brown, Todd, Chief Warrant Officer Three, U.S. Army. "Apache Night Vision Systems." Night Vision '92 Conference and Exhibition. London, United Kingdom, September 3, 1992.

Byran, Mike A. "Integration of Night Vision Goggles in the A-6E Intruder Airplane." University of Tennessee. August 1993.

Bui, Trang H. and Gillespie, J. Brian. "Night Pilotage Sensors Field Assessment." U.S. Army CECOM Center for Night Vision and Electro-Optics.

Bull, G.C. "Night Vision by NVG with FLIR." North Atlantic Treaty Organization Advisory Group for Aerospace Research and Development (AGARD) Conference Proceedings, No. 379. (December 1985).

Burt, Peter J. "Pattern Selective Fusion of IR and Visible Images Using Pyramid Transforms." David Sarnoff Research Center. April 23, 1992. p.3.

Culbertson, David. "Notes on Qualitative Flight Evaluation of the AH-64 Apache Aircraft." November 1992.

Culbertson, David. "Notes on Flight Evaluations of F/A-18 aircraft equipped with CATS EYES NVGs and NAVFLIR." March 1991.

Culbertson, David. "Notes on Qualitative Flight Evaluation of F-15E." November 1992.

Dryden, Joe Bill. "Design Philosophy Comparisons" Code One, (January 1989), pp. 22-23.

Dryden, Joe Bill. "Out of the Dark." Code One, (January 1992), pp. 17-19.

Dryden, Joe Bill. "Out of the Dark, Through the Glass." Code One, (October 1992), pp. 12-15.

Efkeman, Albert, and Jenkins, Donald. "Development of Aviator's Night Vision Imaging System (ANVIS)." Optical Engineering, 20 (March/April 1981), 208-211.

Electronic Warfare and Radar Systems Engineering Handbook. Naval Air Systems Command. Washington D.C. First Edition. March 1992.

FLIR Performance Handbook. DCS Corporation. 1968.

Fulghum, David A. "Navy Orders Contractors to Stop Work On Ejectable Night Vision Helmets," Aviation Week & Space Technology, December 3, 1990, p. 67-68.

Greenly, Brendan M. Jr. "Navy, USMC Push Development of Night-Attack Capability." Aviation Week & Space Technology, July 7,1986, pp. 98-100.

Greenly, Brendan M. Jr. "Single-Seat System Relies on FLIR/Goggle Combination." Aviation Week & Space Technology, August 8, 1988, pp. 34-36.

Hale, R.A., et al. "Falcon Knight Dual Line-of-Sight FLIR." 1994 IRIS PASSIVE SENSORS MEETING. March 1994.

Helicopter NVG Manual. Marine Aviation Weapons and Tactics Squadron One, September 1, 1990.

"Helmet Displays are Near a Breakthrough." Interavia Aerospace Review, (February, 1991), pp. 43-45.

An Integrated Night Vision System for the TF-18 Hornet. PL3741. GEC Avionics Limited.

Introduction to Cats Eyes. Training Work Book 171.4. Marine Strike Fighter Training Squadron One Hundred and One. November 14, 1991.

Keane, J., Major, U.S. Marine Corps. "Forward Looking Infrared and Night Vision Goggles: A Pilot's Perspective Related to JVX." Naval Air Development Center Memorandum 09L2, February 16, 1984.

LANTIRN FIRE CONTROL SYSTEM . System Description Document OR 17, 280-1. Martin Marietta Corporation. November 1983.

Lydick, Larry N. "Building the System." Code One, (January, 1989), pp.19-20.

McGraw-Hill Encyclopedia of Physics. McGraw-Hill Incorporated. 1983.

NATOPS Flight Manual Performance Chart F/A-18 A/B/C/D. A1-F18AC-NFM-200 Naval Air Systems Command. Washington D.C. August 1992.

"Night Vision Systems Yield Payoff in Persian Gulf War." Aviation Week & Space Technology, February 3, 1992, p. 42.

Nordwall, Bruce D. "New Goggles Improve Night Vision But Do Not Match Daylight Conditions." Aviation Week & Space Technology, April 10, 1989, pp. 86-87.

Peck, G.,Sqn Ldr Royal Air Force, and Reech, D. Flt Lt Royal Air Force. An Assessment of Passive Night Goggles for Strike Ground Attack Operations at Night. Royal Aircraft Establishment Technical Memorandum EFD 811. October 1981.

Pickering, Steve. "Turning Night Into Day." Electronics & Power: The Journal of the Institution of Electrical Engineers, 33 (July 1987), pp. 447-50.

Rash, Clarence E. and Verona, Robert W. Ph D. "Compatibility of Aircraft Cockpit Lighting and Image Intensification Night Imaging Systems." Optical Engineering, 29 (August 1990), 863-869.

Rock, Dan, et al. "Falcon Eye Forward-Looking Infra-Red (FLIR) System." Proceedings of the International Society for Optical Engineering, 782 (May 1987), 38-45.

Rosell, Fred and Harvey, George. The Fundamentals of Thermal Imaging Systems. Naval Research Laboratory Report 8311, (May 1979).

Scott, William B. "LANTIRN Provides Breakthrough In Night Fighting Capabilities.." Aviation Week & Space Technology, April 25, 1988, pp. 34-42.

Scott, William B. "Falcon Eye FLIR, GEC Helmet Aid F-16 Mission Flexibility." Aviation Week & Space Technology, April 17, 1989, pp. 35-47.

Scott, William B. "F-15E's Night Attack Capability Assessed in Low-Level Flight." Aviation Week & Space Technology, April 30, 1990, pp. 36-38,43,46.

Scott, William B. "F/A-18D Night Attack Features Boost Marine Air Effectiveness." Aviation Week & Space Technology, February 3, 1992, pp. 38-42.

Swales, Michael R., Commander Royal Navy and Cason, Randall W., Major U.S. Army. "Helicopter Night Vision Goggle Testing in the United Kingdom." Aeroplane and Armament Experimental Establishment. Boscombe Down, United Kingdom.

Tapscott, Mark. "At Night: First Look, First Shot Wins." Defense Electronics, April 1992, pp. 50-54.

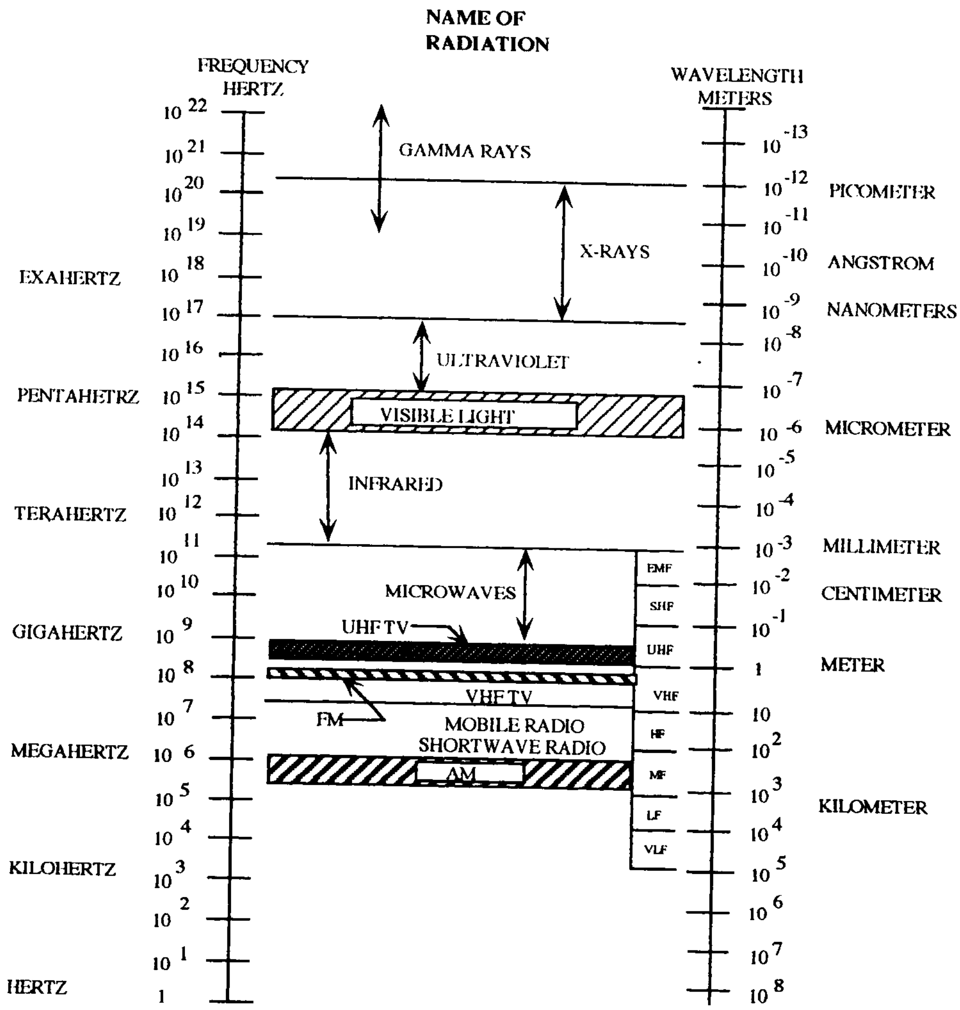
Tinker, Richard and McFarland, Fredrick H. Jr. "Enhanced Night Operational Effectiveness Utilizing Multi-Spectral Image Fusion." Night Vision '92 Conference and Exhibition. London, United Kingdom, September 3, 1992.

Verona, Robert W. Ph D. "Image Intensifiers: Past and Present." North Atlantic Treaty Organization Advisory Group for Aerospace Research and Development (AGARD) Conference Proceedings, No.379 (December 1985), p. 1-1 to 1-5.

Verona, Robert W. Ph D. Human Factors and Safety Considerations of Night Vision Systems Flight. USAARL Report No. 89-12. July 1989.

Vollmerhausen, Richard H. and Nash, Carolyn J. "Design Criteria for Helicopter Night Pilotage Sensors." U.S. Army CECOM Center for Night Vision and Electro-Optics. Ft. Belvoir, VA.

APPENDIX

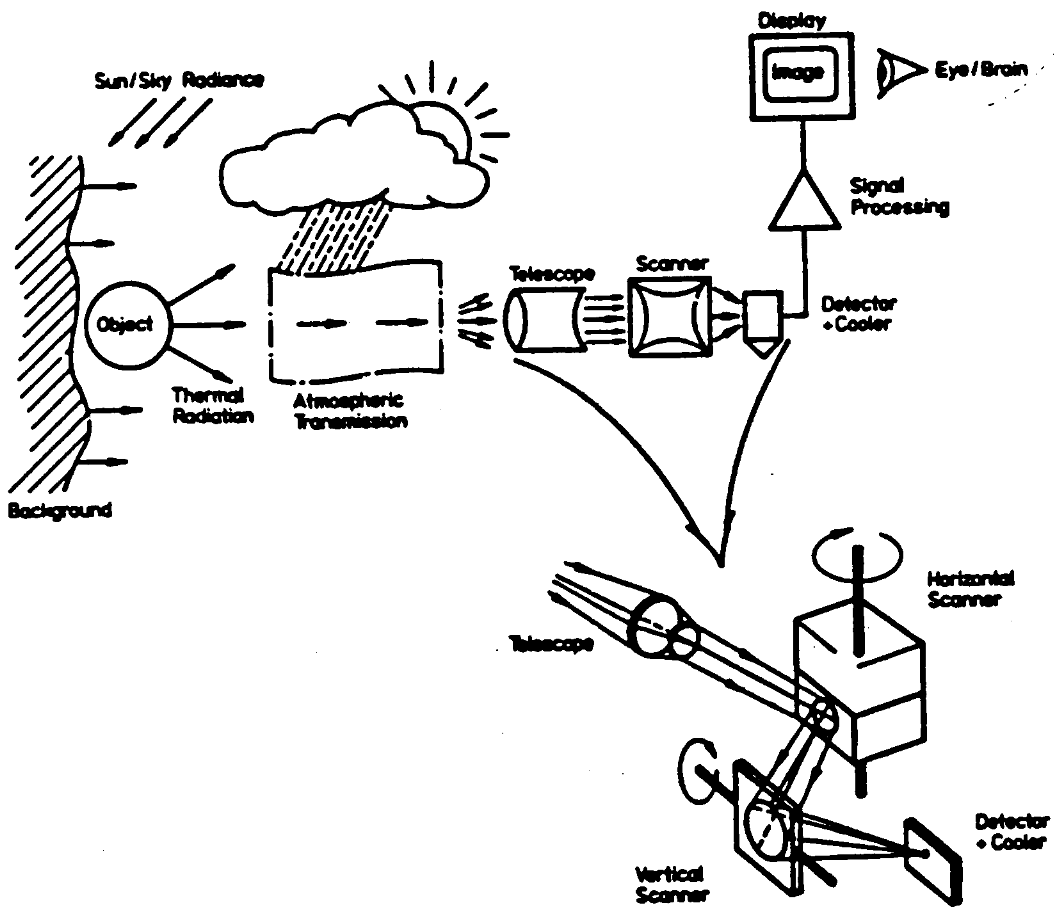


Electromagnetic Radiation Spectrum

Figure 1

Source: Electronic Warfare and Radar Systems Engineering Handbook, Naval Air Systems Command, Washington D.C., First Edition, March 1992, p. 1-3.2.

APPENDIX



Simple FLIR System

Figure 2

Source: H.D.V. Böhm, "FLIR, NVG and HMS/D Systems for Helicopter Operation Review", North Atlantic Treaty Organization Advisory Group for Aerospace Research and Development (AGARD) Conference Proceedings, No. 379, (December 1985), 2-13.

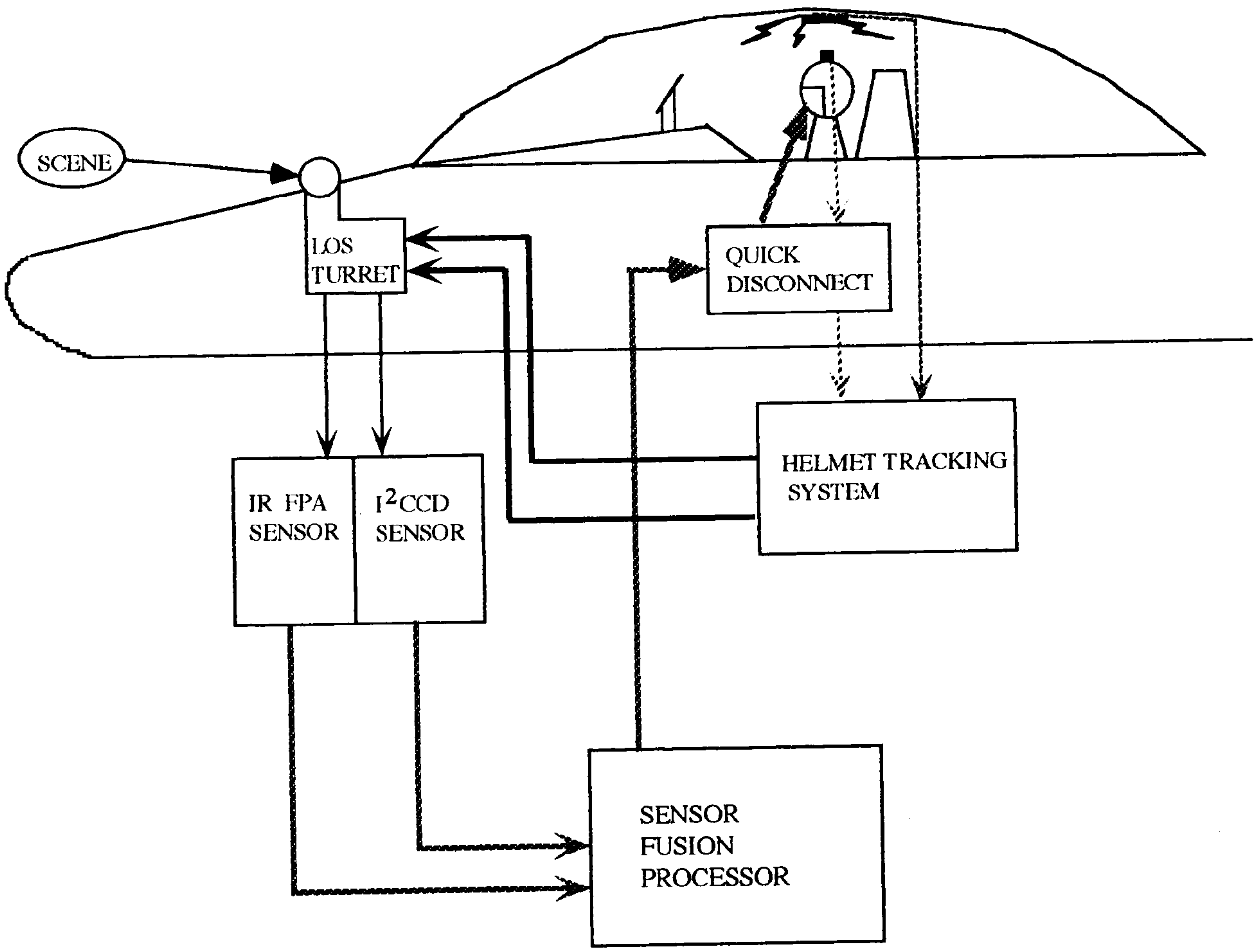
APPENDIX

TABLE 1
COMPARISON OF EXISTING NIGHT VISION SYSTEMS

PARAMETER	LANTIRN	NIGHT BIRD		FALCON EYE
PLATFORMS	F-16C & F-15E	F/A-18 C/D	& AV-8B	F-16 DEVELOPMENT
NIGHT VISION SYSTEM	LANTIRN (AAQ-13) NAVFLIR	F/A-18-(AAR-50) AV-8B-(AAR-51) NAVFLIR	CATS EYES NVGS (MXU-810)	HEAD STEERED FLIR
FIELD OF VIEW (AZIMUTH) (ELEVATION)	28 deg 21 deg	17.5 deg 20 deg	30 deg 30 deg (1)	30 deg 22.5 deg
FIELD OF REGARD (AZIMUTH) (ELEVATION)	+/- 42 deg +/- 38 deg	(FIXED) 17.5 deg 20 deg	unlimited(2)	+/- 150 deg +60/-20 deg
SENSOR EM SPECTRUM	8-12 micrometers	8-12 micrometers	.665 to .95 micrometers	8-12 micrometers
DISPLAY TYPE	WIDE FOV RASTER HUD	RASTER HUD	HELMET MOUNTED COMBINER GOGGLES	INTEGRATED HELMET MOUNTED DISPLAY
WEIGHT	430 lbs (3)	270 lbs	1.8 lbs	125 lbs
SLEW RATE	N/A	N/A	EQUAL TO THE AIRCREW	3 rad/s

NOTES: (1) CATS EYES FOV-30 deg circular with clipped bottom(Baseball field diamond)
(2) Field of Regard of NVGs almost equal to what the Field of Regard of the unaided pilot- Limited only by airplane structure and individual head dexterity.
(3) Weight of entire AAQ-13 pod-NAVFLIR and terrain following radar.
(4) Source: LANTIRN FIRE CONTROL SYSTEM, "Notes on Qualitative Flight Evaluations of F/A-18 aircraft equipped with CATS EYES and NAVFLIR," An Integrated Night Vision System for the TF-18, "Falcon Eye Forward-Looking Infra-Red (FLIR) System."

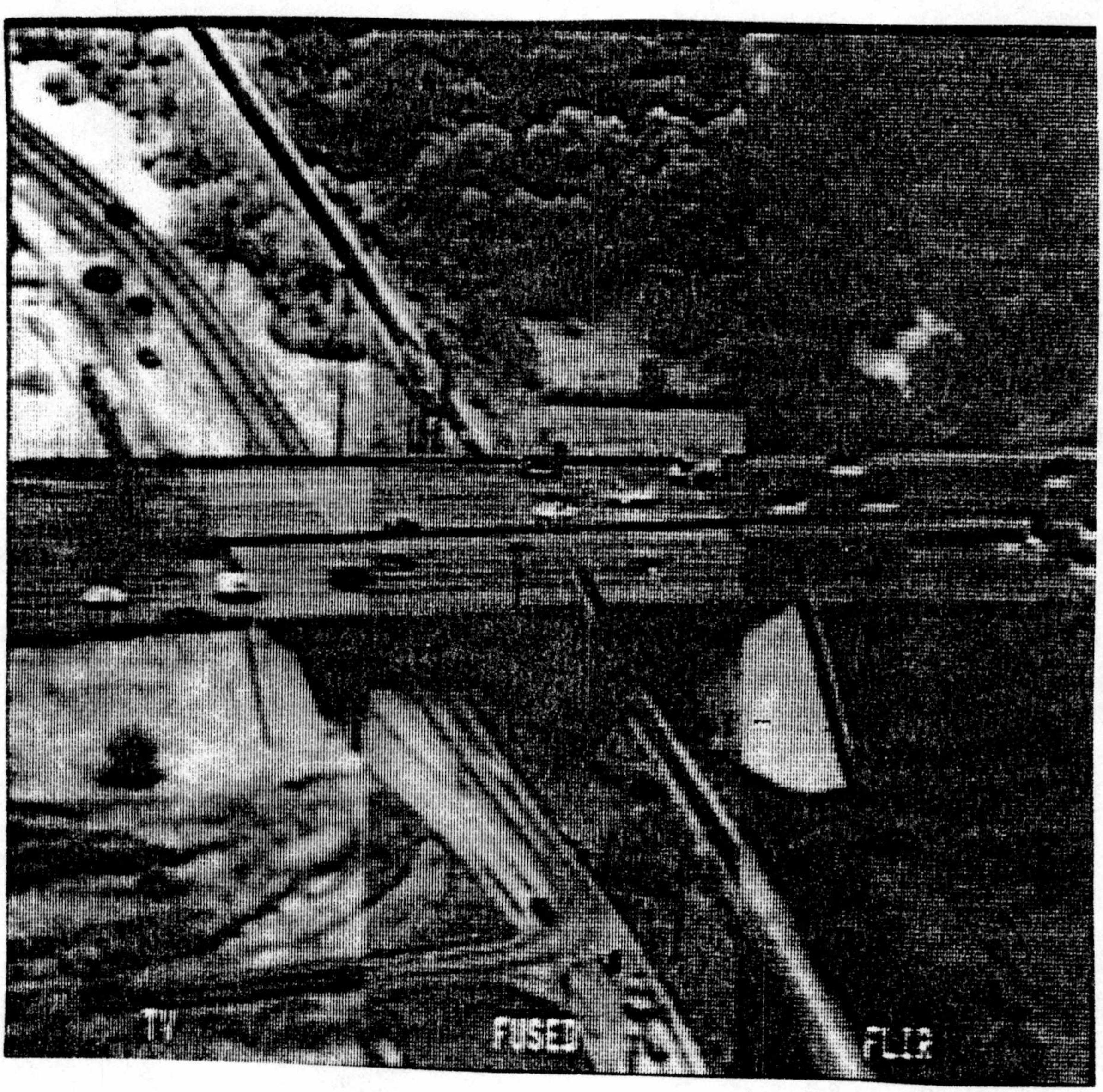
APPENDIX



Pictorial Diagram of Conceptual Night Vision Design

Figure 3

APPENDIX



Example of a Fused Image

Figure 4

Source: Richard Tinker and Fredrick H. McFarland Jr., "Enhanced Night Operational Effectiveness Utilizing Multi-Spectral Image Fusion," Texas Instruments, Night Vision '92 Conference and Exhibition. London, United Kingdom, September 1992.

APPENDIX

TABLE 2

Qualitative Operational Assessment of Conceptual Design

Function	Conceptual Design	F-15E LANTIRN	F-16 FALCON KNIGHT	F/A-18 CATS EYES / NAVFLIR
Low Lighting Conditions	+++	++ (1)(2)	++	+ (2)
Low Thermal Detection Conditions	+++	+ (1)	-	++
Aggressive Terrain Masking Maneuvering	+++	- (2)(3)	++ (4)	++ (5)
Navigation	+++	+ (2)	++	++
Ejection Capability	+++	+++	+	-
GROWTH -Off Boresight Target A/A	+++	-	++	-
-Targeting FLIR Handoff A/G	+++	+	++	+
-IRST Growth A/A	++	-	+	-

Notes:
(1) Capable if Active Terrain Following Radar Utilized
(2) Limited NAVFLIR FOV
(3) Active Terrain Following Radar has Angle of Bank Restrictions
(4) Depends upon Thermal Detection Conditions
(5) Depends upon Ambient Lighting Conditions
(6) LEGEND- (+++) means excellent
(++) means OK
(+) means limited
(-) means none

VITA

LCDR David Culbertson received his Bachelor of Science in Ocean Engineering with Distinction from the United States Naval Academy in May 1982. Following a temporary assignment at Virginia Beach, Virginia with reserve Fighter Adversary Squadron Twelve, he reported to Pensacola, Florida for Navy Flight Training. After successfully completing the Jet pipeline and flying the T-34C, T-2C, and TA-4J trainer aircraft, he was designated as a Naval Aviator in August 1984. Following completion of his first assignment as a T-2C Basic Jet Flight Instructor in Beeville, Texas, he reported to NAS Cecil Field, Florida in 1986, where he flew the F/A-18 for three years with Strike Fighter Squadrons 106 and 87. Selected for U.S. Naval Test Pilot School, LCDR Culbertson reported to Patuxent River, Maryland in June 1989. Upon graduation in June 1990, he served as a test pilot with Strike Aircraft Test Directorate at the Naval Air Test Center and as a Test Pilot Instructor flying various F/A-18 and A-7E test missions. In January 1993, he reported to his present assignment as the Lead Avionics Engineer for the F/A-18 program at Naval Air Systems Command. LCDR Culbertson has accumulated over 200 carrier arrestments and over 2,500 flight hours primarily in tactical jet aircraft. He has over 60 hours test flying the Night Attack F/A-18 equipped with CATS EYES Night Vision Goggles and Navigation FLIRs. He has additionally flown over 30 different aircraft, including fixed wing, helicopter, and glider aircraft.