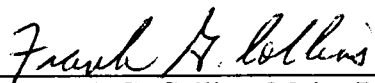


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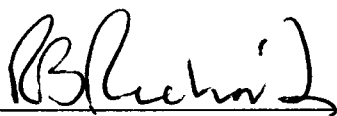
I am submitting herewith a thesis written by Mike A. Bryan entitled "Integration of Night Vision Goggles in the A-6E Intruder Airplane." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.


Dr. Frank G. Collins, Major Professor

We have read this thesis
and recommend its acceptance:


Dr. C. Ted. Paludan


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INTEGRATION OF NIGHT VISION GOGGLES
IN THE A-6E INTRUDER AIRPLANE

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Mike Alan Bryan
August 1993

DEDICATION

This thesis is dedicated to my parents

Leland Wayne Bryan

and

Ardith Lee Bryan

who have provided me with constant and unshakable support throughout my life.

ACKNOWLEDGMENTS

I would like to thank the following people for their assistance during the writing of my thesis:

Steve Adams, for his enthusiastic and seemingly endless technical expertise in NVG theory and document support, and

Werner Hueber, for his eager assistance in accessing the imposing Naval Air Warfare Center public release process on such short notice.

ABSTRACT

Throughout the lifetime of a military aircraft, a continuous process of upgrades and improvements is performed to increase the warfighting capabilities of the platform. The A-6E Intruder is one such aircraft. Improvements have been completed in the radar, computer, inertial navigation system, weapons system, and airframe. A recent technological enhancement to the A-6E cockpit suite was the introduction of night vision goggles (NVGs). Capable of amplifying extremely low light levels to a viewable image, NVGs have revolutionized the conduct of the night attack mission.

This study covers the operating theory of NVGs, NVG testing, and A-6E integration issues. The integration of NVGs into the A-6E is best described as a "turnkey approach", where the new technology was introduced very rapidly with little foresight and planning. This has resulted in several shortcomings that deserve attention and correction in order to maximize the capabilities of the A-6E, as well as increase the level of flight safety during night operations. In particular, deficiencies exist in the areas of aircraft windscreens, cockpit lighting, cockpit storage of NVGs, and ejection while wearing NVGs.

Due to the poor transmissivity performance of production leaded glass windscreens, NVG flight with these windscreens is much more difficult and dangerous than with high transmissivity windscreens. High transmissivity windscreens should be procured in adequate numbers and installed in all NVG A-6E aircraft.

Cockpit lighting modifications such as externally attached filter plates on cockpit instruments or floodlights do not adequately illuminate the cockpit instruments. Additionally, mixed cockpit lighting configurations of red non-NVG-compatible lighting and green/blue NVG-compatible lighting result in a distracting and unsuitable cockpit

lighting condition. Integral cockpit lighting modifications provide a uniform backlit lighting scheme that is NVG-compatible, and should be installed in all NVG A-6E aircraft.

Current A-6E cockpits do not provide for the safe storage of NVGs during flight. This condition presents the potential for damaging the NVGs, as well as the possibility of loose items roaming free in the cockpit. A permanent NVG storage unit located between the ejection seats should be provided to allow for the safe storage of the NVGs to increase flight safety and decrease the potential for damage to the NVGs.

Due to the forward location of the center of gravity of the NVGs while attached to the helmet, ejection while wearing current helmet-mounted NVGs will certainly result in severe injury to the aircrew, and will most likely cause death. The total weight of the NVGs must be decreased and evenly distributed throughout the helmet in order to prevent a downward rotation of the pilot's head during the ejection sequence. A totally integrated NVG helmet design would move the center of gravity of the NVGs aft and reduce the total weight by the removal of external support brackets currently in use. Implementation of an advanced totally integrated NVG helmet design should be accomplished as soon as technically possible.

This thesis and all reference material listed are unclassified. In addition, information from limited distribution government reports was not carried over into the content of this thesis.

This thesis was approved for public release by the Naval Air Warfare Center, China Lake public release process. The completed approval form is provided as Appendix E.

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NOMENCLATURE

ABC	Automatic Brightness Control
ADI	Attitude Display Indicator
AGC	Automatic Gain Control
AMTI	Airborne Moving Target Indicator
ANVIS	Aviator's Night Vision Imaging System
APU	Auxiliary Power Unit
ARM	Anti-Radiation Missile
ASR	Automatic Scene Rejection
B/N	Bombardier/Navigator
BuNo	Bureau Number
c	Speed of Light (2.9979×10^8 m/sec)
CG	Center of Gravity
DIANE	Digital Integrated Attack Navigation Equipment
DRS	Detection and Ranging System
DVRI	Direct View Radar Indicator
E	Energy Level
eV _o	Photoelectric Work Function
FLIR	Forward Looking Infrared
ft	Foot
ftc	Foot-Candle
ftL	Foot-Lambert
G	Normal Load Factor

GaAs	Gallium Arsenide
GPS	Global Positioning System
h	Planck's Constant (6.6262×10^{-34} J-sec)
HMX-1	Marine Helicopter Squadron One
HT	High Transmissivity
HUD	Head Up Display
IMP	Integrated Missile Panel
INS	Inertial Navigation System
IR	Infrared
$K_{\max}$	Maximum Kinetic Energy
L	Lambert
λ	Wavelength
lb	Pound
LGB	Laser Guided Bomb
m	Meter
MCP	Microchannel Plate
MFD	Multi Function Display
mm	Millimeter (1×10^{-3} meter)
NATOPS	Naval Air Training and Operating Procedures Standardization
NAVFLIR	Navigation Forward Looking Infrared
NM	Nautical Mile (6076 feet or 1.151 statute miles)
nm	Nanometer (1×10^{-9} meter)
NR	Night Vision Imaging System Radiance
NVG	Night Vision Goggle

NVIS	Night Vision Imaging System
NWC	Naval Weapons Center (China Lake, CA)
Oz	Ounce
p	Linear Momentum
PPG	Pittsburgh Plate Glass
PRF	Pulse Repetition Frequency
sec	Second
SRTC	Search Radar Terrain Clearance
SWIP	System Weapon Improvement Program
TC	Terrain Clearance
TRAM	Target Recognition and Attack Multisensor
TRIM	Trails-Roads Interdiction Multisensor
υ	Frequency
V	Volt
VA-42	Attack Squadron Four Two
VA-65	Attack Squadron Six Five
VX-5	Air Test and Evaluation Squadron Five
WCSI	Weapons Control System Improvement

INTRODUCTION

Since the first flight of the A-6 Intruder in April 1960, the aircraft has undergone continuous system and airframe modifications in order to ensure the Intruder remains an effective all-weather attack platform.¹ Numerous advances in forward looking infrared (FLIR) receiver, ground-mapping radar, Doppler radar, inertial navigation system, and laser technology have been incorporated in the A-6.

One of the more recent technological advancements to be added to the A-6E cockpit suite is the incorporation of night vision goggles (NVG). These devices allow the user to see the outside world in clear air lighting conditions as dim as mean starlight. Properly designed and integrated, NVGs have the capability to revolutionize the night attack mission.

The introduction of NVGs in the Navy's premier night attack aircraft, the A-6E Intruder, has had a marked effect on the employment of this strike platform. Airframe design, sensor integration, and aircrew coordination have all been impacted by NVGs. In order to fully exploit this new technological advancement, A-6E aircrew must have a thorough understanding of both the aircraft systems and NVG capabilities in order to properly utilize this new sensor. The night has long been a sanctuary from optical weaponry and has helped to provide an element of surprise for attacking aircraft. Previously accomplished only through the use of an onboard ground mapping radar system, flight in this regime is now possible with NVGs in a totally passive manner with greater maneuverability and target recognition capabilities.

¹ Aeroguide 15, Grumman A-6E Intruder (1986), p. 7, Essex: Linewrights Ltd

With proper education in tactical employment, NVGs offer a unique capability for A-6E aircrew to continue to dominate the night attack arena. An anonymous Soviet field marshal stated it best when he said:

"Darkness is a double-edged sword, and like the terrain, it favors the one who best uses it and hinders the one who does not."²

²Tactics Guide TZ 1031-03-93 for A-6E Night Attack (1993), p.1, China Lake: Air Test and Evaluation Squadron Five

CHAPTER 1

IMAGE INTENSIFIER THEORY

NEWTON'S CORPUSCULAR THEORY

The characteristics and behavior of light have puzzled scientists for centuries. The earliest recorded observations of optical phenomena have been attributed to the ancient Greeks, however, it was not until the late seventeenth century that definitive theories on the nature of light were developed. An early attempt to describe the behavior of light was made by Isaac Newton (1642-1727) in his *corpuscular theory*. This theory stated that the light emitted by a source was comprised of corpuscles or particles which streamed out in all directions from the source.³

HUYGEN'S WAVE THEORY

In 1670, Christian Huygens (1629-1695) proposed a contradictory *wave theory* of light. This theory stated that light was a disturbance traveling through some medium, typically referred to as the ether. Disturbances in the ether were perfectly transmitted such that the velocity of the light waves remained constant.⁴

Proof of the wave nature of light finally came when Thomas Young (1773-1829) shined two coherent beams of light onto the same area of a viewing screen and produced alternating dark and bright bands, a typical result of wave-like interference phenomena.⁵

It was James Clerk Maxwell (1831-1879) who in his famous Maxwell Equations provided a complete and quantitative description of all electromagnetic phenomena, of

³Solomon Gartenhaus (1977), Physics, Basic Principles, p.915, New York: Holt, Rinehart and Winston

⁴Solomon Gartenhaus (1977), *ibid.*, p.916

⁵Solomon Gartenhaus (1977), *ibid.*, p.916

which visible light is but a very small part. The Newton-Huygens controversy of a wave or corpuscular description of light appeared now to be finally settled in favor of the wave theory.⁶

EINSTEIN'S PHOTOELECTRIC EFFECT EQUATION

Brilliant scientists such as Max Planck (1858-1947) and Albert Einstein (1879-1955) later correctly hypothesized that under suitable conditions, electromagnetic waves might actually take on the attributes of streams of corpuscles rather than waves. These corpuscles are referred to today as photons, each with a energy level and linear momentum described by the following equations⁷:

$$E=h\nu \quad (1-1)$$

$$p=h/\lambda \quad (1-2)$$

$$\lambda=c/\nu \quad (1-3)$$

where,

E = energy level

h = *Planck's constant* (6.6262×10^{-34} J-sec)

ν = frequency

p = linear momentum

λ = wavelength

c = speed of light (2.9979×10^8 m/sec)

In 1905, it was Einstein who described in his Nobel Prize-winning scientific paper how the particle behavior of light can produce the phenomenon known as the *photoelectric*

⁶Solomon Gartenhaus (1977), *ibid.*, p.916

⁷Solomon Gartenhaus (1977), *ibid.*, p.917

effect. This effect occurs when an electromagnetic wave of an appropriate wavelength is incident on a metal such as zinc or copper, and electrons are emitted from its surface.⁸

The stream of photons that make up the electromagnetic wave impact the metal surface with an energy level of $h\nu$ for each photon within the stream. Assuming that a given electron is not likely to absorb more than one photon, the maximum energy acquired by a single electron must therefore be $h\nu$. This added energy must exceed the potential barrier that holds the electron to the surface of the metal in order for the electron to be emitted. Therefore, the energy $h\nu$ of the incident photons must exceed a threshold of eV_0 in order for electrons to leave the surface. Additionally, it follows from the conservation of energy that the maximum kinetic energy ($K_{\max}$) of these ejected electrons is the difference ($h\nu - eV_0$). In equation form, this is represented by:

$$K_{\max} = h\nu - eV_0 \quad (1-4)$$

This is Einstein's famous photoelectric effect equation. The quantity eV_0 is known as the *photoelectric work function*. Sample photoelectric work function values for typical metal elements and Gallium Arsenide are presented in Table 1-1.

⁸Nigel Calder (1982), Einstein's Universe, p. 28, New York: Viking Press

Table 1-1

Photoelectric Work Function Values

Source: Handbook of Chemistry and Physics (1986), pp. E-81 to E-82, Cleveland: CRC Press

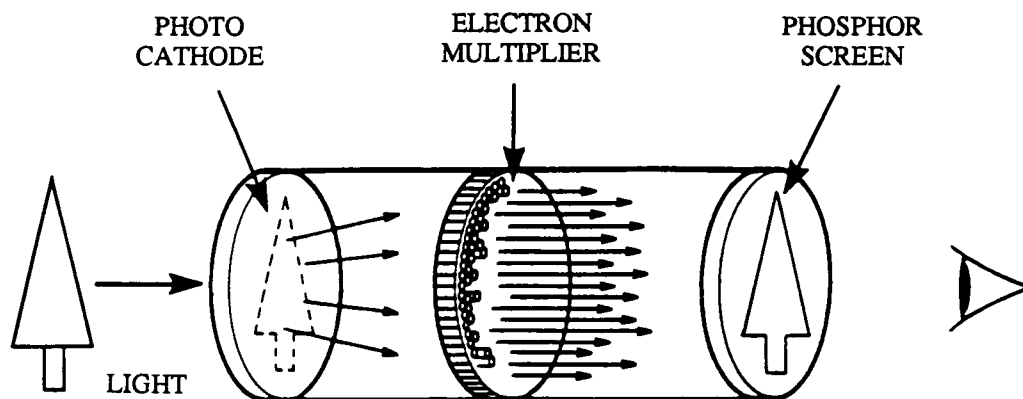
PHOTOCATHODE MATERIAL	SYMBOL	PHOTOELECTRIC WORK FUNCTION (electron-volts)
Gallium Arsenide	GaAs	1.40
Potassium	K	2.24
Cesium	Cs	2.84
Zinc	Zn	3.08
Iron	Fe	3.91
Aluminum	Al	4.08
Silver	Ag	4.56
Nickel	Ni	5.01

The value of the photoelectric work function equates to the threshold value that must be achieved in order for an electron to be released from the material. Typical Third Generation NVGs utilize a Gallium Arsenide photocathode, and it can be seen from Table 1-1 that this material will release electrons at a lower threshold value compared to typical simple metal photocathodes. It is even possible for a material to have a negative photoelectric work function value, meaning that once excited, the metal will actually repel electrons without needing to overcome a threshold value.

PHOTOMULTIPLIER TUBE

A device known as a photomultiplier tube utilizes the photoelectric effect and secondary electron emission in order to detect very low light levels. Perhaps the most recognizable of these devices is the Night Vision Goggle (NVG). The basic operating concept of the photomultiplier tube used in NVGs is that focused photons of light from an outside image cause electrons to be ejected from a photocathode; the electrons then strike a phosphor screen to produce a visible image. Secondary electrons can be produced

through the use of individual multiplier tubes, or microchannel plate assemblies. An example of a photomultiplier tube, or image intensifier, is shown in figure 1-1.



Photomultiplier Tube

Figure 1-1

Source: Tacair Night Attack Concept Formulation, Phase 1 (1988), p.47, Patuxent River: Naval Air Test Center

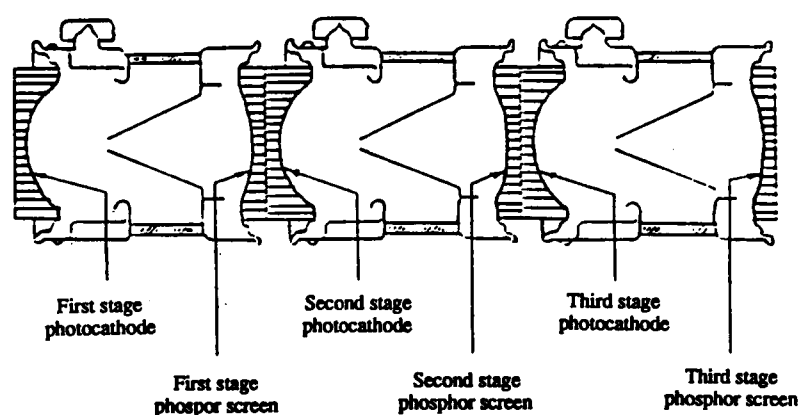
FIRST GENERATION IMAGE INTENSIFIER

The process of image intensification begins with the visual image being focused by a lens onto the surface of a very thin layer of special metal or semiconductor called the photocathode. The photocathode is located on the inside surface of the input window, and when photons strike the surface of the photocathode, electrons are ejected from the surface into the vacuum of the intensifier tube. Current aviation NVGs use a photocathode that responds from the orange region of the spectrum out to the near infrared (IR) region, or from about 600 to 900 nanometers (nm).⁹ A graphic depiction of the electromagnetic spectrum is provided in Appendix A, Figure 1.

⁹John J. Martin (1989), Naval Weapons Center Catseye Night-Vision Goggle Sensor Engineering Issues Report, p. 4, China Lake: Naval Weapons Center

An electric potential of about 10,000 to 15,000 volts accelerates the electrons through the tube towards the positively charged anode. Coated with a luminescent phosphor, the anode releases photons into the output window when struck by the electrons. A reflective aluminum backing layer can be used to force all fluorescent light to leave through the output window. This basic single-stage image intensification process will produce an output image about 50 times brighter than the actual image.¹⁰

If the intensifiers are linked in series, the photons released at the first stage phosphor anode can be utilized as the input image for the next stage photocathode, or dynode. This design has been designated a First Generation intensifier tube, and was incorporated in the starlight scope used by snipers in the Vietnam Conflict. These scopes used a three-stage intensifier tube design capable of intensifier gain values of 40,000 to 60,000.¹¹ A diagram of a first generation intensifier tube is shown in figure 1-2.



First Generation Intensifier Tube

Figure 1-2

Source: Tactics Guide TZ 1031-03-93 for A-6E Night Attack (1993), p.37, China Lake: Air Test and Evaluation Squadron Five

¹⁰The Illustrated Encyclopedia of Science and Technology (1978), pp. 1245-1247, New York: Marshall Cavendish

¹¹Tactics Guide TZ 1031-03-93 for A-6E Night Attack (1993), p.37, China Lake: Air Test and Evaluation Squadron Five

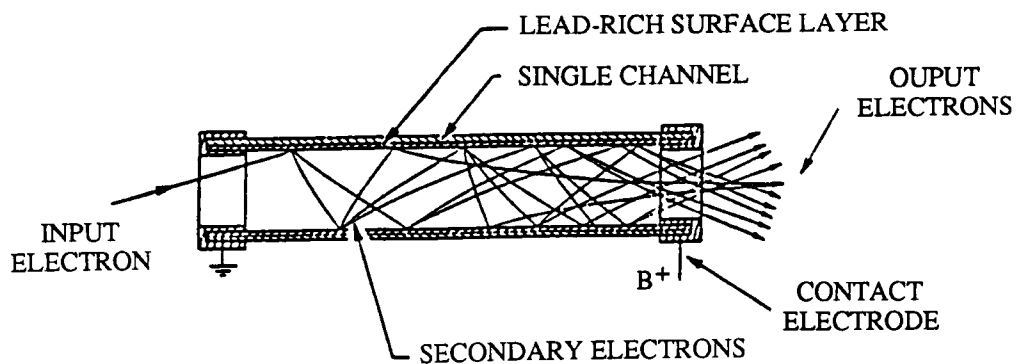
One major drawback of first generation intensifier tubes was their large size and weight. The starlight scope, for example, was approximately 12 inches in length, hardly suitable for use by modern tactical aircraft pilots. Other drawbacks were the high voltage requirement, and a tendency for the image to "bloom" or wash out if a bright light source appeared anywhere within the field of view.¹²

SECOND GENERATION IMAGE INTENSIFIER

A more effective means of image intensification is accomplished by increasing the number of electrons as they travel along the intensifier. Referred to as Second Generation intensifier tubes, these intensifiers utilize the process of secondary electron emission to increase the number of electrons before they strike the phosphor anode screen.

A device called a microchannel electron multiplier is an extremely small glass tube that has been processed to cause the inner lining to be rich in metallic lead. When an electron strikes the inner wall of the tube, approximately three secondary electrons are emitted where the primary electron struck. Each of these secondary electrons then collide with the wall further down the tube, causing the release of even more secondary electrons. The electrons are attracted to the exit window of the microchannel electron multiplier by a positive potential of several hundred volts relative to the input window. Typical microchannel electron multiplier tubes will produce a thousand or more exit electrons for each electron that enters the tube. A microchannel electron multiplier is shown in figure 1-3.

¹²Ibid., p. 37.



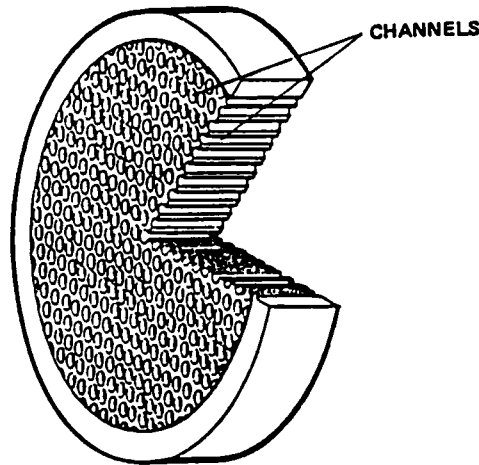
Microchannel Electron Multiplier

Figure 1-3

Source: John J. Martin (1989), Naval Weapons Center Catseye Night-Vision Goggle Sensor Engineering Issues Report, p. 5, China Lake: Naval Weapons Center

A honeycomb-like array of these microchannel electron multipliers is known as a microchannel plate (MCP). The MCP is about the diameter of a nickel with a thickness of less than one millimeter. Located between the photocathode and the phosphor screen, the MCP typically contains about two million microchannel electron multipliers. The pixel-type arrangement of the microchannels allows for the input image to remain relatively intact as the photons are converted to electrons and back again to photons.¹³ A sample MCP is shown in figure 1-4.

¹³John J. Martin (1989), *ibid.*, p. 4



Microchannel Plate

Figure 1-4

Source: John J. Martin (1989), Naval Weapons Center Catseye Night-Vision Goggle Sensor Engineering Issues Report, p. 5, China Lake: Naval Weapons Center

The MCP is typically tilted about eight degrees with respect to the viewing axis to ensure that entering electrons will strike the inner wall. Second Generation intensifier tubes allow for the integration of night vision devices in tactical aircraft through miniaturization provided by lower power requirements, and the close proximity of the photocathode, MCP, and phosphor screen.¹⁴

The material used in Second Generation intensifier photocathodes is of a multi-alkali composition. Typical photocathode coatings include compounds of Cesium-Oxygen-Silver, Cesium-Antimony, Cesium-Antimony-Bismuth, Sodium-Potassium-Antimony, Sodium-Potassium-Cesium-Antimony, Copper-Iodine, and Cesium-Iodine.¹⁵

¹⁴Tactics Guide TZ 1031-03-93 for A-6E Night Attack (1993), p.38, China Lake: Air Test and Evaluation Squadron Five

¹⁵Van Nostrand's Scientific Encyclopedia (1983), p. 2213, 6th edition, Volume II, New York: Von Nostrand Reinhold Company

In comparison to First Generation intensifier gain values of 40,000 to 60,000, the single-stage Second Generation intensifiers produce gain values of only 20,000 to 30,000. "Blooming" is still produced by bright light sources; however, the MCP design allows the saturation of the image to be confined to individual channels instead of the entire image. This localized saturation is seen by the viewer as a halo image around the bright light source, with the size of the halo dependent on the intensity and wavelength of the light source. Another drawback to bright light source exposure is that it decreases the finite lifetime of Second Generation intensifiers.¹⁶

THIRD GENERATION IMAGE INTENSIFIER

Third Generation intensifiers became operational in 1981 with use by American and United Kingdom forces. The intensifier gain value of about 30,000 is slightly higher than that of a Second Generation intensifier, however, as explained below, the greater spectral coverage provided by Third Generation NVGs greatly improves the performance of this generation of goggles.¹⁷ Third Generation intensifiers were a result of two major improvements over Second Generation intensifiers¹⁸:

- 1) The multi-alkali photocathode material was replaced by a Gallium Arsenide compound.
- 2) A metal oxide film was added to the MCP.

The Gallium Arsenide photocathode improved spectral response over Second Generation multi-alkali photocathodes at wavelengths beyond 550 nm. The result is that Third Generation intensifiers are several times more sensitive in the non-visible region of

¹⁶Tactics Guide TZ 1031-03-93 for A-6E Night Attack (1993), p.38, China Lake: Air Test and Evaluation Squadron Five

¹⁷John J. Martin (1989), *ibid.*, p. 9

¹⁸George Marsh and Paul Beaver, Defence Helicopter World (1986), "Gen 3 Goggles Give Pilots Cats' Eyes", p. 19, February-March 1986, Burnham Bucks, England: Shephard Press Ltd

near IR where radiation from the night sky is plentiful. In the region of about 800 to 900 nm, the peak sensitivity demonstrated by modern Third Generation tubes has a five to seven times greater photon rate than in the visible region.¹⁹ Night sky radiation relative to wavelength is illustrated in figure 1-5.

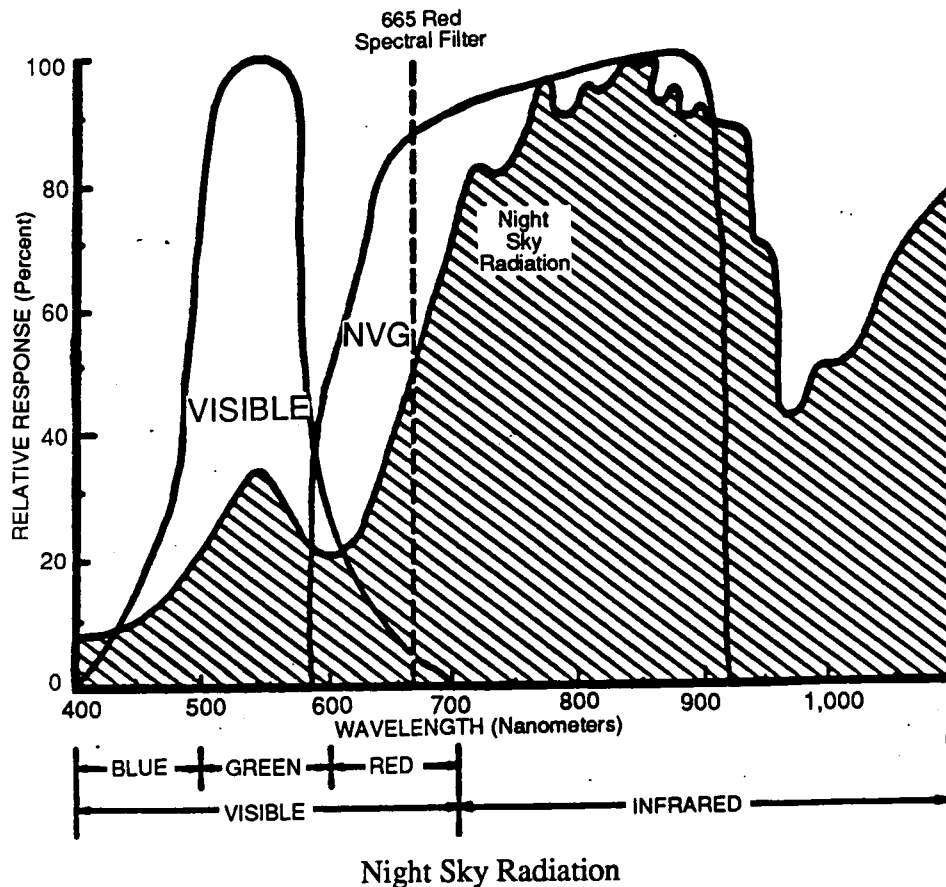


Figure 1-5

Source: Tactical Jet Night Vision Device Manual (1990), p.2-2, Yuma: Marine Aviation Weapons and Tactics Squadron One

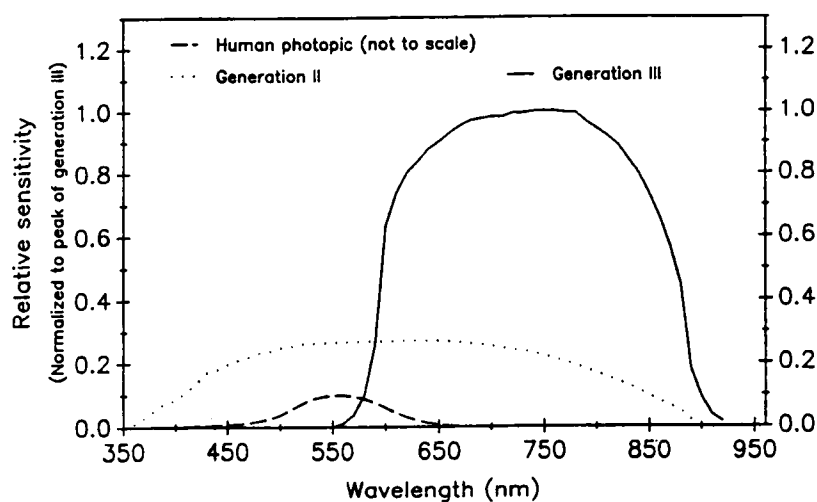
The addition of a metal oxide film to the MCP greatly extended the service life of Third Generation intensifiers by protecting the photocathode from damaging ions emitted from within the electron multiplier. Positively charged ions are released when electrons strike the inner walls of the electron multiplier, and without the barrier of a metal oxide

¹⁹Tactics Guide TZ 1031-03-93 for A-6E Night Attack (1993), p.39, China Lake: Air Test and Evaluation Squadron Five

film, travel "upstream" to impact the photocathode. This results in an accelerated decay of the photocathode due to the ion bombardment. The metal oxide film allows passage of electrons from the photocathode to the MCP, but does not allow ions to exit from the MCP and impact the photocathode. As a result, intensifiers coated with a metal oxide MCP film have a service life about 50 times that of uncoated intensifiers.²⁰

HUMAN EYE RESPONSE

As shown in figure 1-5, the response of the human eye is limited to that region of visible light from about 400 to 700 nm. Response areas for NVGs vary with type of technology employed (generation) and specific design features. A comparative presentation of the response of the human eye, Second Generation and Third Generation NVGs is provided in figure 1-6.



NVG and Human Eye Response

Figure 1-6

Source: John C. Kotulak and Clarence E. Rash (1992), Visual Acuity with Second and Third Generation Night Vision Goggles Obtained from a New Method of Night Sky Simulation Across a Wide Range of Target Contrast, p. 13, Fort Rucker: United States Army Aeromedical Research Laboratory

²⁰Ibid., p. 39.

NVG LIGHT AMPLIFICATION GAIN

The system gain of an intensifier tube does not directly translate to an equivalent light amplification gain. A common misinterpretation of a system gain value of 30,000 is that the intensified image has been amplified by a factor of 30,000. Due to the design mechanics and transmission losses of the NVGs, actual image intensification gain is around 2,500. This night vision performance is actually somewhat better than 2,500 due to the optical advantage provided by the NVG objective lens allowing for a greater field of view than the unaided human retina. A brief summary of a light amplification gain calculation follows:

$$\text{Gain} = G T_o T_f T_e (A/a) \sin^2 q \quad (1-5)$$

where:

G = Intensifier tube gain in foot-Lamberts/foot-candles (ftL/ftc): 30,000 nominal

T_o = Transmission of objective lens structure: 0.93 nominal

T_f = Transmission of filter: 0.96 nominal

T_e = Transmission of eyepiece: 0.68 nominal

A = Usable objective lens aperture area: 169 mm²

a = Image area focused at tube face (photocathode): 77.44 mm²

$2q$ = Field angle: $2q = 30^\circ$, therefore $q = 15^\circ$ nominal

Therefore, equation (1-5) reduces to:

$$\text{Gain} = (30,000) (0.93) (0.96) (0.68) (169/77.44) (\sin^2 15^\circ) = 2,663 \quad (1-6)$$

An alternative calculation method can be performed using the following equation:

$$\text{Gain} = G T_o T_e ((2 \sin a)^2/4) \quad (1-7)$$

This calculation yields a nominal gain value of 2,459. Therefore, typical Third Generation NVGs, such as Cats Eyes, provide a light amplification gain of about 2,500.²¹

²¹John J. Martin, Catseye Gain Memorandum (1993), China Lake, CA: Naval Air Warfare Center

CHAPTER 2

NIGHT VISION GOGGLES

GENERAL

An early use of night vision devices was the tripod mounting of First Generation intensifiers for night field viewing by infantry forces in World War II.²² Since that time, there has been a concentrated effort to advance image intensifier technology and to properly integrate night vision devices in airborne platforms. Three well known aviation NVG designs include the AN/PVS-5A, AN/AVS-6, and Cats Eyes NVGs. A comparison of the characteristics of these NVGs is provided in Appendix B, Table 1.

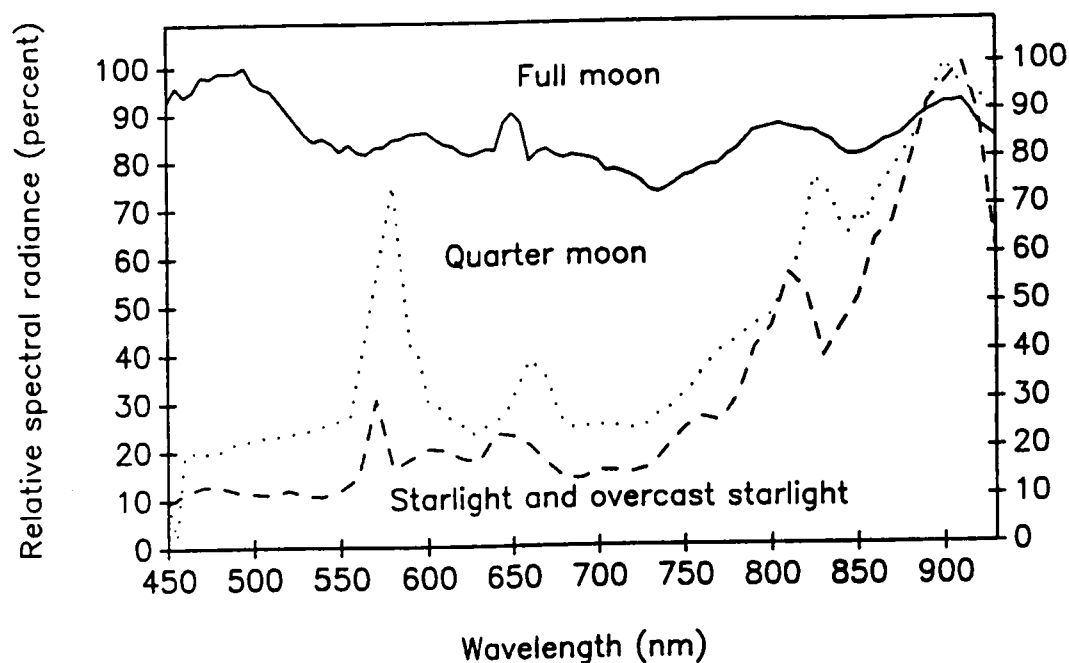
AN/PVS-5A NIGHT VISION GOGGLES

AN/PVS-5A NVGs are binocular, direct-view goggles that use Second Generation intensifier tubes. These simple night vision devices resemble a small set of binoculars with a soft molded faceplate that covers the pilot's face from the nose to forehead.

These goggles were originally intended for use by ground personnel, but were later modified for use by aviators. The first operational employment of these NVGs by United States Army and Marine Corps helicopter pilots was in 1979. A comparison test of the AN/PVS-5A and AN/AVS-6 NVGs was performed in 1987 by Marine Helicopter Squadron One (HMX-1). Results of this evaluation included a recommendation to use AN/PVS-5A goggles only in equivalent light levels of moon angles of 30 degrees or more

²²The Illustrated Encyclopedia of Science and Technology (1978), p. 1247, New York: Marshall Cavendish

above the horizon and fractional illumination of the moon of 20% or greater.²³ A graphic depiction of night sky radiance related to moon and starlight condition is shown in figure 2-1.



Night Sky Radiance

Figure 2-1

Source: John C. Kotulak and Clarence E. Rash (1992), *ibid.*, p. 12

The helmet attachment design of these goggles requires the aviator to strap the intensifier tubes and integrated face mask to the helmet. The results of such an integration design were excessive neck fatigue due to the forward positioning of the center of gravity (CG) of the NVGs, a loss of peripheral vision cues, and an increased level of difficulty in viewing cockpit instruments.

²³ HMX-1 Evaluation Report, AN/PVS-5A and AN/AVS-6 Comparison (1987), pp 1-6, Quantico: Marine Helicopter Squadron 1

AN/AVS-6 NIGHT VISION GOGGLES

AN/AVS-6 NVGs are binocular, Type I (direct view through intensifier tubes), Third Generation goggles that are designed to be usable down to conditions of mean starlight. Commonly referred to as ANVIS (Aviator's Night Vision Imaging System) NVGs, these devices were the first NVGs designed specifically for use by aviators.²⁴ The first operational use of these goggles was by the United States Army in 1983.²⁵ ANVIS NVGs are designated Class A since they utilize a 625 nm "minus blue" cut-off filter that is designed to prevent the passage of wavelengths less than 625 nm.²⁶ The following is a description of the various Types and Classes of Third Generation intensifiers:

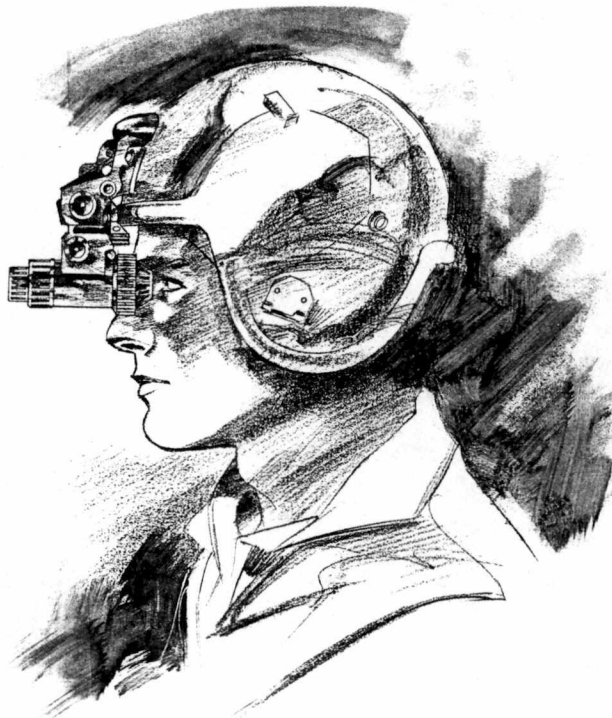
- a. Type I: Direct view image using Third Generation intensifiers
- b. Type II: Projected image using Third Generation intensifiers
- c. Class A: Incorporates a 625 nm "minus blue" cut-off filter
- d. Class B: Incorporates a 665 nm "minus blue" cut-off filter

ANVIS NVGs are shown in figure 2-2.

²⁴The Litton Aviator's Night Vision System, p.1, Tempe: Litton Electron Devices

²⁵Al Paddack, "Night Vision Goggle Memorandum" (1993), Washington D. C.: SEMCOR Corporation

²⁶Ibid.



AN/AVS-6 (ANVIS) Night Vision Goggles

Figure 2-2

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

An evaluation of Second (AN/PVS-5) and Third Generation (AN/PVS-6) NVGs conducted by the United States Army Aeromedical Research Laboratory (January 1992) provides a quantitative assessment of the visual acuity performance differences between the two generations. Normal human eye visual acuity is defined as 20/20, with the first term defining the distance the subject requires to see a particular object, while the second term defines the distance a person with normal visual acuity requires. Therefore, a subject with a degraded visual acuity of 20/47 would need to be at a distance of 20 feet to see an object that a subject with 20/20 visual acuity could see at 47 feet. Comparative data of visual acuity differences between Second and Third Generations are provided in Table 2-1.

Table 2-1

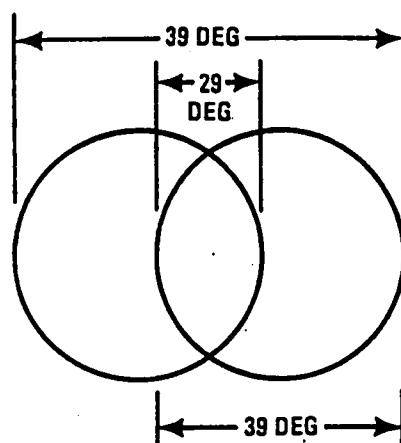
Comparison in Visual Acuity (2nd/3rd Generation NVGs)Source: John C. Kotulak and Clarence E. Rash (1992), *ibid.*, p. 31

NIGHT SKY CONDITION	CONTRAST LEVEL					
	HIGH		MEDIUM		LOW	
	AN/PVS-5	AN/PVS-6	AN/PVS-5	AN/PVS-6	AN/PVS-5	AN/PVS-6
Full Moon	20/47	20/33	20/98	20/58	20/172	20/186
Quarter Moon	20/63	20/40	20/185	20/90	>20/250	20/191
Starlight	20/92	20/54	20/269	20/146	>20/250	>20/250
Overcast	20/183	20/87	>20/600	20/317	>20/250	>20/250

Integration problems of the AN/PVS-5A NVGs were improved upon in AN/PVS-6 NVGs through the use of a single point of attachment to the pilot's helmet, and the removal of the face mask. The removal of the face mask allows for improved cockpit instrument field of view and peripheral vision cues. The single point of attachment design, integrated with an offsetting battery pack on the back of the helmet, lessens the neck fatigue commonly experienced with the forward mounted AN/PVS-5A NVGs. A "flip-up" feature allows the pilot the option of rotating the goggles up and out of view whenever he chooses to revert to natural lighting conditions.²⁷

Advantages of direct view goggles such as AN/PVS-5A NVGs over combiner concept NVGs (such as Cats Eyes) are consistent optical resolution over entire image, a larger field of view (39 degrees), and a slightly clearer image. The instantaneous field of view of ANVIS NVGs is shown in figure 2-3.

²⁷The Litton Aviator's Night Vision System, p.1, Tempe: Litton Electron Devices



ANVIS Instantaneous Field of View

Figure 2-3

Source: A-6E Quicknight (1987), p. 6, Patuxent River: Naval Air Test Center

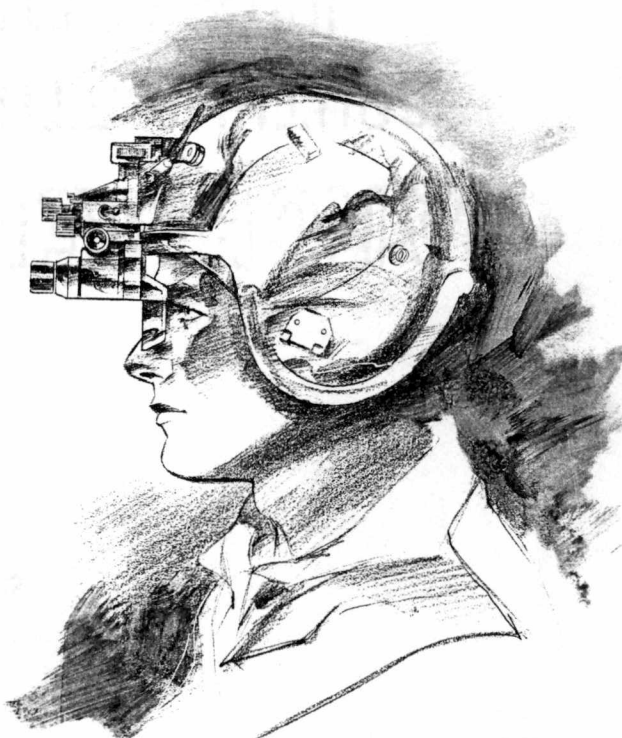
Disadvantages include increased difficulty in viewing Head Up Display (HUD) imagery, and cockpit instrument displays located high in the cockpit that require looking beneath the tubes.²⁸

CATS EYES NIGHT VISION GOGGLES

A common Third Generation image intensifier in use today is the Cats Eyes NVG, produced by GEC Avionics (a division of General Electric Company, United Kingdom). These goggles were designed for use by tactical aircraft aviators, and utilize a Type II, Class B combiner design (intensified image reflected by combiner lens). As described in Chapter 1, an intensifier system gain of 30,000 equates to a light amplification gain of approximately 2,500.

²⁸Tactics Guide TZ 1031-03-93 for A-6E Night Attack (1993), p.40, China Lake: Air Test and Evaluation Squadron Five

A three-view diagram of Cats Eyes NVGs and the associated adjustment controls and features is provided in Appendix A, Figure 2. The most noticeable difference of the Cats Eyes in comparison to Second Generation NVGs is the use of the combiner or beam-splitter type eyepiece as shown figure 2-4.



Cats Eyes Night Vision Goggles

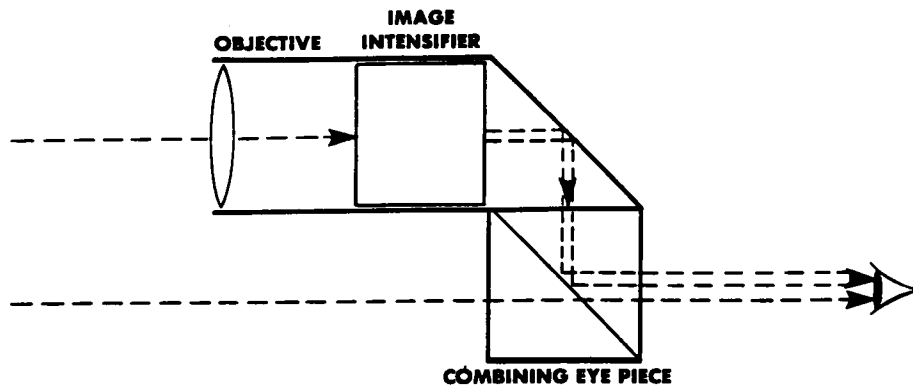
Figure 2-4

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

The current model of Cats Eyes NVG in use today by Navy and Marine Corps tactical aircraft aviators is the MXU-810/U. This NVG weighs 28 ounces, and has an instantaneous field of view of 30 degrees.

The first element of the Cats Eyes is the objective lens, which has an adjustable focal range of 15 feet to infinity. This shorter focusing distance is provided for ground

simulation training. After passing through the objective lens, the image is intensified by the image intensifier assembly and the resulting image is reflected twice to finally reach the viewer. A basic diagram of a combiner glass system is provided in figure 2-5.

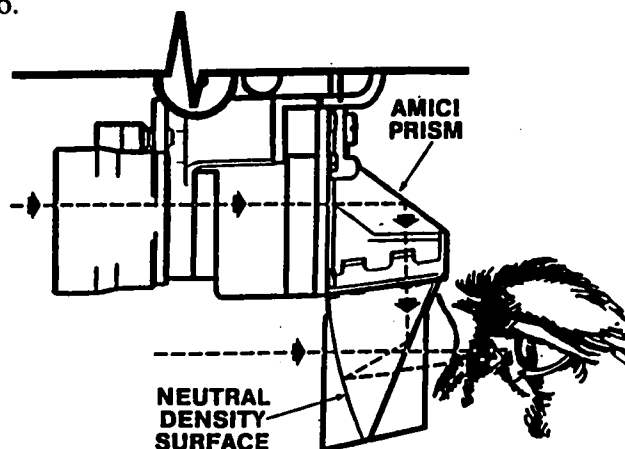


Combiner Glass System

Figure 2-5

Source: Tactics Guide TZ 1031-03-93 for A-6E Night Attack (1993), p.41, China Lake: Air Test and Evaluation Squadron Five

As installed in the Cats Eyes NVGs, the combiner glass system and optical path is shown in figure 2-6.

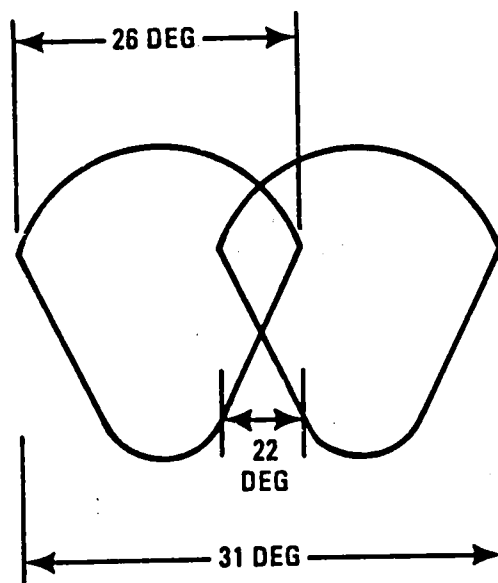


Cats Eyes NVG Optical Path

Figure 2-6

Source: Tactics Guide TZ 1031-03-93 for A-6E Night Attack (1993), p.43, China Lake: Air Test and Evaluation Squadron Five

As light leaves the objective lens, it passes through the 1.8 millimeter (mm) thick RG-655 "minus blue" cut-off filter. The intensified image from the phosphor screen is reflected 90 degrees through an Amici prism, and then another 90 degrees to the pilot's eyes. The 30 degree field of view gets clipped slightly as it is turned in the prism, so the image has the appearance of a modified baseball diamond shape, as shown in figure 2-7.



Cats Eyes Instantaneous Field of View

Figure 2-7

Source: A-6E Quicknight (1987), p. 8, Patuxent River: Naval Air Systems Command

The resulting image is composed of varying shades of green, and is scaled 1:1 with the outside world scene.²⁹ Cats Eyes are effective down to light levels as low as mean starlight. A tabular summary of lighting conditions and resultant illumination levels is provided in Appendix B, Table 2.

²⁹Tactics Guide TZ 1031-03-93 for A-6E Night Attack (1993), pp. 42-43, China Lake: Air Test and Evaluation Squadron Five

NIGHT VISION GOGGLE FEATURES

DICHROIC COATINGS

"Dichroic" is a term used to describe the capabilities of a coating to reflect specific colors (or wavelengths). In regard to NVGs, the final intensity of the viewed image is directly dependent upon how much of the intensified image has been reflected by the combiner element. Multi-layered dichroic coatings may be used on the reflective surfaces of the combiner assembly to enhance the reflectivity of the specific wavelength desired.

Reflection and transmission percentages are inversely proportional. This means that if a surface is extremely reflective for the image wavelength (in the case of NVGs: green), then it will have correspondingly poor transmission of this wavelength. This means that the green imagery the pilot needs to see while looking through the combiner, such as HUD symbology or cockpit instruments, will be difficult to see because the combiner assembly will not transmit an adequate amount of the light to the pilot's eyes. This will require increased brightness settings for these displays in order for the pilot to receive an adequate amount of light.

The human eye utilizes receptors located in different areas of the eye for photopic (daylight-adapted) and scotopic (night-light adapted) vision. Photopic vision primarily uses the cones, located at the fovea centralis, the visual center of the retina. Scotopic vision uses the rods, located on the outer peripheral retina. Rods are the primary visual receptor in dim light conditions, and are about 1,000 times as sensitive to light as cones.³⁰ Relative spectral response for photopic (day-adapted) and scotopic (dark-adapted) vision is presented in Appendix A, figures 3 and 4.

³⁰AH-1 Tactical Manual (1989), NWP 55-3-AH1, Vol 1, Rev D, p. 15-11, Washington D. C.: Chief of Naval Operations

The baseline reflection value for Cats Eyes combiners is 68% ($\pm 2\%$) photopic, meaning that 68% of the intensified image brightness in the spectral region matching the photopic response of the human eye is reflected to the viewer's eye from the intensifier tube screen. The baseline transmission value is 23% ($\pm 2\%$) photopic, hence, only 23% of the brightness passes through the combiner to be viewed by the pilot.³¹ At any single wavelength, the sum of the transmission and reflection percentages adds up to only about 90%, with the missing 10% due to unavoidable optical losses.³² It is important to focus on the photopic, or daylight-adapted, region of human eye response since the eyes of a pilot using NVGs will remain photopic when viewing intensified imagery.

NEUTRAL DENSITY COATING

A compromise between reflectivity and transmissivity is found in the neutral density coating. This coating is made with fewer layers than the dichroic type, and since it is not tuned to a specific wavelength, it exhibits a flatter response across the visible spectrum. The neutral density combiner coating results in a photopic reflection percentage equivalent to that of a dichroic coating (68%). The transmission value is only 5% less than dichroic coatings, and in practice, has been shown to result in better performance in the green region than the dichroic coating. Due to the lower cost, ease of manufacturing, and improved cockpit display viewability, neutral density coatings are utilized in production Cats Eyes NVGs.³³

PHOSPHORS

Phosphor type is selected for spectral response, conversion efficiency, persistence, and resolution. The performance and suitability of two types of phosphor

³¹John J. Martin (1989), *ibid.*, p. 12

³²John J. Martin (1989), *ibid.*, p. 14

³³John J. Martin (1989), *ibid.*, pp.14-15

coatings for use in Cats Eyes NVGs were evaluated in tests conducted by the Naval Weapons Center in 1988 in support of the AV-8B Night Attack program. In this test, two types of phosphor were evaluated: RCA 10-52 and P-20.

RCA 10-52 is a proprietary phosphor manufactured by RCA that has a peak emission around 530 nm. The image appears as a neutral to slightly cool green color. The persistence of this phosphor gives a brightness decay to 10% of original brightness in about 20 milliseconds (ms) after excitation removal.³⁴

P-20 is a nonproprietary commercial phosphor registered with the Electronic Industries Association and has a peak emission around 560 nm. The resulting image appears as a warm, slightly yellowish green. The persistence of P-20 gives a brightness decay to 10% of original brightness in approximately two milliseconds after excitation removal.³⁵

Since the RCA 10-52 phosphor takes about ten times longer to decay than the P-20 phosphor, the background image appears smoother with RCA 10-52 in comparison to P-20. Unfortunately, details of objects moving quickly through the field of view are also smoothed out or smeared. Point light sources will have attached comet trails that are produced by the phosphor persistence. P-20 produces slight sparkles due to its short integration time and the natural noise in the intensification process being averaged out less than with RCA 10-52. However, P-20 presents more usable image details and clean-cut edges than RCA 10-52. Based on these results from the Naval Weapons Center (NWC) evaluation, P-20 is the phosphor used in production Cats Eyes NVGs.³⁶ A depiction of the spectral energy distribution characteristics of P-20 phosphor is presented in Appendix A, figure 5.

³⁴John J. Martin (1989), *ibid.*, p. 15

³⁵John J. Martin (1989), *ibid.*, p. 16

³⁶John J. Martin (1989), *ibid.*, p. 16

AUTOMATIC BRIGHTNESS CONTROL

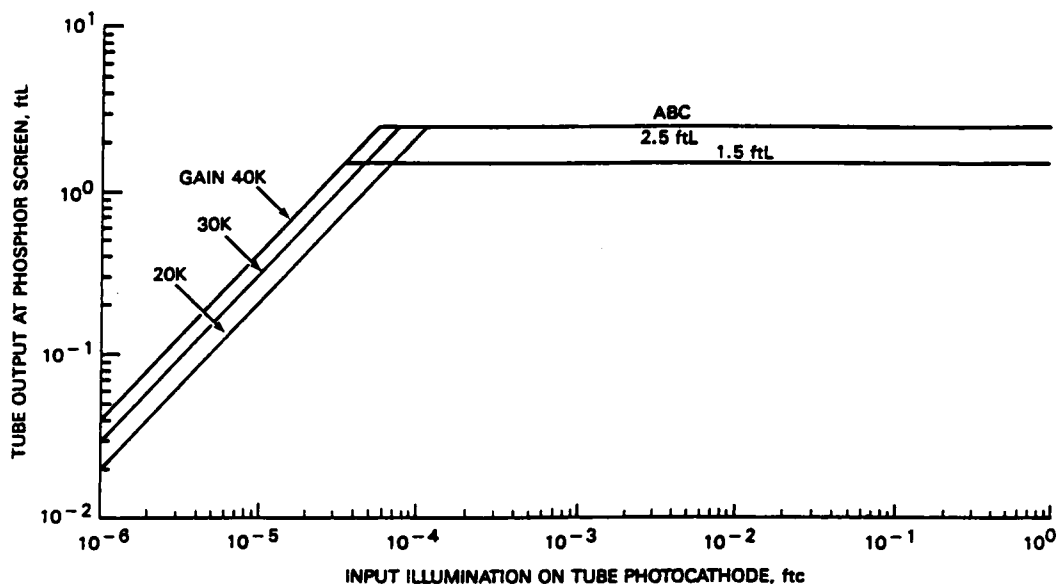
Automatic brightness control (ABC) acts as a protective governor for NVGs by setting an upper limit on the intensifier tube output to prevent damage to both the tube and the viewer's eyes. Without ABC limiting, an intensifier tube such as Cats Eyes would have a constant gain of 30,000, regardless of light level input. Therefore, if one were to view a daytime scene, or a bright flare at night, the intensifier would amplify the image by a factor of 30,000. Until the tube produced permanent internal damage, viewing the scene would be like staring at a welding torch arc.³⁷

During the 1988 Cats Eyes evaluation conducted by NWC, ABC settings of 2.5 ftL (nominal design value) and 1.5 ftL were evaluated. A gain of 30,000 and an ABC setting of 1.5 ftL means that the intensifier tube will go into ABC mode at input levels greater than 5×10^{-5} ftc, as shown by:

$$(30,000 \text{ ftL/ftc}) \times (5 \times 10^{-5} \text{ ftc}) = 1.5 \text{ ftL} \quad (2-1)$$

This is graphically depicted in figure 2-8.

³⁷John J. Martin (1989), *ibid.*, p. 10



Intensifier Gain and ABC versus Input and Output

Figure 2-8

Source: John J. Martin (1989), *ibid.*, p. 11

At high input levels where the intensified image brightness is at a maximum (in ABC mode), cockpit displays may appear dim in comparison to the intensified image. This will require HUD and cockpit instrument brightness to be increased accordingly. Theoretically, a reduced ABC setting should allow the pilot to set his instruments at lower settings due to the lower brightness value of the intensified image. Test results indicated that pilots performed equally well with both ABC settings, however, they expressed a desire that the image be no dimmer than 1.5 ftL. As a result of the findings of these tests, production Cats Eyes NVGs have a 1.5 ftL ABC setting.³⁸

³⁸John J. Martin (1989), *ibid.*, p. 11

CHAPTER 3

NIGHT VISION GOGGLE TESTING

NIGHTBIRD

The first technical effort aimed at incorporating an inexpensive, passive night navigation and attack system for use by military pilots was started by the Royal Air Force in conjunction with civilian technical experts at a Royal Air Force Establishment in Farnborough, England. Started in the late 1970's, the NIGHTBIRD program used a two-seat Hunter aircraft and was aimed at assessing the suitability of displaying imagery on a raster HUD in order to enable a pilot to fly low altitude at night. The results of the test focused on a solution that incorporated the fused imagery of NVGs and a wide field of view HUD that displayed imagery from a navigation forward looking infrared (NAVFLIR) receiver.³⁹

CHEAPNIGHT

The first outgrowth of the NIGHTBIRD program was the CHEAPNIGHT test program conducted at the Naval Weapons Center in China Lake, CA from April to September 1984. This evaluation used a TA-7C aircraft with modified United Kingdom components that included a raster HUD, a NAVFLIR, Second and Third Generation NVGs, and a moving map.⁴⁰

³⁹Tactics Guide TZ 1031-01-91 for AV-8B Night Attack (1991), pp. 1-1 to 1-2, China Lake: Air Test and Evaluation Squadron Five

⁴⁰Ibid., p 1-2

QUICKNIGHT

The QUICKNIGHT program was conducted from October 1984 to December 1985, and focused on the potential of integrating NVGs into the A-6E aircraft. Test objectives included a side-by-side comparison of ANVIS and Cats Eyes NVGs, low altitude comfort levels while using NVGs, cockpit lighting, training requirements, and the use of the targeting FLIR as a NAVFLIR. Test results concluded that NVGs could provide the A-6E with a passive night attack capability; however, this could only be accomplished through the proper integration of a wide field of view NAVFLIR, HUD, and a moving map.⁴¹

REALNIGHT

REALNIGHT (Phase I) was conducted from June 1986 to December 1987, and utilized a modified A-6E suite equipped with Cats Eyes NVGs, NAVFLIR, digital color map, multi-function displays, and two wide field of view HUDs. This modified night attack testbed successfully demonstrated the additional capabilities that could be achieved with a properly integrated night attack suite.

FLEET EVALUATION

The next phase of test for the A-6E was a Fleet Evaluation conducted by Attack Squadron 65 (VA-65) from September 1987 to March 1988. VA-65 pilots and bombardier/navigators (B/Ns) evaluated the potential effectiveness of Cats Eyes NVGs while conducting deployed flight operations onboard the aircraft carrier USS Coral Sea. This test program provided valuable fleet operator feedback early in the system design process, and signified the beginning of NVG use by fleet A-6E aviators.⁴²

⁴¹Ibid., p 1-2

⁴²Ibid., p 1-2

OPERATIONAL TESTING

One of the primary missions of operational test squadrons such as Air Test and Evaluation Squadron Five (VX-5) is to evaluate the potential operational suitability and effectiveness of a new aircraft system or weapon. The extensive operational testing process allows for possible safety and mission effectiveness deficiencies to emerge in a controlled test environment and be highlighted for subsequent correction. To date, no operational testing has been conducted on the integration of NVGs in the A-6E aircraft.

CHAPTER 4

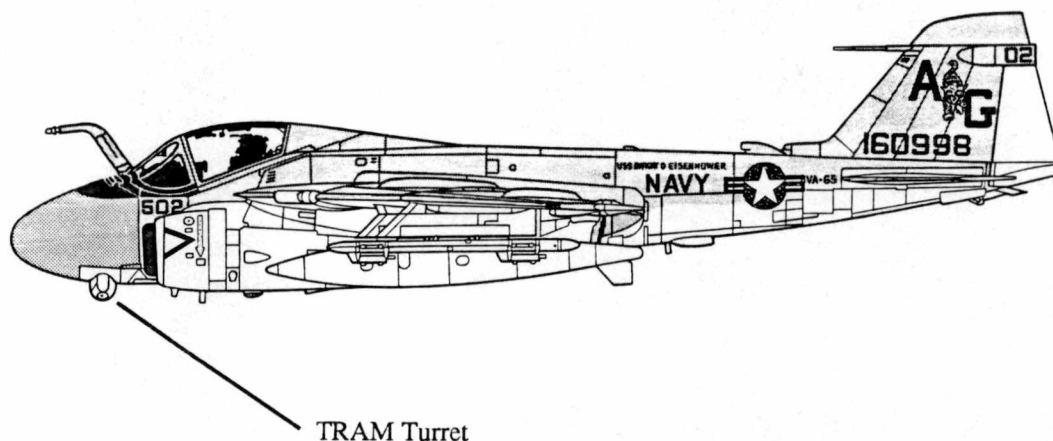
A-6E INTRUDER

GENERAL

In order to fully understand the issues concerning the integration of NVGs into the A-6E aircraft, a basic understanding of the aircraft and the associated systems used to accomplish the All Weather Attack mission is required. The A-6 aircraft has been steadily modified since its 1963 introduction. A detailed description of the history of the various versions resulting from these modifications is provided in Appendix C.

AIRCRAFT DESCRIPTION

The A-6E Intruder is a two-place, twin-engine, subsonic attack aircraft manufactured by Grumman Aerospace Corporation. The aircraft is powered by two Pratt and Whitney J52-P8B, nonafterburning, axial-flow turbojet engines, each capable of producing 8,700 lbs military rated static thrust. A detailed description of the aircraft is contained in the A-6E TRAM/KA-6D NATOPS Flight Manual, and an illustration of the A-6E is provided in Appendix A, figure 6. A side-view drawing of an A-6E with the markings of VA-65 is shown in figure 4-1.



A-6E Intruder

Figure 4-1

Source: Aeroguide 15, Grumman A-6E Intruder (1986), p. 36, Essex: Linewrights Ltd

A-6E TRAM Model

The current version flying today is the A-6E TRAM (Target Recognition and Attack Multisensor), an early 1980's upgrade to existing A-6E aircraft. As shown in figure 4-1, the TRAM system is housed in a rotating turret located on the lower nose radome surface. It contains a FLIR sensor, a laser designator/ranger, and a laser receiver. Capabilities added with the TRAM turret included laser ranging for free-fall ordnance deliveries, laser designation of targets for Laser Guided Bombs (LGBs), and infrared imagery of potential target areas. Additional improvements over the basic A-6E included the upgraded APQ-156 search/track radar, and the replacement of the ASN-31 with the ASN-92 inertial navigation system (INS).

SYSTEM DESCRIPTION

APQ-156 Search/Track Radar

The APQ-156 is a high resolution, real beam, air-to-ground search radar that provides the A-6E with five operating modes: ground mapping, target tracking, Search Radar Terrain Clearance (SRTC), Airborne Moving Target Indicator (AMTI), and beacon. Operating in a narrow bandwidth in the upper J-band, the radar has three selectable Pulse Repetition Frequency (PRF) ranges (Low, Medium, and High), and a maximum search range of 150 nautical miles.⁴³ Raw radar video is presented to the B/N on the Direct View Radar Indicator (DVRI), located on the B/N's instrument panel as shown in Appendix A, figure 7.

Forward Looking Infrared Receiver (FLIR)

The FLIR is a passive detection device used to detect infrared emissions of potential targets. A two-stage modified split-Sterling refrigerator is utilized to cool FLIR detectors to approximately -246 degrees Celsius. Capable of detecting temperature differences of less than one degree Celsius, the FLIR allows the aircrew to see terrain and targets in day and night conditions.⁴⁴ FLIR imagery is presented to the B/N on the Infrared Indicator display as shown in Appendix A, figure 8.

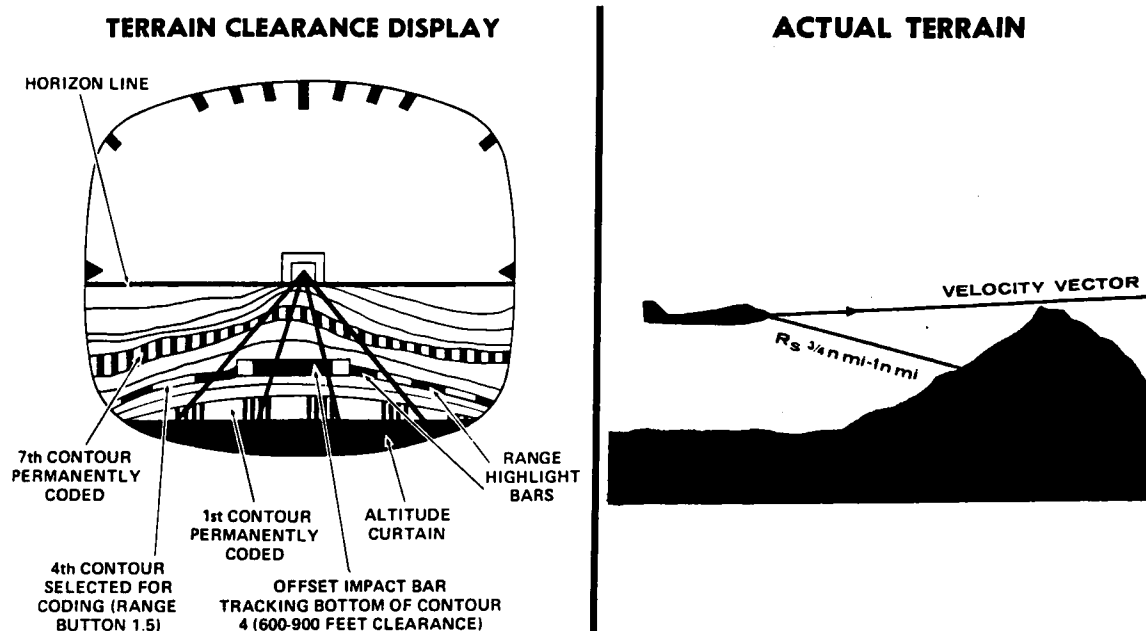
Attitude Display Indicator (ADI)

The Attitude Display Indicator (ADI) is the primary attitude display for the Intruder. The ADI is located in the center of the pilot's instrument console, as shown in

⁴³ A-6E Navigation Manual (1986), p. 1-3-11, Oak Harbor: Attack Squadron 128

⁴⁴ Rick McQueen (1989), Evaluation of the Forward Looking Infrared (FLIR) Subsystem of the AN/AAS-33A Detection and Ranging Set (DRS), as Installed in the TC-4C Airplane, for the All-Weather Attack Mission, pp. 42-44, Patuxent River: U. S. Naval Test Pilot School

Appendix A, figure 9. With the Terrain Clearance (TC) mode selected, the ADI changes to the TC display shown in figure 4-2.



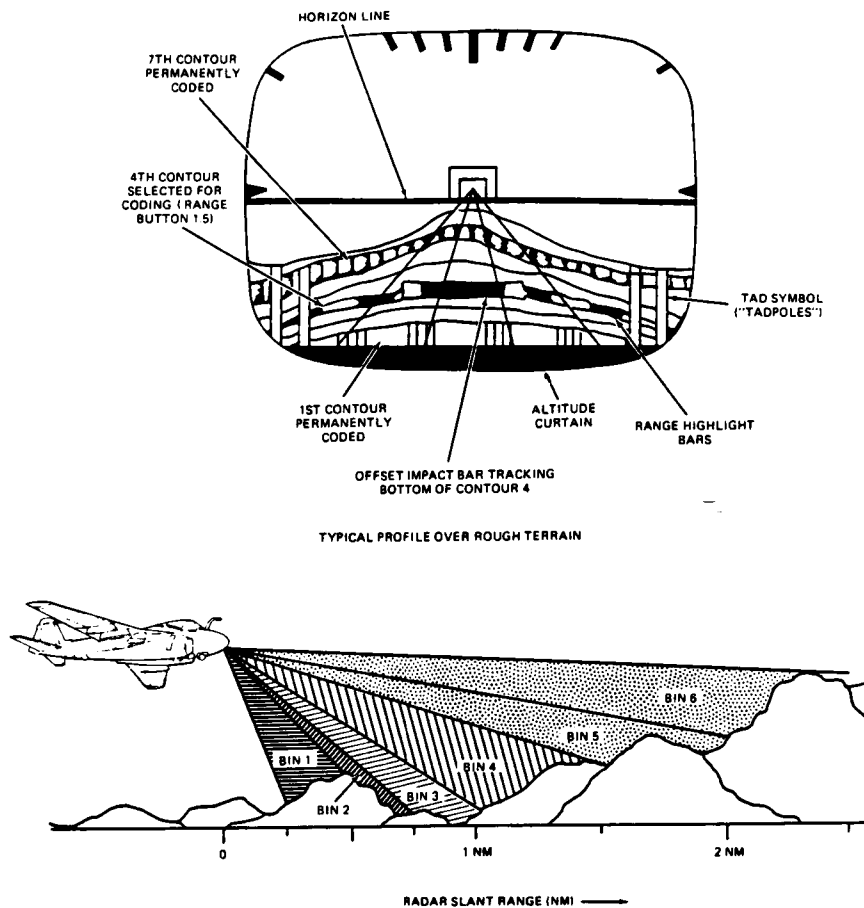
A-6E Terrain Clearance (TC) Mode of ADI

Figure 4-2

Source: NATOPS Flight Manual, Navy Model A-6E TRAM/KA-6D Aircraft, NAVAIR-01-85ADF-1, Change 2, (1991), p. VIII-27-52, Washington D. C.: Chief of Naval Operations

In the TC mode, terrain forward of the aircraft is displayed on the ADI as seven ground texture or range contour lines. The horizontal bar represents the aircraft; by selecting or "coding" a particular contour line, the pilot is able to "fly" the aircraft symbol in order to stay above the coded line, thereby maintaining the desired aircraft to ground clearance. The terrain window included in the radar TC coverage is defined by 53 degrees in azimuth, +8 to +32 degrees in elevation (ADI display is limited to +26 degrees), and

0.25 to 8.5 nautical miles (NM) in range. A depiction of radar slant range and range contour line depictions on the ADI is shown in figure 4-3.



A-6E Radar Slant Range Depictions on ADI

Figure 4-3

Source: NATOPS Flight Manual, Navy Model A-6E TRAM/KA-6D Aircraft, NAVAIR-01-85ADF-1, Change 2, (1991), p. VIII-27-57, Washington D. C.: Chief of Naval Operations

Through intense training, an Intruder pilot and B/N can utilize their complimentary sensor displays to tactically and safely navigate around and over any terrain in any weather condition, solely utilizing cockpit instruments. The obvious military advantage of this capability is the ability to strike any enemy target under the cover of night or inclement

weather, thereby negating visually operated defensive weapons. However, the requirement for active radar emissions by an All Weather Attack aircraft serves to announce the presence of the aircraft to enemy sensors. This is one of the reasons that NVGs have been integrated into aircraft such as the A-6E Intruder. Night vision goggles also provide A-6E aircrew the opportunity to fly at lower altitudes, maneuver their aircraft more aggressively, and more easily spot visually significant targets at night.

CHAPTER 5

NVG INTEGRATION INTO THE A-6E INTRUDER

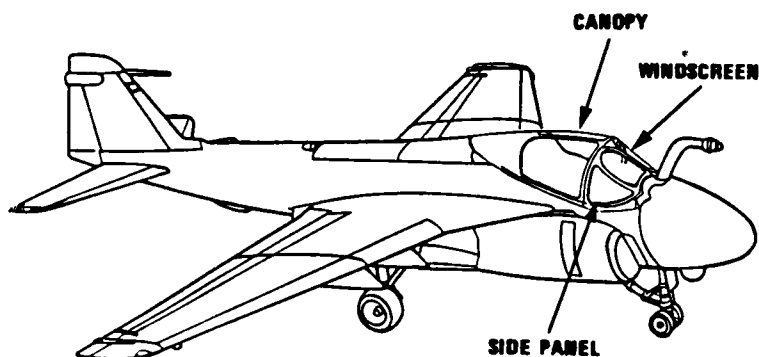
GENERAL

The integration of NVGs into the A-6E cockpit has not been the result of a well developed acquisition, test, and fleet introduction effort. Once Navy leadership saw the potential of NVGs in military aircraft, they sought the quickest, cheapest, and simplest method of introducing NVGs to fleet units. Unfortunately, the lack of proper funding, testing, and training has resulted in a "turnkey approach" to implementing this new technology into the fleet. This non-integrated approach has resulted in numerous long-term problems and difficulties in the use of NVGs by fleet aviators. For the A-6E, areas of concern include windscreen transmissivity, cockpit lighting, external aircraft lighting, NVG storage, and aircrew helmets.

COCKPIT GLASS

General

The primary components of the A-6E cockpit glass are two forward windscreen sections, two lower side panels, and a movable clamshell-type canopy. These sections are illustrated in figure 5-1.



A-6E Cockpit Glass

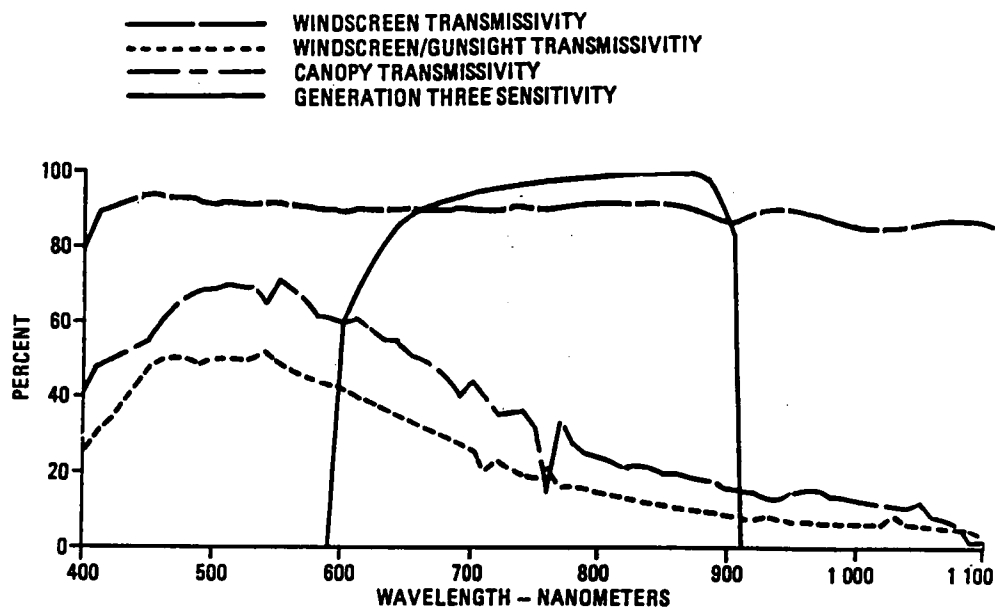
Figure 5-1

Source: Tacair Night Attack Concept Formulation, Phase 1 (1988), p.59, Patuxent River: Naval Air Test Center

Production Glass Windscreen

The production laminated glass windscreen is manufactured by Pittsburgh Plate Glass (PPG) and, when dealing with night vision goggles, is referred to as "green" glass. The amount of attenuation associated with this windscreen ranges from 30% in the visible spectrum to 95% in the near IR. When combined with the pilot's gunsight, the attenuation increases an additional 10% in the range from 400 to 1,000 nm.⁴⁵ Transmissivity versus wavelength data are shown below in figure 5-2.

⁴⁵A-6E Quicknight (1987), p. 8, Patuxent River: Naval Air Test Center



A-6E Windscreen and Canopy Transmissivity

Figure

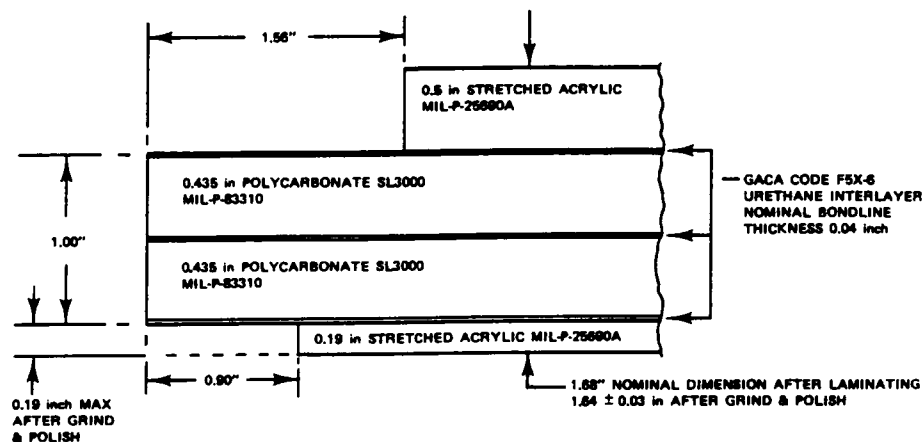
Source: A-6E Quicknight (1987), p. 9, Patuxent River: Naval Air Test Center

As illustrated in figure 5-2, an A-6E pilot using NVGs with production "green" glass windscreens receives an average of only 30% of the light available in the wavelength range for Third Generation NVGs (about 600 to 900 nm). When viewed through the gunsight, this value drops down to less than 20% of available light.

High Transmissivity (HT) Glass Windscreen

High transmissivity glass windscreens do not refer to a particular brand name or manufacturer, but rather to a specifically designed windscreen that best allows passage of light in the wavelengths compatible to night vision goggles. Current HT glass windscreens installed in the A-6E are provided by PPG, and are known as "white water" windscreens. A similar type windscreen, also designated as HT glass, was utilized in the

Realnight test program on aircraft Bureau Number (BuNo) 156997. This windscreen was a polycarbonate and acrylic laminated windscreen manufactured by the Goodyear Aerospace Corporation.⁴⁶ A detailed description of this windscreen is shown below in figure 5-3.



Project Realnight Polycarbonate/Acrylic Windscreen

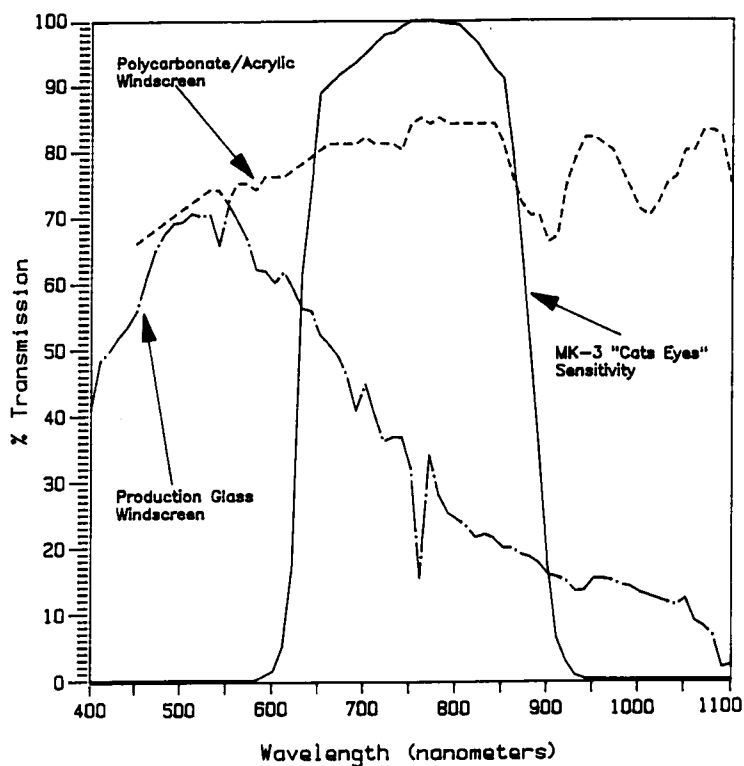
Figure 5-3

Source: Tacair Night Attack Concept Formulation, Phase 1 (1988), p.59, Patuxent River: Naval Air Test Center

Typical HT windscreens appear to offer no associated structural strength penalties compared to "green" glass. This fact is evidenced by the uneventful result of a direct birdstrike sustained during Realnight testing. One undesirable byproduct of the increased transmissivity of the Goodyear HT windscreen was the buckling of the cockpit instrument glareshield during tests in the summer in the high desert of China Lake, CA. This

⁴⁶Tacair Night Attack Concept Formulation, Phase 1 (1988), p.59, Patuxent River: Naval Air Test Center

buckling was due to heat buildup after prolonged sunlight exposure with the canopy closed.⁴⁷ Transmissivity versus wavelength data are shown below in figure 5-4.



Polycarbonate/Acrylic Windscreen Transmissivity

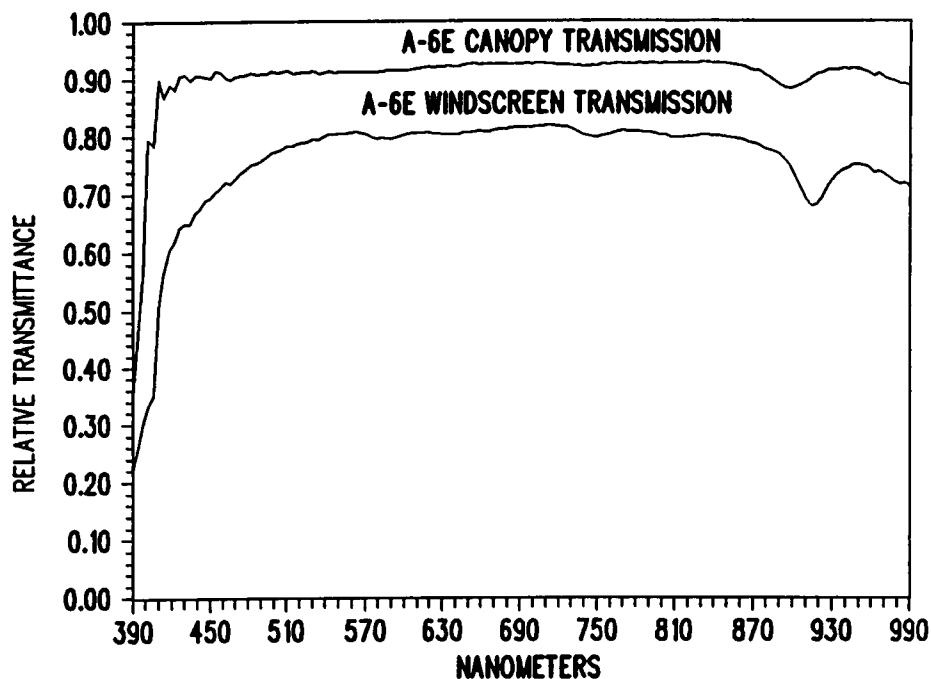
Figure 5-4

Source: Tacair Night Attack Concept Formulation, Phase 1 (1988), p.32, Patuxent River: Naval Air Test Center

From about 600 to 900 nm, the Goodyear HT windscreen has an average transmissivity value of about 83%, as compared to the value of about 30% for production "green" glass. With an average degradation of about 10% for the pilot's gunsight, the resulting transmissivity is a much more desirable value of 73% (vice 20% with "green" glass).

⁴⁷Ibid., p.31

The HT windscreen produced by PPG has a similar transmissivity profile of about 80% across the 600 to 900 nm wavelength band, as shown in figure 5-5.



PPG HT Glass Windscreen and Canopy Transmissivity

Figure 5-5

Source: A-6E Night Vision Imaging System (NVIS) (1990), p.12, Patuxent River: Naval Air Test Center

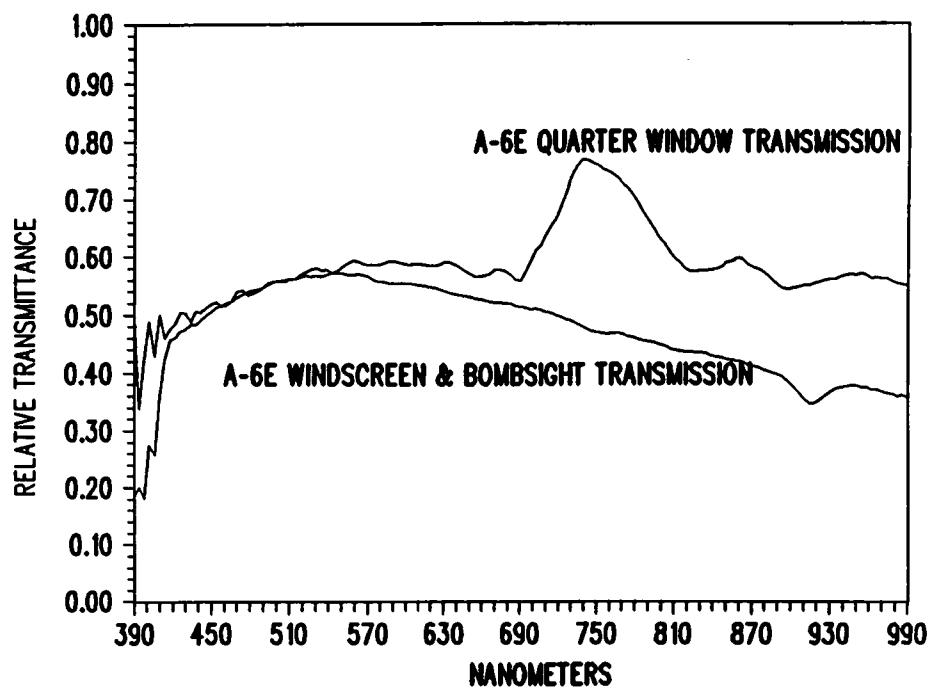
Canopy

Production acrylic canopies demonstrated high transmissivity values throughout the range tested in the A-6E Quicknight evaluation (see figure 5-5). For the 600 to 900 nm range, an almost constant transmissivity value of 90% was observed.⁴⁸ The high transmissivity characteristics of the canopy do not require the use of a special canopy for the night vision modification to the A-6E.

⁴⁸A-6E Quicknight (1987), p.9, Patuxent River: Naval Air Test Center

Quarter Windscreen Panels

Due to the remote location and infrequent use of the quarter windscreen panels by the aircrew during flight, these panels are not replaced during night vision modification to the A-6E. Light transmission is degraded approximately 40%, as shown in figure 5-6.



Quarter Windscreen Transmissivity

Figure 5-6

Source: A-6E Night Vision Imaging System (NVIS) (1990), p.11, Patuxent River: Naval Air Test Center

Flight Safety

An undesirable result of viewing the night scene with NVGs is an unavoidable decrease in visual acuity. Even with properly adjusted goggles, the best visual acuity achievable in laboratory conditions is about 20/50. Although this seems a drastic drop from normal 20/20 vision, it is a vast improvement over the unaided eye's visual acuity value at night of about 20/200 to 20/400. The 20/50 value is dependent on correctly

focusing and setting the interpupillary distance prior to flight.⁴⁹ When combined with the high attenuation values associated with typical "green" glass windscreens, a dangerous combination may be produced that could result in the presentation of an inadequate night vision image to the pilot. The high attenuation values produced by production "green" glass windscreens make them incompatible for use with NVGs. These windscreens were not designed to allow passage of the necessary wavelengths of light, and should be replaced by high transmissivity glass windscreens as soon as possible.

The current Navy flight clearance for flight with night vision goggles in the A-6E does not specify "white water" glass for windscreens. This results in squadrons flying NVG training missions with whatever windscreens are available, either "green" or "white water" glass.⁵⁰

COCKPIT LIGHTING

General

Normal cockpit lighting consists of red filtered incandescent tungsten lamps with a spectral emittance in the near infrared with a maximum at 640 nm. As described in Chapter 2, typical Third Generation NVGs, such as Cats Eyes, operate in the 600 to 900 nm range. Therefore, they are extremely sensitive to frequencies associated with normal aircraft lighting. NVG-suitable cockpit lighting is accomplished by shifting the spectral emittance down to the blue-green spectrum (approximately 520 nm).⁵¹

In order to achieve full compatibility between cockpit lighting and NVGs, cockpit lighting should have little or no overlap in the spectral response range of the intensifier tubes. Linear spectral radiance plots may appear to show minimal overlap, but only when

⁴⁹Tactics Guide TZ 1031-03-93 for A-6E Night Attack (1993), p.48, China Lake: Air Test and Evaluation Squadron Five

⁵⁰Al Paddack, "Night Vision Goggle Memorandum" (1993), Washington D. C.: SEMCOR Corporation

⁵¹A-6E Quicknight (1987), p. 5, Patuxent River: Naval Air Test Center

reduced to Night Vision Imaging System (NVIS) radiance, or NR, can an accurate measure of overlap can be achieved. NR is defined as the integral of the curve generated by multiplying the spectral radiance of a light source by the relative response of the NVG.⁵² An example showing this method is provided in Appendix D.

Initial NVG Cockpit Modification

The initial method of providing suitable cockpit lighting for NVG use was to add 490 nm band pass filters to cockpit flood lights, ADI, DVRI, and FLIR displays. The floodlights in the A-6E were designed only for emergency area illumination, not routine use during flight. For this reason, they do not provide adequate illumination of all instruments; and for the areas they do illuminate, the lights cast distracting shadows. Additionally, without a rheostat control for brightness, aircrew were forced to use only the "Bright" setting, resulting in a significant reflection on the canopy that hindered out of the cockpit viewing.⁵³ The net result of the initial cockpit lighting modification was a usable lighting system; however the stopgap installation of NVG suitable light filters increased aircrew workload and did not fully illuminate all needed instruments.

Integral Lighting Modification

Test programs, such as Quicknight, highlighted the need for an integral lighting scheme in the A-6E. This design approach would provide typical backlit instrument lighting, but in NVG-compatible wavelengths. One problem that exists with such a lighting scheme is the poor viewability of these wavelengths in daylight conditions. For the A-6E, this results in decreased viewability of caution and warning lights and the gunsight reticle. Initial wavelengths were in the yellow band, and were practically

⁵²A-6E Night Vision Imaging System (NVIS) (1990), p. 2, Patuxent River: Naval Air Test Center

⁵³A-6E Quicknight (1987), p. 5, Patuxent River: Naval Air Test Center

invisible under bright sunlight conditions. Efforts have been ongoing to incorporate more suitable blue-green wavelengths with improved daylight viewability. Recent design efforts include the use of the 665 nm "minus-blue" cutoff filter and wavelengths around 610 nm that appear more red to the aircrew. The goal of this lighting modification is to provide more of a red color to warning lights to improve safety by enhancing aircrew recognition of these lights.⁵⁴

EXTERNAL LIGHTING

General

The A-6E NVG lighting modification does not include a complete rework of external lights. The only significant change is the replacement of the red rotating anti-collision light with a NVG-suitable green light. The white tail light, red port wingtip light, and yellow underwing pylon lights tend to blossom and blend together when viewed through NVGs. During night rendezvous, a joining wingman will request the lead pilot to deselect each light as he approaches, even to the point of having all external lights extinguished once the flight is joined.⁵⁵

Chemlites

Ingenuity on the part of Desert Storm pilots resulted in the use of near infrared Chemlites during night NVG formation flight. The lead aircraft would have a Chemlite stick taped to the back of an ejection seat. A large piece of tape was placed over the stick in order to prevent light from reflecting inside the lead cockpit and distracting the aircrew.

⁵⁴ Al Paddack, "Night Vision Goggle Memorandum" (1993), Washington D. C.: SEMCOR Corporation

⁵⁵ Tactics Guide TZ 1031-03-93 for A-6E Night Attack (1993), pp.82-84, China Lake: Air Test and Evaluation Squadron Five

This form of lighting provided visual cues to NVG-equipped aircrew, but remained invisible to the non-aided human eye.⁵⁶

NVG COCKPIT STORAGE

The non-integrated approach to integrating NVGs into A-6E fleet units resulted in a failure to provide a suitable cockpit storage unit. Since NVGs are not used during takeoff and landing phases of flight, they must obviously be stored in a place where they will not be damaged, or present a cockpit hazard. Cockpit storage areas are limited to a small metal box on the pilot side, and an open box area and elastic pouch on the B/N side. Both of these areas are not adequately suitable to store the sensitive NVGs during dynamic catapult launches or arrested landings at sea. Typically, A-6E aircrew carry the NVGs to the airplane in the padded storage boxes for protection against accidental damage. For takeoffs and landings, the B/N will place the boxes containing the NVGs on his right console area, and hold them down with his right hand to prevent them from traveling aft on catapult launches and forward on arrested landings. This procedure still presents a potential loose object hazard and serves to distract the B/N's attention from monitoring cockpit instruments during these critical stages of flight. A more suitable means of cockpit storage must be provided.

A possible solution for the inflight storage of NVGs is a permanent storage unit located on the side console areas of the pilot and B/N. With limited console area available, implementation of such a design would significantly decrease the available area for storage of inflight publications currently placed in these console areas. For the pilot, an NVG storage unit located in the aft left console area would limit the area for storage of inflight publications to his left windscreen area. Additionally, an NVG storage unit in the left

⁵⁶Ibid., p. 84

console area might interfere with his operation of the emergency ram-air turbine handle located in this area.

A more desirable solution to the cockpit storage problem is to provide a permanent storage container in the area located between the two ejection seats. Properly designed, an NVG storage unit located in this area of the cockpit could be easily accessible by either the pilot or B/N for storing or removing NVGs during flight. As with any major hardware modification, installation of an NVG storage unit in this area would require a dedicated design effort, structural analysis, human factors, and operational evaluation to assess the suitability of such an installation. Such a permanent NVG storage unit would allow aircrew to safely store the NVGs during takeoff and landing, thereby increasing flight safety and greatly decreasing the potential for damage to the NVGs.

NVG EJECTION COMPATIBILITY

A serious limitation of NVG operation in ejection seat equipped aircraft is that the goggles add considerable mass to the upper helmet area and therefore present a lethal hazard to a pilot during ejection. The tremendous inertial forces experienced during ejection will either cause fatal neck injuries to the pilot, or if the NVGs somehow break free, will present a serious injury hazard as they travel downward towards the pilot's legs. The solution at this time is to remove the NVGs prior to ejection, but in certain quick reaction cases, this may not be possible. The problem lies not with the total mass of the NVGs, but with the forward location of the NVGs relative to the center of gravity of the pilot's head. During ejection, a head-down moment results from the inertial forces of the ejection sequence that will seriously injure or kill a pilot ejecting with NVGs attached to his helmet. Table 6-1 describes the dynamics of the ejection sequence with various helmet and NVG combinations.

Table 6-1

Ejection Sequence Relative Weights

DESCRIPTION	WEIGHT ¹	RELATIVE WEIGHT (Initial Acceleration) ²	RELATIVE WEIGHT (Sustained Acceleration) ³
HGU-33 Helmet	3.06 lbs	214.2 lbs	33.7 lbs
HGU-66 Helmet	2.19 lbs	153.3 lbs	24.1 lbs
HGU-66 Helmet + NVGs	3.75 lbs	262.5 lbs	41.3 lbs

Notes

1. Helmet and NVG weight measurements of sample VX-5 flight equipment.
2. Initial acceleration of 70 Gs.
3. Sustained acceleration of 11 Gs.

The older and noticeably heavier HGU-33 helmet is still in use today, and has been worn by pilots during numerous safe ejections. It follows from Table 6-1, that a pilot wearing NVGs and a lightweight HGU-66 helmet has only 11 ounces more weight on his head than a pilot wearing just an HGU-33 helmet. However, it is the distribution of this weight (or mass) that is the critical element of a safe or fatal ejection. Simple arithmetic shows that if the total weight of the NVGs (1.56 lb) could be reduced by 0.69 lb, then the total weight of the helmet and NVGs would weigh the same as the ejection safe HGU-33 helmet. This could be made possible by integrating the NVG sensors within the helmet design, thereby reducing the need for a metal support structure that contributes to the total weight of the current NVG design. The design challenge would be to evenly distribute the mass such that the pilot's head would not be rotated forward during the ejection sequence, while still allowing the pilot to firmly place the back of the helmet into the ejection seat headrest area.

With relatively small intensifier tube assemblies located just outboard of the pilot's eyes and completely integrated within the helmet design, the current forward mass distribution of the NVGs could be moved aft, closer to the center of gravity of the pilot's

head. Once the technical challenges of displaying an image to the pilot through an indirect light path such as this are solved, tactical aviators would have a light-weight integrated design that would simplify NVG flight by decreasing installation and removal requirements of current externally mounted designs, and greatly improve flight safety by allowing for safe ejection with a fully integrated NVG helmet design.

PILOT NECK FATIGUE

Another problem resulting from current NVG design and location on the helmet is the fatigue the offset weight of the goggles produces on the pilot. Even in non-maneuvering flight, the offset weight of the NVGs tends to rotate them forward and down in the case of a loose fitting helmet design, or results in neck strain in a proper tightly fitting helmet design. The integrated nape/chin strap utilized by NVG-compatible helmets such as the HGU-66 helmet helps to prevent the NVGs from rotating forward, but the tight straps and NVG center of gravity location still cause neck fatigue. A contributing factor to this fatigue is that the narrow field of view of NVGs requires greater than normal head and neck movement in order to adequately scan the outside scene. Additionally, the instantaneous and sustained normal load factor (G) capabilities of modern fighters further aggravate the problem by increasing the relative weight of the NVGs during maneuvering flight. (A 5-G turn results in the 1.75 pound (lb) Cats Eye NVGs presenting a relative weight of a small sized bowling ball, 9 lb).

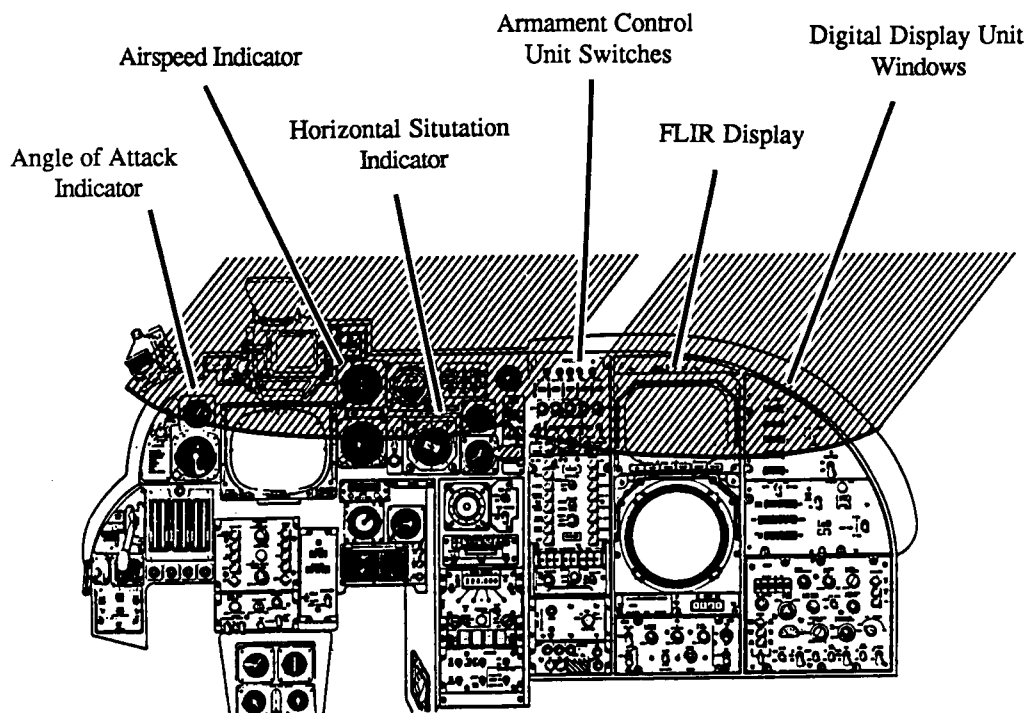
INCLEMENT WEATHER

Night vision goggles are an excellent means of intensifying low light levels while flying in clear weather conditions. However, they do not provide a suitable means to safely navigate at night in inclement weather. Terrain hidden by rain or clouds will not become visible through the use of NVGs. A-6E aircrew have the advantage of being able

to switch to the radar terrain clearance system in order to maintain terrain clearance if inclement weather is encountered. In other NVG aircraft, such as the F/A-18 Hornet, NVGs are the only suitable sensor for night terrain following and terrain clearance. Continuing a flight into inclement weather or very low light conditions without a suitable means of accurate terrain avoidance is an extremely hazardous and foolish decision. A-6E aircrew must recognize the need for a properly functioning terrain clearance system for use as an inclement weather backup, and train to transition smoothly from utilization of the NVGs to the aircraft systems.

COCKPIT INSTRUMENT FIELD OF VIEW

As part of the Quicknight evaluation, pilots evaluated the suitability of both the ANVIS and Cats Eyes NVGs for use in the A-6E. The direct view ANVIS NVGs provide 25 millimeters (mm) of eye relief between the tubes and the pilot's eyes. In order to view critical flight information instruments such as airspeed, angle of attack, and the horizontal situation indicator, the pilot is required to rotate his head approximately 20 degrees aft. Likewise, the B/N is required to rotate his head aft in order to see the FLIR display, upper digital display unit windows, and armament control unit switches. The cockpit field of view for ANVIS NVGs is shown in figure 5-7.

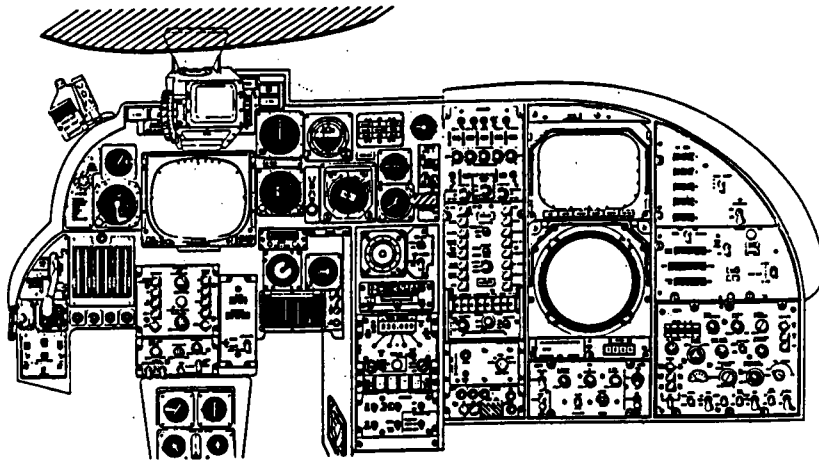


ANVIS NVG Cockpit Field of View

Figure 5-7

Source: A-6E Quicknight (1987), p. 6, Patuxent River: Naval Air Test Center

The combiner glass design of the Cats Eyes NVGs allows for viewing of cockpit instruments either by looking around or through the combiner. Viewing through the combiner obviously requires proper cockpit and NVG wavelength filtering to avoid undue display amplification. The cockpit field of view for Cats Eyes NVGs is shown in figure 5-8.



Cats Eyes NVG Cockpit Field of View

Figure 5-8

Source: A-6E Quicknight (1987), p. 7, Patuxent River: Naval Air Test Center

The degraded cockpit field of view associated with ANVIS direct view NVGs resulted in the selection of Cats Eyes for U. S. Navy and Marine Corps fixed wing aircraft use.⁵⁷

⁵⁷A-6E Quicknight (1987), pp. 6-7, Patuxent River: Naval Air Test Center

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

WINDSCREEN GLASS

Due to the poor transmissivity performance of production leaded glass windscreens, NVG flight with these windscreens is much more difficult and dangerous than with high transmissivity windscreens. The transformation of the night scene into a viewable day-like image can produce a feeling of complacency in the aircrew while using NVGs. In this situation, they are falsely assuming that they are receiving the entire outer scene through the use of NVGs. Optical losses due to windscreens, gunsights, and refractive geometry are a certainty even if the aircrew does not recognize them. Flying with non-NVG suitable windscreens purposely adds an unneeded degradation in the NVG flight process. Recommend suitable high transmissivity windscreens be procured in adequate numbers and installed in all NVG A-6E aircraft.

INTEGRAL LIGHTING MODIFICATION

Installation of proper integral lighting modifications should be a requirement for NVG flight. Makeshift floodlight and instrument filters do not adequately illuminate cockpit instruments and allow for the safe conduct of flight with NVGs. Additionally, it is quite common for A-6E squadrons to cannibalize parts from one aircraft to the other to counter replacement parts shortages. This practice very often results in formerly completely NVG-compatible cockpits taking on a "Christmas tree" appearance with a varying combination of green/blue NVG-compatible instruments and red non-NVG-compatible instruments. With the brightness of all cockpit instruments controlled by only one rheostat, a distracting mix of excessively bright red instruments and overly dim NVG-

compatible instruments occurs. Recommend totally integral cockpit lighting modification and parts support be implemented to provide suitable and safe cockpit lighting configurations for A-6E aircrew.

COCKPIT NVG STORAGE

Suitable NVG storage units should be provided for all aircraft used for NVG flight. The potential for damaging these expensive devices is great, as well as the possibility of loose items roaming free in the cockpit. NVGs, as well as any other loose items must be secured in the cockpit due to the hazard presented by possible jamming of the flight controls and interference with the ejection seats. Recommend installation of a permanent NVG storage unit located between the ejection seats to allow for the safe storage of the NVGs to increase flight safety and decrease the potential for damage to the NVGs.

EJECTION-SAFE NVGs

Ejection while wearing current helmet-mounted NVGs will certainly result in severe injury to the aircrew, and will most likely cause death. The solution of detaching the NVGs prior to ejection should be considered a temporary one, and efforts should continue to devise and implement an ejection-safe NVG design. Presently, there is no simple solution to the problem of providing an ejection-safe NVG design, and flight while wearing current NVGs continues to be a very dangerous event. The current NVG technology requires an externally mounted intensifier tube assembly such as the ANVIS or Cats Eyes design, with the intensifier tubes positioned forward of the pilot's eyes. As long as there exists a requirement to position the NVGs in front of the pilot's eyes, safe ejection will not be possible. The total weight of the NVGs must be decreased and evenly distributed throughout the helmet in order to prevent a downward rotation of the pilot's

head during the ejection sequence. In the opinion of the author, this will be made possible only through advances in NVG technology and miniaturization that will allow for a totally integrated NVG design where the NVG intensifier tube sensors are integrally mounted into the pilot's helmet. With the intensifier tubes located just outboard of the pilot's eyes, the forward center of gravity problem is solved and the total weight is reduced by the removal of external support brackets currently in use. The night scene could be displayed to the pilot on lightweight glass panels in front of his eyes, or on a visor surface. A design concept such as this is currently under study at General Dynamics, Fort Worth, however, the current level of technology still requires an unsuitably large wire bundle connection to the back of the pilot's helmet. The only solution for safe ejection while utilizing NVGs remains to remove the NVGs prior to ejection, however, this condition can not be allowed to continue. Investments today in miniaturization and advanced integrated NVG designs will save the lives of aircrew as they continue to utilize NVGs in military training and operational missions. The lighter weight and more evenly distributed mass would allow for the safe ejection of pilots wearing the fully integrated NVG helmet. Recommend implementation of an advanced totally integrated NVG helmet design as soon as technically possible.

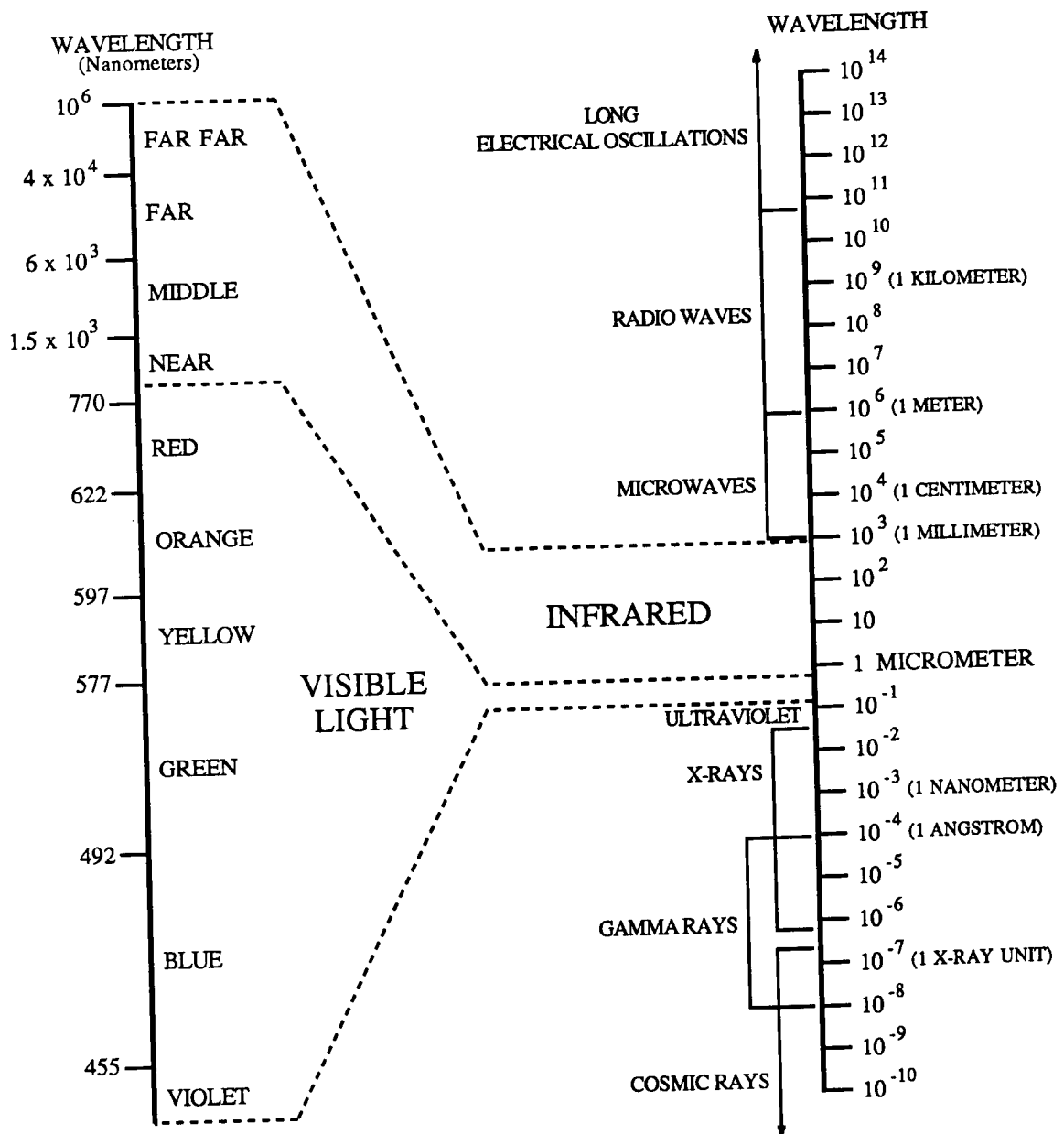
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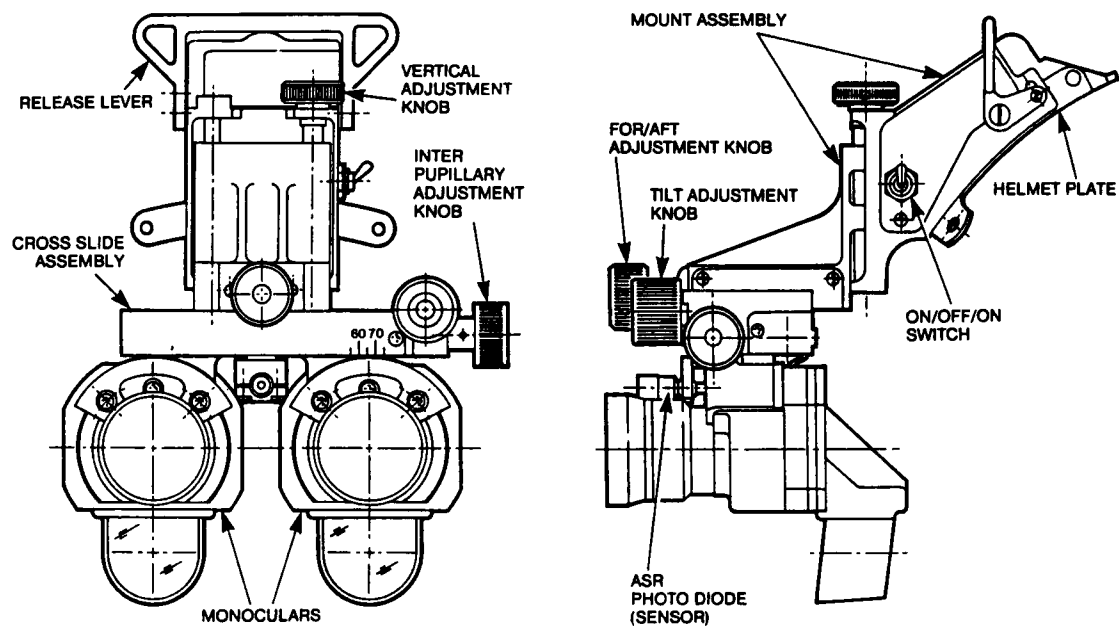
APPENDICES



Electromagnetic Spectrum

Figure 1

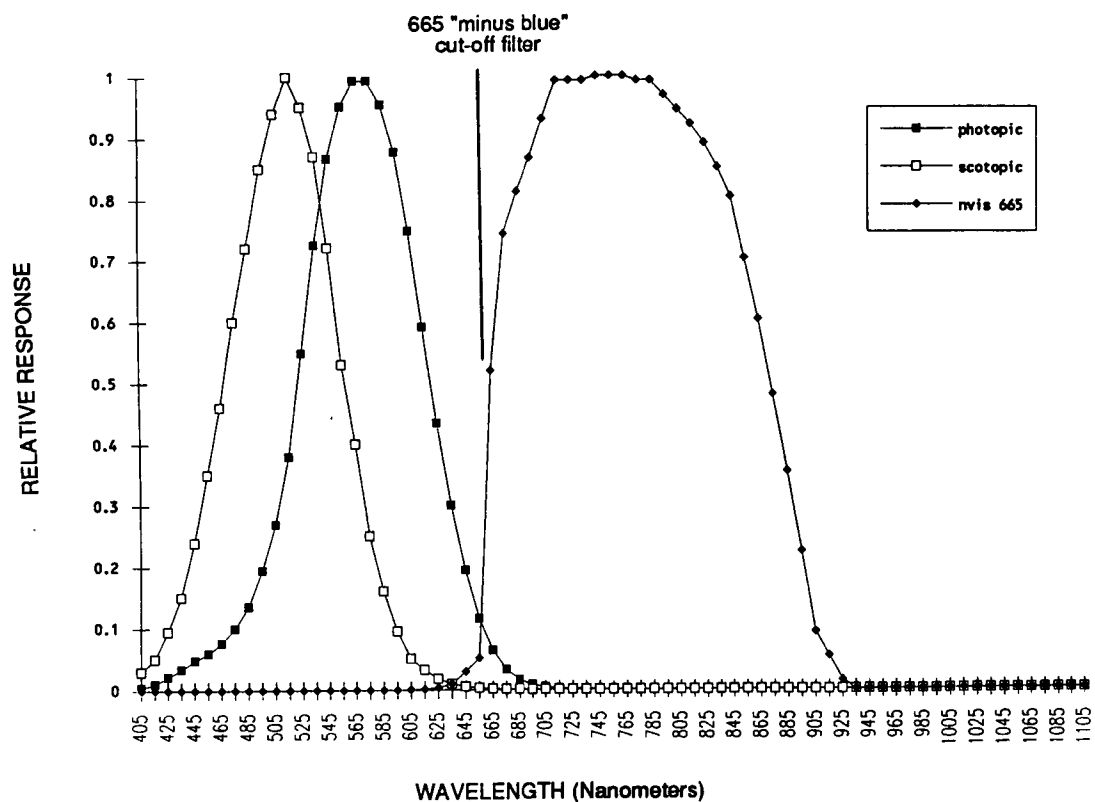
Source: Tactics Guide TZ 1031-03-93 for A-6E Night Attack (1993), p.10, China Lake: Air Test and Evaluation Squadron Five



Cats Eyes Night Vision Goggles

Figure 2

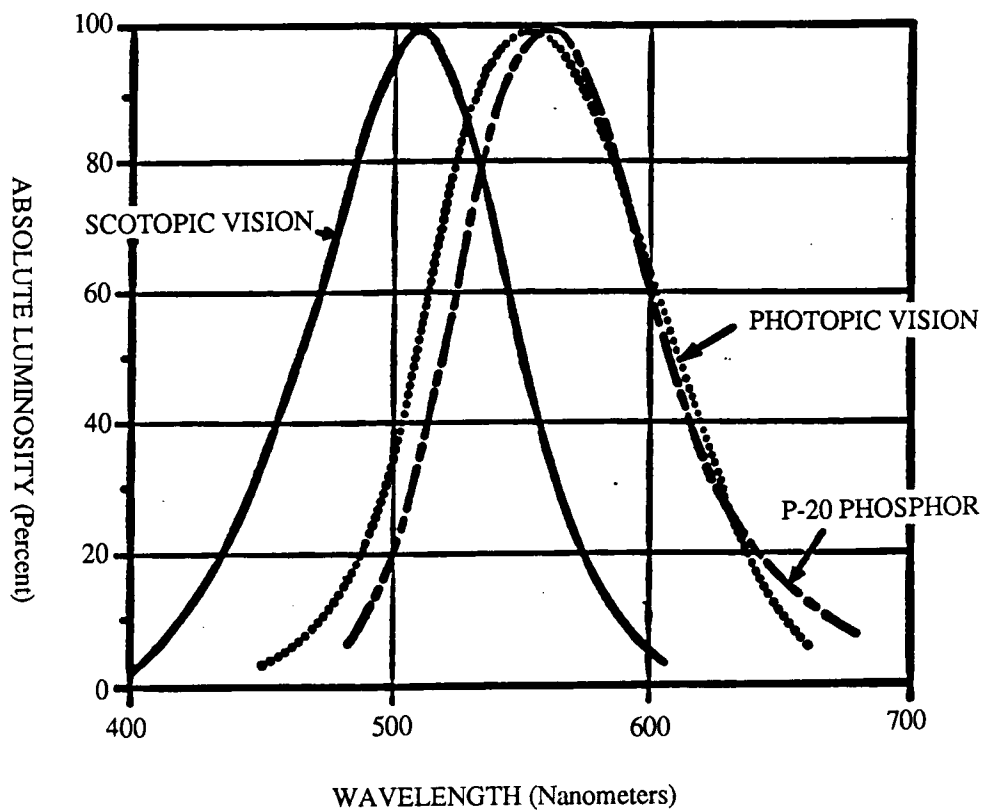
Source: Operating Instructions for Cats Eyes Night Vision Goggles (1986), pp. 2-3,
Rochester Kent, England: GEC Avionics Limited



Photopic/Scotopic Vision Range Comparison with NVIS 665

Figure 3

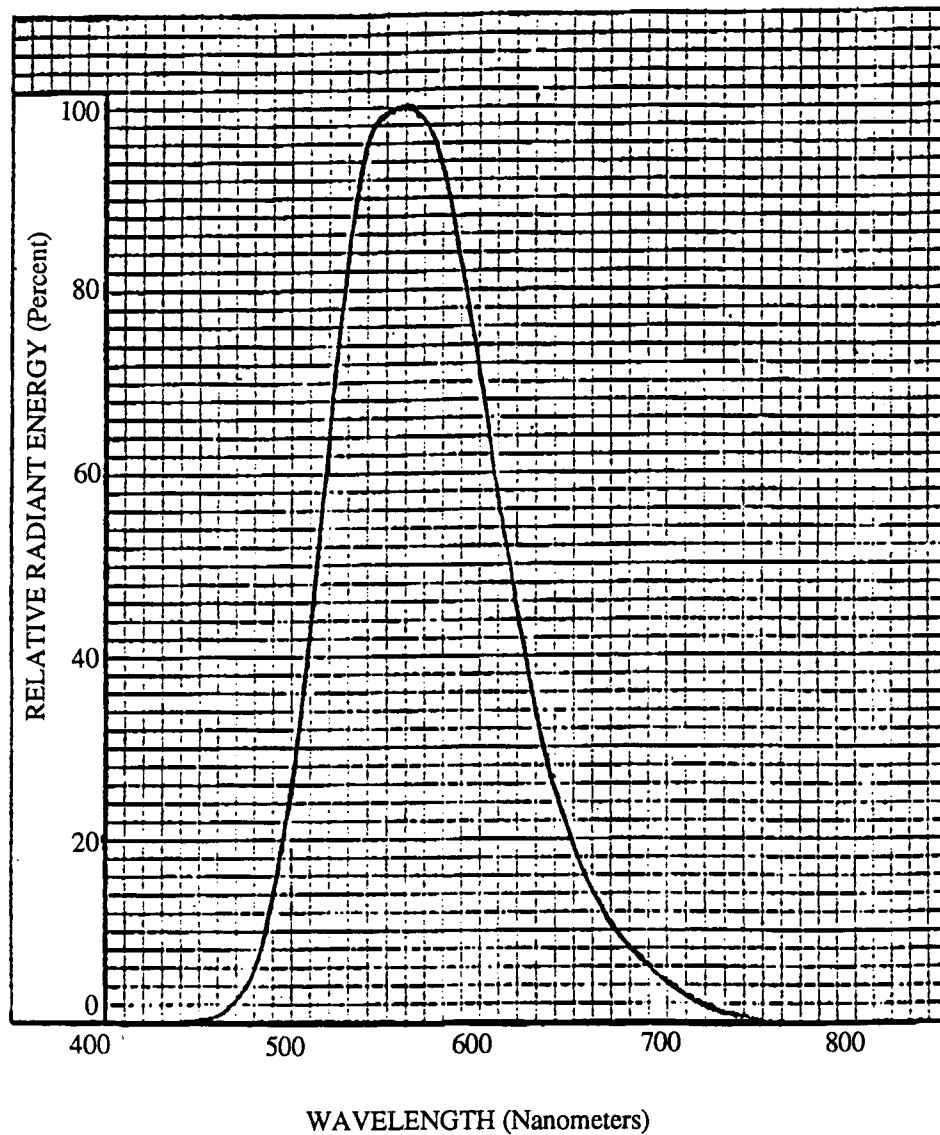
Source: Steve Adams, "Night Vision Goggle Memorandum" (1993), China Lake: Naval Air Warfare Center



Photopic/Scotopic Vision Range Comparison with P-20 Phosphor

Figure 4

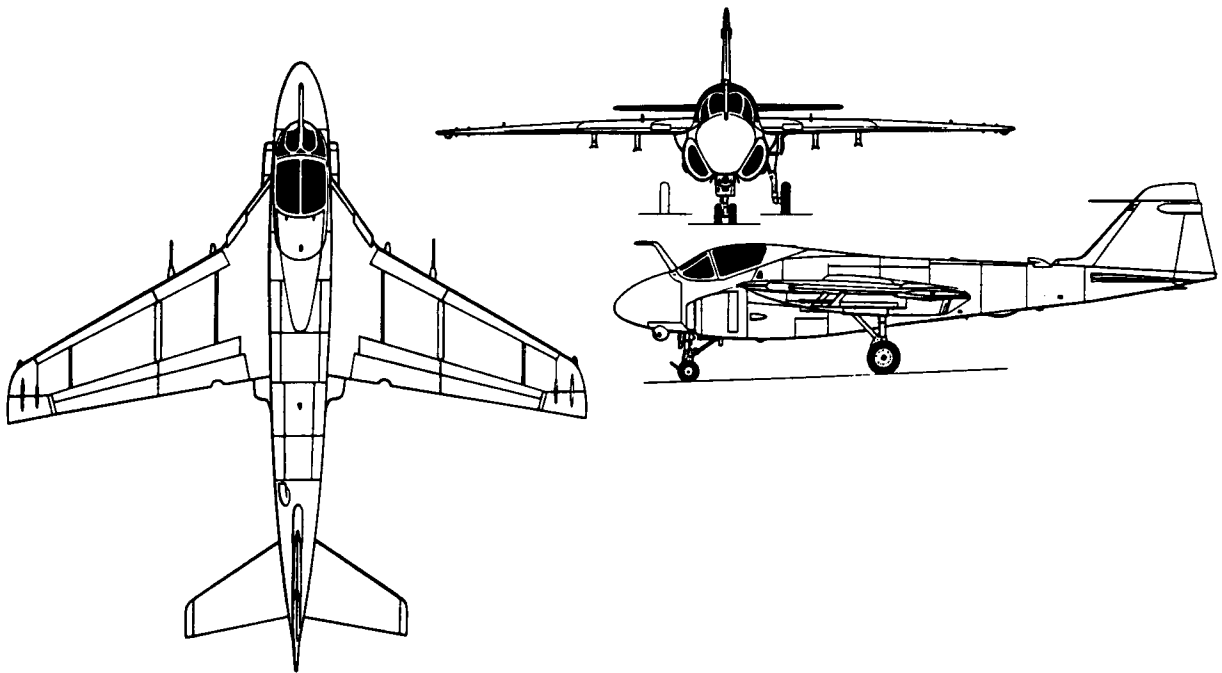
Source: Tactical Jet Night Vision Device Manual (1990), p. 5-12, Yuma: Marine Aviation Weapons and Tactics Squadron One



Spectral Energy Distribution Characteristics of P-20 Phosphor

Figure 5

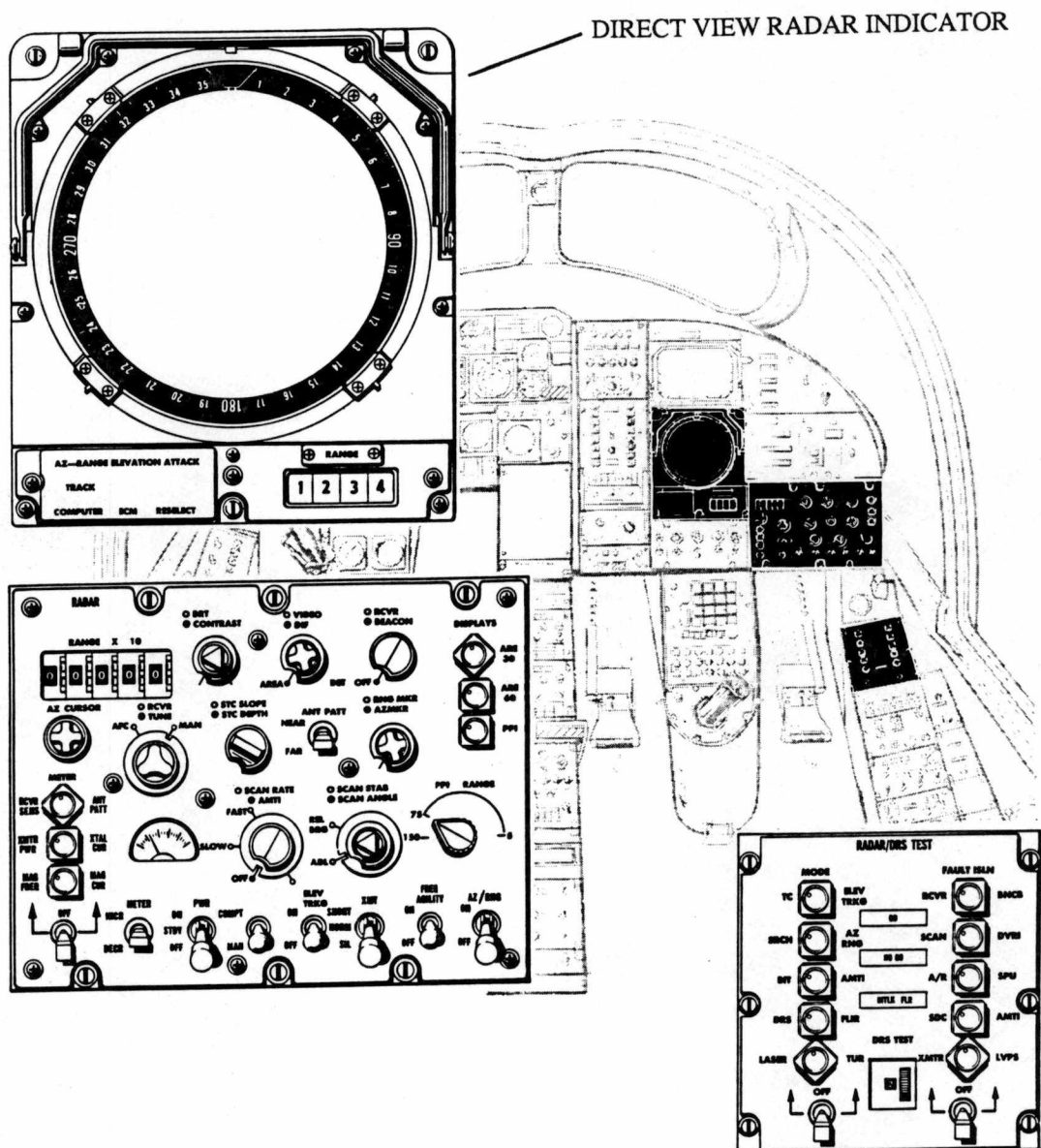
Source: Al Paddack, "Night Vision Goggle Memorandum" (1993), Washington D. C.: SEMCOR Corporation



A-6E Intruder

Figure 6

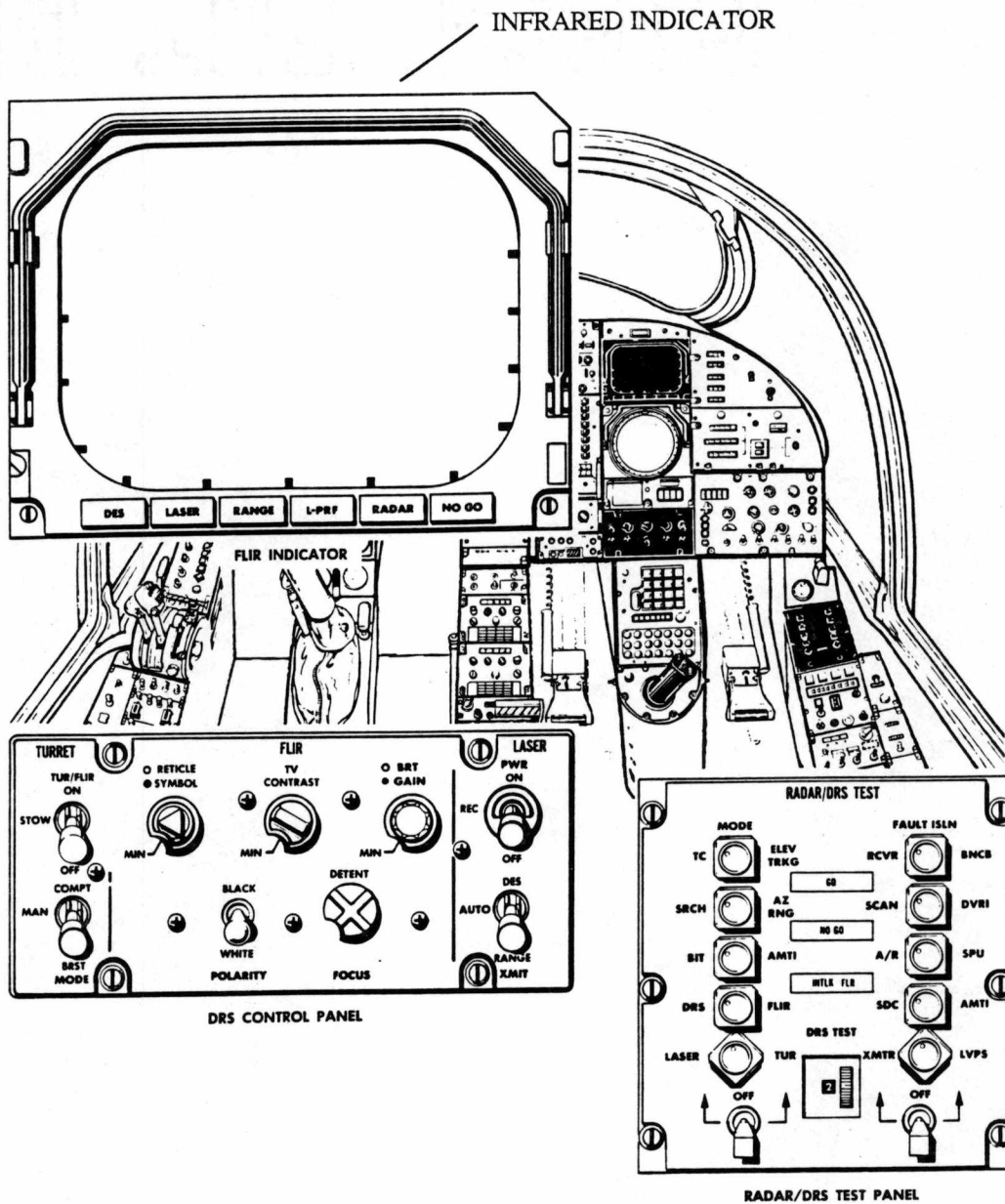
Source: Janes All the World's Aircraft (1992), p.407, Coulsdon, Surrey: Sentinel House



A-6E Direct View Radar Indicator

Figure 7

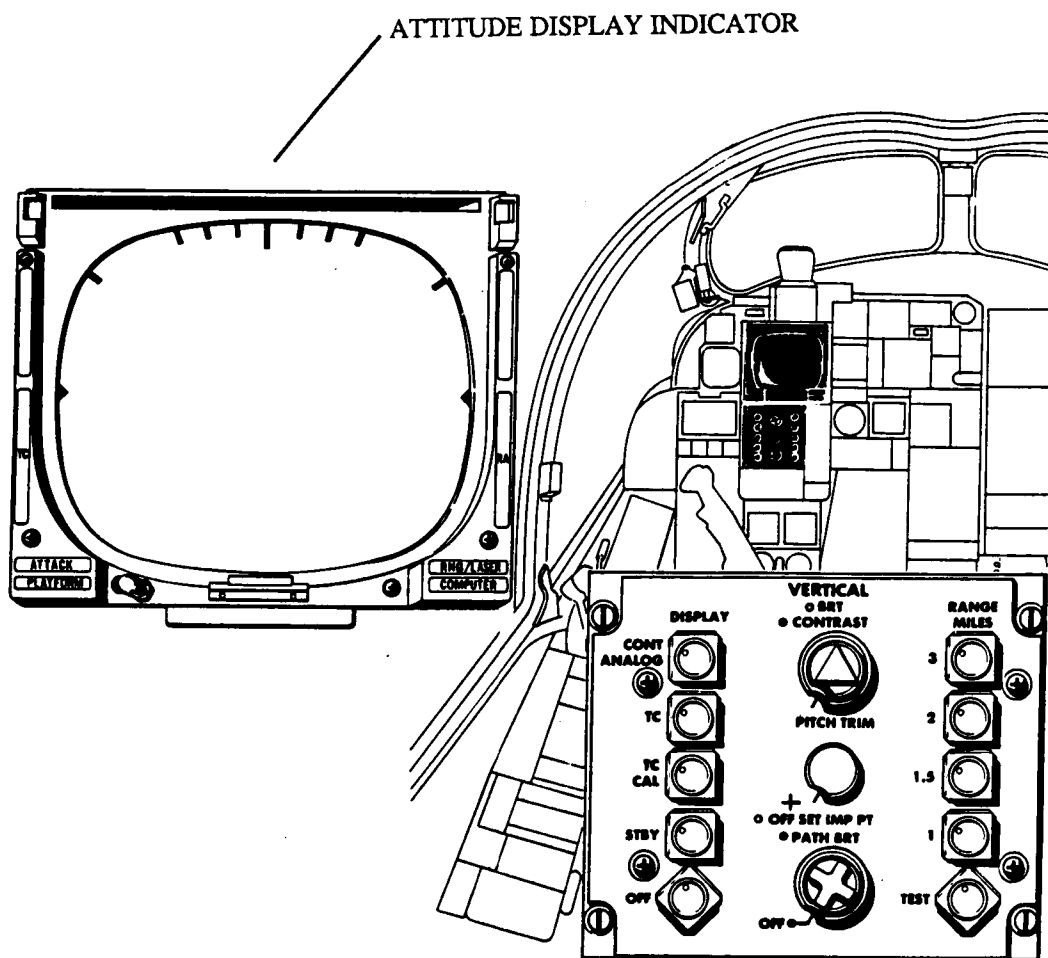
Source: NATOPS Flight Manual, Navy Model A-6E TRAM/KA-6D Aircraft (1991), p.VII-27-11, Washington D. C.: Naval Air Systems Command



A-6E Infrared Indicator

Figure 8

Source: NATOPS Flight Manual, Navy Model A-6E TRAM/KA-6D Aircraft (1991), p.VII-27-16, Washington D. C.: Naval Air Systems Command



A-6E Attitude Display Indicator

Figure 9

Source: NATOPS Flight Manual, Navy Model A-6E TRAM/KA-6D Aircraft (1991), p.VIII-27-41, Washington D. C.: Naval Air Systems Command

Nominal Specification Comparison of Night Vision Goggles

Table 1

	AN/PVS-5A (Gen II) ¹	ANVIS (Gen III) ¹	Catseye (Gen II, III) ^{2,3}
Intensifier type	Generation II	Generation III	Generation II, III
Gain	10,000	25,000	30,000
Objective	f/1.4	f/1.2	f/1.25
Magnification	1:1	1:1	1:1
Field of View	40°	40°	30°
Focus range/position	10 inches to infinity	10 inches to infinity	15 feet to infinity
Diopter adjustment	+2 to -6	+2 to -6	Not applicable
Interpupillary distance	55 to 72 mm	55 to 72 mm	55 to 73 mm
Power	2.7 V (Lithium)	3.0 V (Lithium)	3.5 V (Lithium)
Life	10 hrs	20 hours	12 hours
Weight	30 oz	16 oz	27 oz
Mounting	Head straps	Helmet mount	Helmet mount

NOTES:

1. Source: HMX-1 Evaluation Report, AN/PVS-5A and AN/AVS-6 Comparison (1987), pp. 2-10, Quantico: Marine Helicopter Squadron One
2. Source: John J. Martin (1989), Naval Weapons Center Catseye Night-Vision Goggle Sensor Engineering Issues Report, p. 9, China Lake: Naval Weapons Center
3. Source: "Cats Eyes: The Unique Aviators Night Vision Goggle", (1985), pp. 1-3, Rochester Kent England: GEC Avionics

Light Condition and Scene Illumination Comparison

Table 2

Source: Reconnaissance Reference Manual, (1982), p. 148, Washington D. C.:
Naval Air Systems Command

LIGHT CONDITION	SCENE ILLUMINATION ¹		Relative Power for 100 ft ² area (Watt) ²
	(foot-candle) or (lumen/ft ²)	(lux) or (lumen/m ²)	
Direct sunlight	10,000	108,000	1,000,000
Full daylight	1,000	10,800	100,000
Overcast sky	100	1,080	10,000
Very dark day	10	108	1,000
Twilight	1	10.8	100
Deep twilight	0.1	1.08	10
Full moon	0.01	0.108	1
Quarter moon ³	0.001	0.0108	0.1
Eighth moon	0.0002	0.0022	0.02
Starlight	0.0001	0.0011	0.01
Overcast starlight	0.00001	0.0001	0.001

NOTES:

1. Lumen is the unit of luminous flux, equivalent to the luminous flux through a unit-solid angle (steradian) from a uniform point source of one international candle.
(1 lumen/ft² = 1 foot-candle = 10.8 lux; 1 lumen/m² = 1 lux).
2. Typical power conversion for wavelength of 550 nm.
3. A typical city seldom reaches light levels below 10⁻³ lumen/ft² in open areas.

History of the A-6 Intruder

General

The introduction of night vision goggles to the A-6 Intruder is just one of many upgrades and enhancements performed on this attack platform. This appendix describes the major modifications that have occurred since the introduction of the first operational Intruder to Navy service almost 30 years ago.

A2F (A-6A) Model

Prior to 1950, the focus of the United States military was that of a nuclear strike force. Detonation of only a few nuclear devices would surely bring certain victory in any conflict. This short-sighted strategy was quickly upset by the events of the Korean War. Suddenly, the weapons of mass destruction were not usable in the conduct of this war. What was needed was an attack aircraft capable of finding and destroying point targets at night and in inclement weather. Aircraft design teams rushed to meet the need for an All Weather Attack platform specified in a 1956 Request for Proposal issued by the United States government. The most convincing design proposal came from a team headed by Lawrence Mead and Robert Nafis at Grumman. The aircraft they foresaw would be known as the Intruder.⁵⁸

Following a 26 March 1959 contract award, Grumman's initial design prototype (BuNo 147864), designated the A2F, took to the air on 20 April 1960 in the skies over Calverton, New York. Redesignated the A-6A, the Intruder performed carrier suitability testing onboard the USS Enterprise in December 1962. The first two production aircraft

⁵⁸Aeroguide 15. Grumman A-6E Intruder (1986), pp. 2-3, Essex: Linewrights Ltd

were delivered to Attack Squadron 42 (VA-42) in March 1963, however, it was not until 10 October 1963 that the first truly operational Intruder, airframe No 32, was delivered.⁵⁹

A-6A Model

The A-6A performed the All-Weather Attack mission through the use of then state-of-the-art electronic equipment, designated Digital Integrated Attack Navigation Equipment (DIANE). The primary equipment and sensors were the Litton ASQ-61 digital (drum memory) computer, the Ku-band Norden APQ-92 search radar, the Ku-band Norden APQ-88 track radar, and the Litton ASN-31 inertial navigation system (INS). These sensors allowed the aircraft to navigate, prosecute stationary and moving targets, and map terrain in night and inclement weather conditions.

A-6B Model

The A-6B version was a short-lived modification to existing A-6A aircraft that was designed for the radar suppression mission. Three distinct sub-variants were produced that could carry the AGM-78 Standard ARM (Anti-Radiation Missile).

A-6C Model

Another modified A-6A design version was the A-6C that was optimized for attacking targets that could not be easily detected by radar or visual means. This design included the Trails-Roads Interdiction Multisensor (TRIM), a large ventral tub located along the lower fuselage centerline. TRIM equipment included Forward Looking Infrared and low-light television sensors.⁶⁰

⁵⁹Ibid., pp. 5-8

⁶⁰Ibid., pp. 8-9

A-6E Model

The A-6E version of the Intruder signified a significant electronic upgrade to the aircraft systems. The search and track radars were replaced by the Norden APQ-148 multi-mode radar, and the rotating drum computer was replaced by the IBM ASQ-133 solid state computer.⁶¹ A follow-on software change, designated Weapons Control System Improvement (WCSI), added capabilities for the Harpoon missile. A subsequent software and hardware improvement was designated System Weapon Improvement Program (SWIP). This upgrade added the Integrated Missile Panel (IMP) and ALR-67 Countermeasures Receiving Set, and provided additional capabilities for the following weapons: High speed Anti-Radiation Missile (HARM), Harpoon Block 1C missile, Standoff Land Attack Missile (SLAM), and Maverick missile (IR and laser guided). As of 16 June 1993, the A-6 Class Desk reported that the A-6E fleet consists of 339 aircraft as shown in table 1.

A-6E Aircraft Composition

Table 1

Source: CDR Steve Enewold, A-6E Class Desk, (1993), Washington D. C.: Naval Air Systems Command

Description	Quantity
Total A-6s in Fleet and Reserve units	209
Total A-6s in modification pipeline	117
Total A-6s in Test & Evaluation units	13
Fleet SWIP models	298
Fleet WCSI models	27
Reserve WCSI models	14

⁶¹Ibid., pp. 9-10

A-6F/A-6G Models

These upgrades to the Intruder were both stopped short of production by Department of Defense acquisition decisions. Improvements contained in these versions were new wings, new higher thrust engines (General Electric F404), extra wing stations, Auxiliary Power Unit (APU), HUD, Multi-Function Displays (MFDs), and new landing gear. Cancellation of these aircraft versions (and shortly thereafter the A-6E TRAM production line) signaled the end of the Intruder.

A-6E TRAM Model

As discussed in Chapter 4, the current version flying today is the A-6E TRAM. The TRAM system is housed in a rotating turret located on the lower nose radome surface and contains a FLIR sensor, a laser designator/ranger, and a laser receiver. Capabilities added with the TRAM turret included laser ranging for free-fall ordnance deliveries, laser designation of targets for LGBs, and infrared viewing of targets. Additional improvements included the upgraded APQ-156 search/track radar and the replacement of the ASN-31 with the ASN-92 INS.

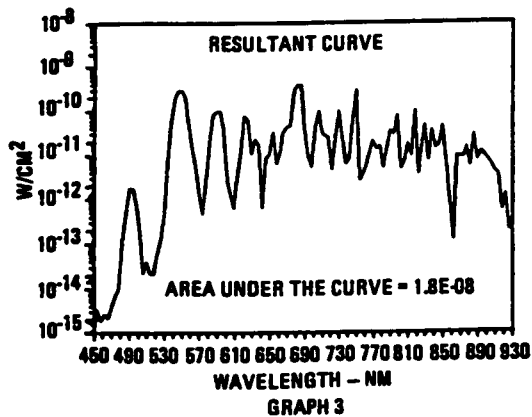
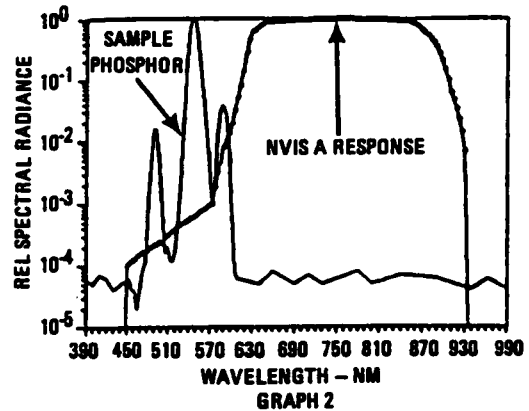
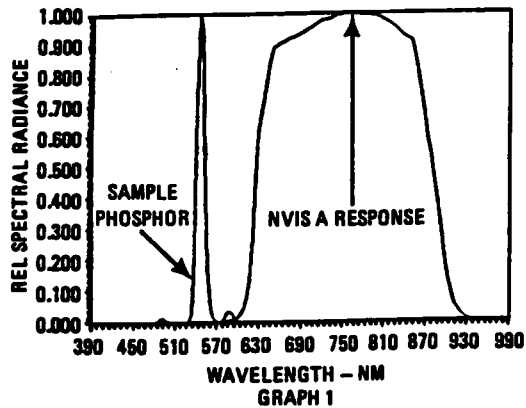
A-6E Block 1A Model

This upgrade to A-6E TRAM aircraft was developed as a stopgap measure to enhance the survivability and effectiveness of the Intruder until the A-12 Avenger reached a production stage. Even though the A-12 program has been canceled, the Block 1A upgrade is still proceeding towards a late 1995 fleet introduction date. Improvements include the installation of a HUD, MFD, Global Positioning System (GPS) receiver, the ASN-139 Ring Laser Gyro, an additional countermeasures dispenser, and a modification to the leading edge of the wing that allows for decreased landing approach speeds. A full-scale development aircraft is currently under test at the Naval Air Warfare Center,

China Lake. The author has had the fortunate opportunity to fly and evaluate this prototype while in test at China Lake. Whether or not this needed upgrade to the aging Intruder will see operational service is yet to be decided.

NVIS Radiance Sample Calculation

Source: A-6E Night Vision Imaging System (NVIS) (1990), p.2, Patuxent River: Naval Air Test Center



THESE GRAPHS ARE PROVIDED TO GIVE AN EXAMPLE OF HOW NR_0 VALUES ARE DERIVED. GRAPH 1 DEPICTS BOTH A CLASS A (625 NM) RESPONSE CURVE AND THE SPECTRAL DISTRIBUTION OF A SAMPLE CRT PHOSPHOR. THESE CURVES ARE PLOTTED LINEARLY AND THERE APPEARS TO BE MINIMUM OVERLAP. WHEN PLOTTED LOGRITHMICALLY (GRAPH 2), HOWEVER, IT IS APPARENT HOW MUCH OVERLAP IS ACTUALLY PRESENT. THESE CURVES ARE MULTIPLIED TOGETHER RESULTING IN THE CURVE DEPICTED IN GRAPH 3. THE INTEGRAL OF THIS CURVE IS NR_0 (1.8E-8). WHEN REVIEWING DATA PLOTS BE AWARE OF THE MANNER IN WHICH THE DATA IS PRESENTED (LINEAR OR LOG-LINEAR).

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(All previous revisions are obsolete)

APPENDIX E

VITA

LT Mike A. Bryan received his Bachelor of Science in Aerospace Engineering from the Georgia Institute of Technology in June 1984. Following completion of Aviation Officer Candidate School in Pensacola, FL, he reported to Navy primary flight school in Milton, FL. After designation as Naval Aviator in August 1986, he reported to NAS Whidbey Island, WA, where he flew the A-6E Intruder for four years with Attack Squadrons 128 and 95. Selected for U. S. Naval Test Pilot School, LT Bryan reported to Patuxent River, MD in June 1990. Following graduation, he reported to his current assignment at Air Test and Evaluation Squadron Five in China Lake, CA, where he is the A-6E All-Weather Attack Branch Head. LT Bryan has accumulated 300 carrier arrestments and over 1,500 tactical flying hours in primarily the A-6E and F/A-18. He has flown over 30 different aircraft, including fixed wing, rotary wing, and glider models.