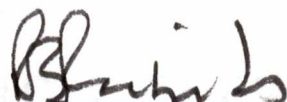


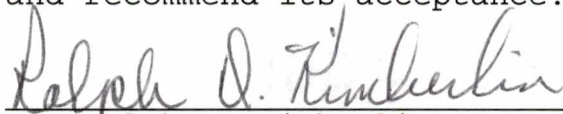
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Mr. Robert B. Richards , Major Professor

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TEST PILOT SCHOOL CATS EYE NIGHT VISION GOGGLE (NVG)
INSTRUCTIONAL TEST CURRICULUM FOR TACTICAL JET AIRCRAFT

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

Barry E. Wilmore
December 1994

DEDICATION

This thesis is dedicated to my future wife who

- fixed me dinner as I researched
- rubbed my neck as I typed
- sacrificed her time with me so I could finish
- loves me

ABSTRACT

Night systems (NS) are playing an ever increasing role in the warfighting capabilities of armed forces world wide through technological advancements in Forward Looking InfraRed (FLIR) and image intensification (I^2), specifically night vision goggle, devices. As NS technology for use in aircraft has evolved, so has the desire to augment existing and future designs with the ability to prosecute enemy targets from passively detected emissions within the electromagnetic spectrum that cannot be detected by the naked eye at night.

Cockpit and system display designers must now meet specification requirements for NVG compatible cockpit and external lighting, windscreens, and displays. As such, evaluation specifications and requirements of the NS themselves and the aircraft and cockpits in which they are used must be assessed to ensure fleet aircrew have the best and safest systems current technology can make available.

This thesis briefly illustrates NVG theory and history, outlines specification and test criteria, and presents a complete test pilot school curriculum to expose prospective Test Pilots, Weapons System Operators, and Engineers to NS test techniques with an emphasis on NVGs and NVG/cockpit lighting compatibility. Extensive academic briefs and test pilot school standard operating procedures will be developed to ensure the night systems evaluation exercise is conducted in the safest possible manner.

The integration of NS into the total aircraft weapon system will be addressed. A methodology for addressing specific questions will be developed which included such factors as target and aircraft characteristics, terrain features, and the contrast between prospective targets and their backgrounds. The methodology stresses the human factors aspects of the man-machine interface, especially display size, image quality, and NVG compatibility.

Finally, an evaluation/demonstration flight will be developed which exposes the prospective evaluator to NVG phenomena, hazards, and operational requirements. The flight will focus on our ability to use current technology to actively (Radar) and passively (NVG and FLIR) prosecute ground and airborne targets at night while simultaneously exposing the prospective evaluator to the NS assessment techniques many may use during their flight test careers.

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NOMENCLATURE

AGL	Above Ground Level
ANVIS	<u>A</u> viator's <u>N</u> ight <u>V</u> ision <u>I</u> maging <u>S</u> ystem - Type I Night Vision Goggles Used Primarily In Helicopters
CATS EYES	Type II Night Vision Goggles Used Primarily In Jet Aircraft
FAM	Familiarization
FOR	Field Of Regard
FOV	Field Of View
FLIR	Forward Looking InfraRed
GEN I	First Generation Night Vision Goggle
GEN II	Second Generation Night Vision Goggle
GEN III	Third Generation Night Vision Goggle
HUD	Heads Up Display
I ²	Image Intensifiers
IAW	In Accordance With
IFR	Instrument Flight Rules
IR	InfraRed
IMC	Instrument Meteorological Conditions
IUT	Instructor Under Training
MCP	Micro-Channel Plate
MICRON	Micrometer: Measure Of Wavelength
MSL	Mean Sea Level
NADC	Naval Air Developmental Center
NVG	Night Vision Goggle
NVGQ	Night Vision Goggle Qualified
NVGI (H)	Night Vision Goggle Instructor Qualified (High Altitude)
NVGI	Night Vision Goggle Instructor Qualified (Low Altitude)
NS	Night Systems
SOP	Standard Operating Procedures
TPS	Test Pilot School
VFR	Visual Flight Rules

VMC

Visual Meteorological Conditions

WSO

Weapons System Operator

CHAPTER I

INTRODUCTION

Night Systems (NS) and their associated technologies have and continue to be one of the most beneficial advancements for today's technically trained United States Armed Forces. NS developed for airborne use are any system primarily designed or utilized to enhance a crewmember's ability to operate his aircraft utilizing visual meteorological conditions (VMC) techniques during periods of darkness. Strategies have long sought to exploit the night in military operations, not only to avoid detection and as a means to defeat visually or optically aimed weapons, but also to deny the enemy an opportunity to rest or resupply his troops. With the advent of practical and effective imaging devices, true night war fighting capability has at last become a reality (as demonstrated in the recent Gulf War). It is safe to assume that night military operations will receive even greater emphasis in the future. Current aviation activities range from basic single pilot helicopter operations with Night Vision Goggles (NVGs) to complex missions utilizing a mix of highly sophisticated aircraft with multiple sensors, precise navigational capabilities, and advanced weapons delivery systems (1). The ability to see and therefore maneuver at night through technological advancements in Forward Looking

InfraRed (FLIR) and image intensification (I²), specifically night vision goggle, devices has led to the development of unique offensive and defensive tactics by both U.S. and foreign airborne, ground, and sea fighting forces.

The earliest I² devices which provided "night vision" were InfraRed (IR) sniper scopes used during the final phases of World War II. The first experiments with I² devices in aircraft was begun in the late 1950's when the U.S. Army evaluated head mounted IR converter devices. Both of these initial devices required a covert IR light source to illuminate (irradiate) the area to be viewed (2). This not only limited their effective range, but also made them easily detectable by an adversary equipped with a similar device. As such, aircraft would be required to be positioned in close proximity to enemy forces to enable sufficient illumination for viewing. This very close exposure to the enemy was deemed unsatisfactory in initial flight tests since the purpose behind the development of NS was to provide a means for aircrew to see at night and visually defeat the enemy while maintaining the element of surprise afforded by night tactics.

Although initially used exclusively in helicopters, NVGs are now seeing service in all types of military aircraft. The first extensive combat experience with NVGs occurred during the Falkland Islands War where they were employed by the British (1). As NS technology for use in aircraft has evolved, so has the desire to augment existing and future

designs with the ability to prosecute enemy targets from passively detected emissions within the electromagnetic spectrum that cannot be detected by the naked eye at night. Cockpit and system display designers must now meet specification requirements for NVG compatible cockpit and external lighting, windscreens, and displays. As such, evaluation specifications and requirements of the NS themselves and the aircraft and cockpits in which they are used must be assessed to ensure fleet aircrew have the best and safest systems current technology can make available.

This thesis will briefly illustrate NVG theory and history, outline specification and test criteria, and present a complete test pilot school (TPS) curriculum to expose prospective Test Pilots, Weapons System Operators (WSO), and Engineers to NS test techniques with an emphasis on NVGs, and NVG/cockpit lighting compatibility. The broad backgrounds of prospective evaluators that are selected for test pilot school, many of which have never been exposed to night systems, require an in depth review of the hazards present while utilizing night systems in the dark. As such, extensive academic briefings and test pilot school standard operating procedures (SOP) will be developed to ensure the night systems evaluation exercise is conducted in the safest possible manner.

The integration of NS into the total aircraft weapon system will also be addressed. A methodology for addressing

these questions will be developed which includes such factors as target and aircraft characteristics, terrain features, and the contrast between prospective targets and their backgrounds. The methodology stresses the human factors aspects of the man-machine interface, especially display size, image quality, and NVG compatibility (3). Finally, an evaluation/demonstration flight will be developed which will expose the prospective evaluator to NVG phenomena, hazards, and operational requirements, and the NS assessment techniques many may use during their flight test careers.

CHAPTER II

NIGHT VISION GOGGLE HISTORY AND BASIC THEORY OF OPERATION

ELECTROMAGNETIC ENERGY

Prospective evaluators of night vision systems need a basic understanding of how electromagnetic energy is produced and how it behaves in accordance with the laws of physics. Electromagnetic energy is characterized by its frequency and wavelength which includes radio waves and microwaves, infrared waves, visible light, ultraviolet waves, x-rays, gamma rays, and cosmic rays as shown in Figure 2-1.

Only a small portion of the electromagnetic energy spectrum is detectable with sensors that are capable of passively detecting the energy that exists in the environment and producing an image that can be discerned visually. Except for a few applications where passive microwave radiometers are used to map large volumes of terrain (i.e. cities), millimeter and greater wavelengths require active transmitting devices such as radars to capture energy and map terrain and man-made objects that are then displayed in the cockpit. Passive imaging has few tactical applications below the ultraviolet wavelengths where energy is most commonly produced from astronomical and atomic reactions. These reactions are primarily detected as reflected energy from the sun, which precludes it from night applications (5). The remaining IR

and visible spectrums shown in Figure 2-2 are capable of being passively detected at night.

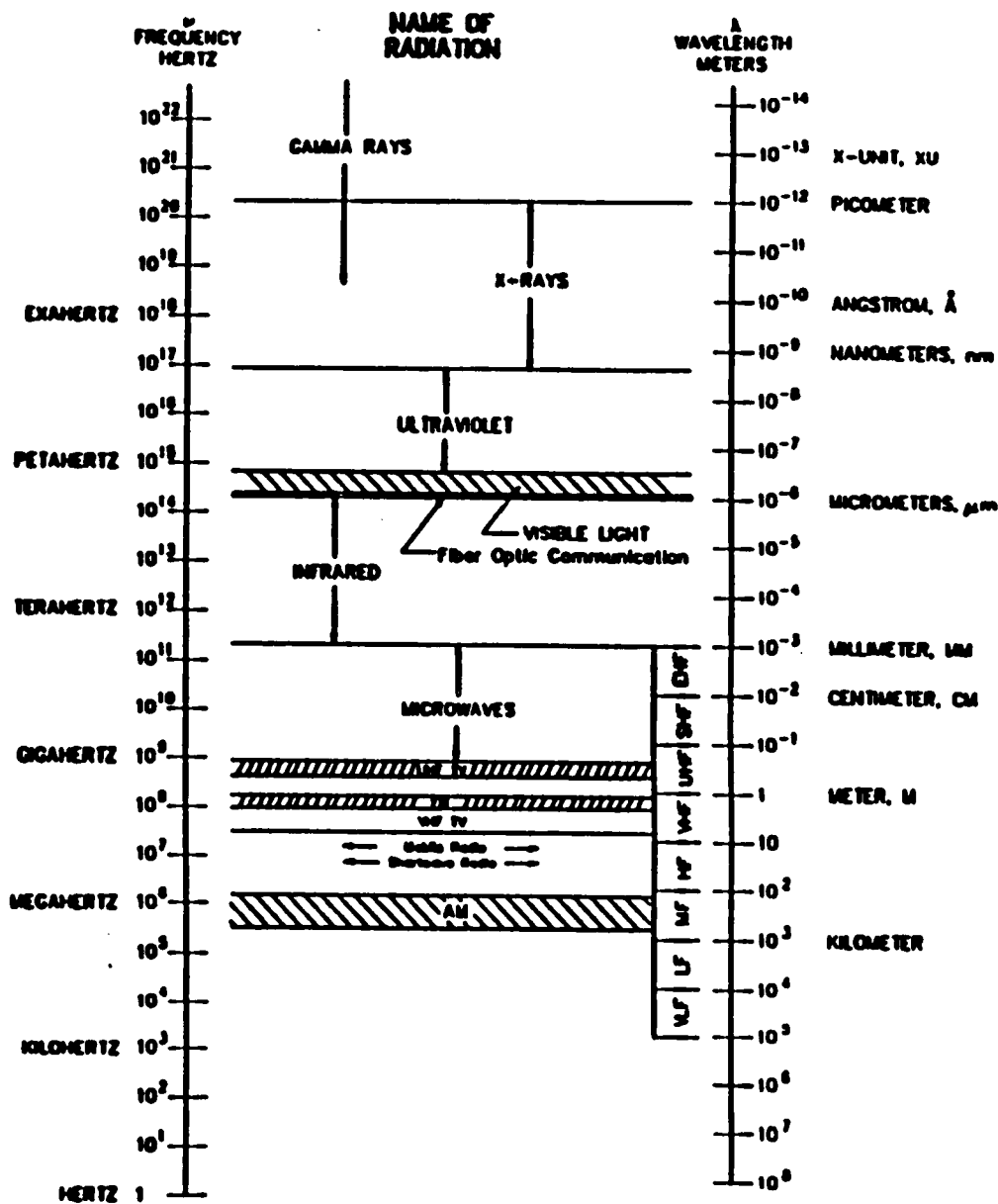


Figure 2-1
ELECTROMAGNETIC ENERGY SPECTRUM (4)

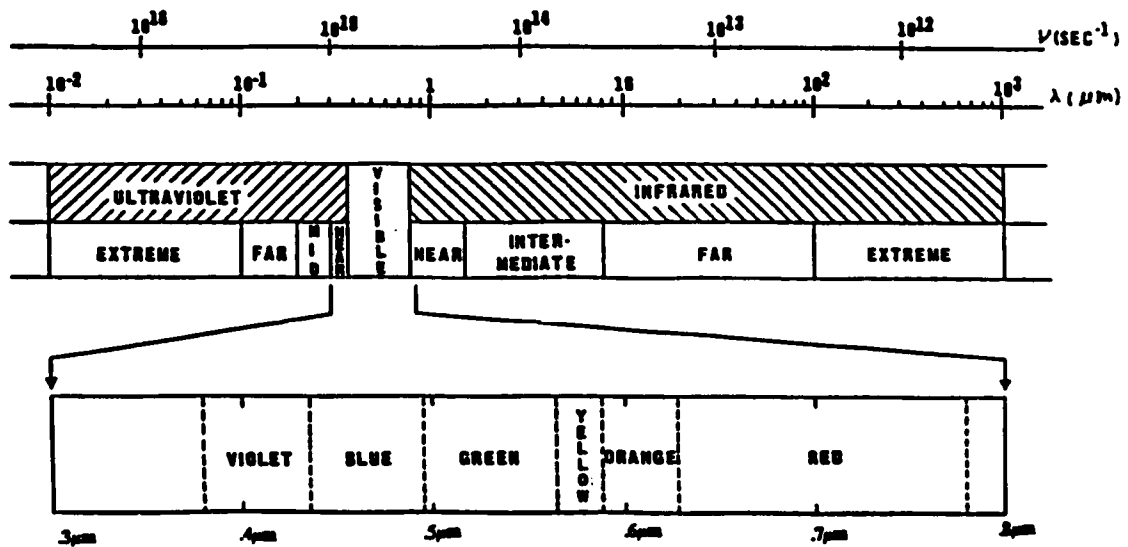


Figure 2-2
IR, VISIBLE, AND ULTRAVIOLET SPECTRUMS (3)

The near IR and visible light regions are dominated with reflected and scattered energy, while the mid and far IR regions are dominated with emitted thermal energy at nominal terrestrial temperatures (6). Image intensifiers (I^2) and thermal detectors (FLIR) have been developed to detect, process, and display in a visible form the energy in these latter two regions.

RADAR

The first "imaging device" employed in military aviation was a radar bombsight used extensively during World War II for strategic bombing. Quite crude by present standards, it did

permit a non-precision delivery of bombs at night, or through cloud cover. Aircraft interception during darkness also began in World War II with the inception of air-to-air radar systems, which despite their limited capabilities, were used by both the Allies and the Luftwaffe with modest success.

Since World War II, radar systems, both air-to-ground and air-to-air, have been steadily improved and employed in a wide variety of strategic and tactical aircraft. Highly sophisticated radar systems are responsible for the majority of U.S. present day all-weather capabilities (1).

IMAGE INTENSIFIER THEORY

The tendency of objects to reflect visible and near IR energy within the electromagnetic spectrum is the fundamental concept upon which I² devices are designed. In simple terms, image intensifiers take this reflected light energy, amplify it, and display the intensified image to the pilot. The luminance of the I² image depends both on the luminance of the image source and the transmission efficiency of the optical system (7). As shown in Figure 2-3, reflected light from terrain features are enhanced in the near IR spectrum in the region of approximately 0.6 to 1.2 micrometers (microns) which benefits present NVG technology which is sensitive to light in the 0.6 to 0.9 microns range. (Note: From this point forward, "micron" refers to the wavelength of electromagnetic energy measured in "micrometers")

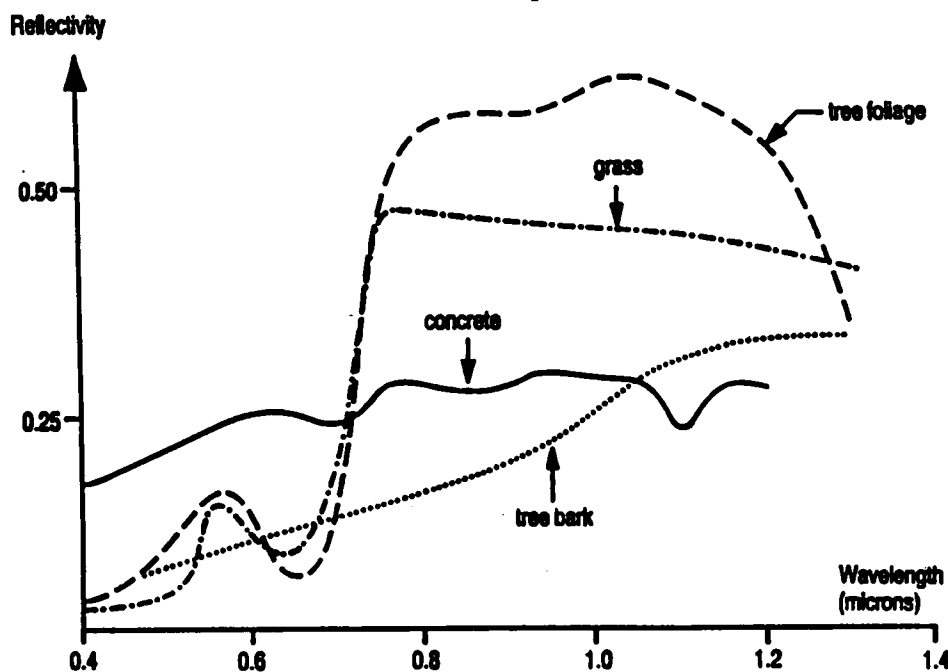


Figure 2-3
REFLECTIVITY OF OBJECTS

Light intensifier tubes have been developed that operate within the electromagnetic spectrum between the ranges of 0.6 to 0.9 microns. The basic concept of the current design is a set of tubes which capture photons of ambient light and bombard them against a photocathode which emits electrons proportional to the amount of light energy striking it. The electrons are accelerated away from the photocathode by an electronic field energized by a high negative charge. The electrons then pass through an electron multiplier called a microchannel plate. The MCP consists of several million fiber optic channels coated with an emissive lead material which releases secondary electrons. This not only multiplies the electrons, but accelerates them towards a phosphor screen

which recreates the image with the multiplied electrons for viewing. A simple diagram is shown in Figure 2-4.

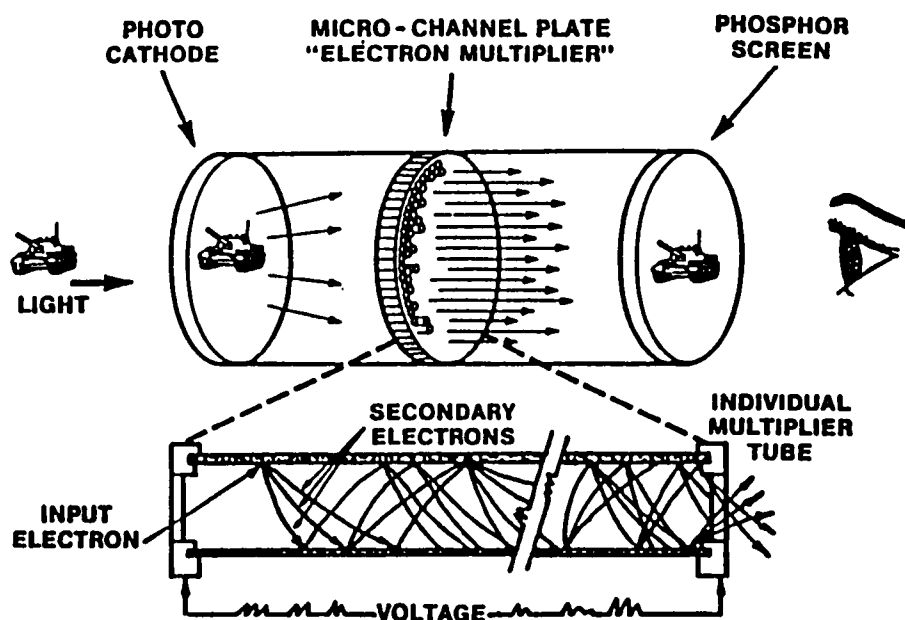


Figure 2-4
SIMPLE ILLUSTRATION OF AN IMAGE INTENSIFIER (I^2) TUBE (8)

As previously stated, current third generation I^2 devices are sensitive to electromagnetic energy in approximately the 0.6 to 0.9 micron wavelengths. This includes a portion of the visible light spectrum which can adversely affect the performance of NVGs. Therefore, cockpit lighting must be NVG compatible to avoid undesired amplification of light within the cockpit which precludes the ability of NVGs to respond to ambient light levels in the environment. In 1986 a military specification, MIL-1-85762, "Lighting, Aircraft, Interior, Night Vision Imaging Compatible," was developed to resolve night vision compatible cockpit lighting problems (9). All

NVG compatible cockpit lighting must be blue-green or below in the visual spectrum to be in compliance with MIL-L-85762. An optical dielectric cutoff filter has been incorporated into most modern NVGs that filter out the blue-green light and thus allow for compatible cockpit lighting. Figure 2-5 shows the typical human eye day and night, and the second and third generation (Gen II and Gen III - discussed in the next section) intensifier response curves. The dielectric cutoff filter positioned at 0.625 (Type A) or 0.665 (Type B) microns, which is incorporated into Gen III NVGs to allow for compatible cockpit lighting, is also depicted.

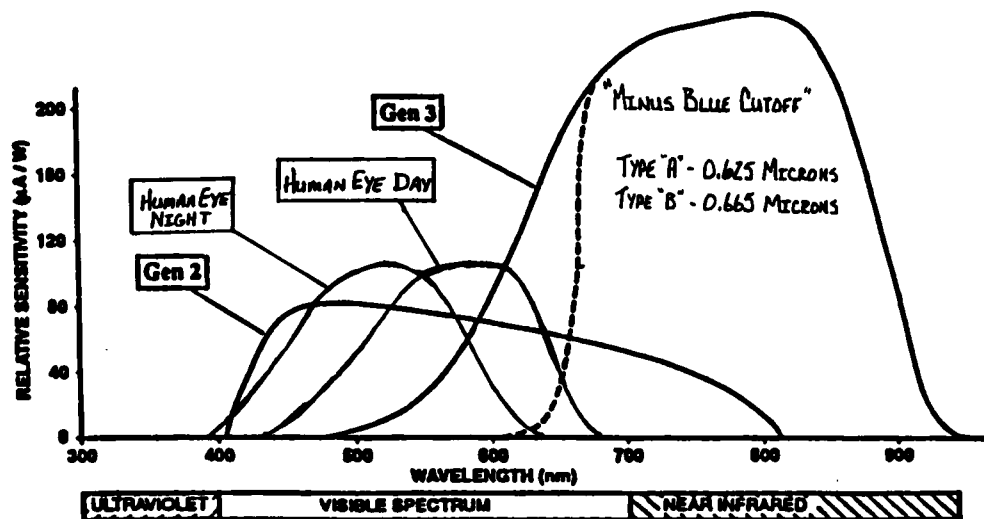


Figure 2-5
HUMAN EYE DAY AND NIGHT, AND SECOND AND
THIRD GENERATION INTENSIFIER TUBE RESPONSE

IMAGE INTENSIFIER HISTORY

As previously stated, the earliest devices which provided night vision were the IR sniper scopes which had the disadvantage of requiring a covert IR light source for illumination (irradiation). In the 1960's the "first generation" (GEN I) I^2 device saw limited aviation service during the Vietnam War, primarily in Forward Air Control (FAC) aircraft. These devices were capable of intensifying ambient illumination and did not require a separate source of IR energy as had the WW II infrared scopes. Gen I I^2 tubes, shown in Figure 2-6, utilized a three stage cascade amplifier process to amplify and accelerate the electrons to the phosphor screen yielding a nominal gain.

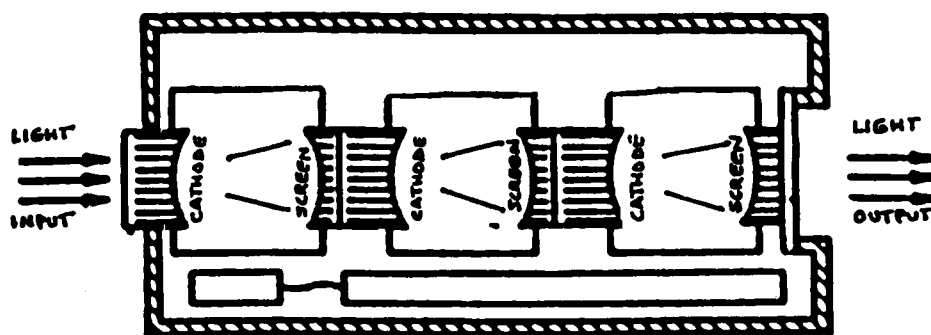


Figure 2-6
FIRST GENERATION IMAGE INTENSIFIER TUBE

In the early 1970's, as a result of evolving semiconductor technology, second generation (GEN II) NVGs

became available. Intended for ground troops, primarily truck and tank drivers, they were binocular in design, head mounted and much smaller and lighter than the first generation devices. The second generation tubes used a Micro-Channel Plate (MCP) which consisted of approximately a million fiber optic channels compacted into an 8 mm wafer. The performance of the second generation I² tubes, shown in Figure 2-7, were not as good as the first generation tubes, but were smaller, lighter and had a lower power requirement. The first experimental attempts to exploit these NVGs for aviation occurred at least as early as 1971, but it was not until 1975 that their true potential was recognized and they were adopted for cockpit use (1).

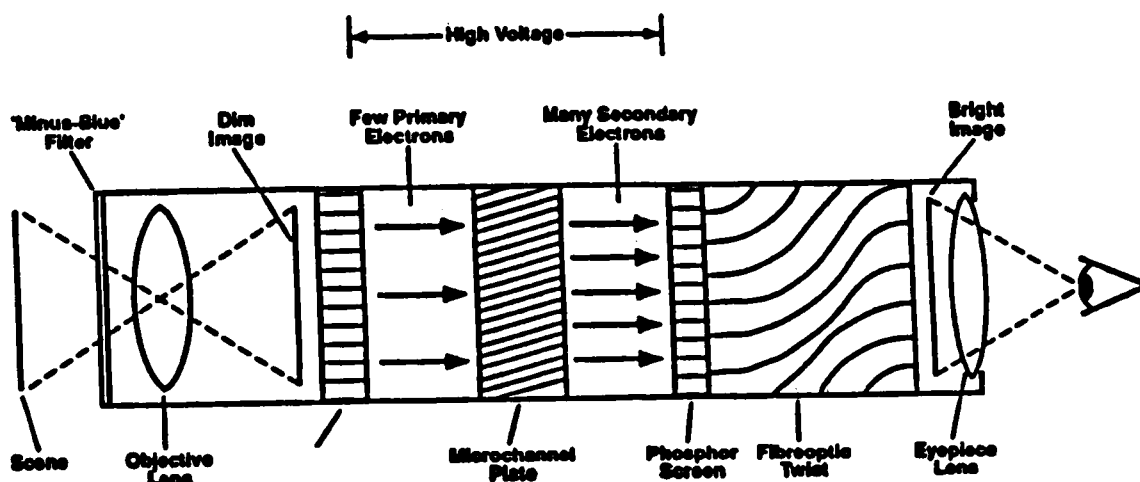


Figure 2-7
SECOND GENERATION IMAGE INTENSIFIER TUBE

The third generation (GEN III) NVGs appeared in the early 1980's in response to desires for a compatible NVG designed

specifically for aviation (helicopter) use. The Aviator's Night Vision Imaging System (ANVIS), AN/AVS-6 goggles used the new third generation I² tubes that improved the gain and resolution of the previous GEN I and GEN II tubes (1). GEN III tubes incorporated gallium arsenide (GaAs) in the photocathode and improvements in the MCP. They had a much improved helmet mount, provided much better response in the 0.6 to 0.9 micron range, and had considerably greater capability at lower light levels than GEN II goggles. Now available in a variety of different designs for different applications and aircraft types, the GEN III tubes have proven to be acceptable in nearly all facets of military aviation (10).

Night vision goggles are classified as either type I or type II as depicted in Figure 2-8.

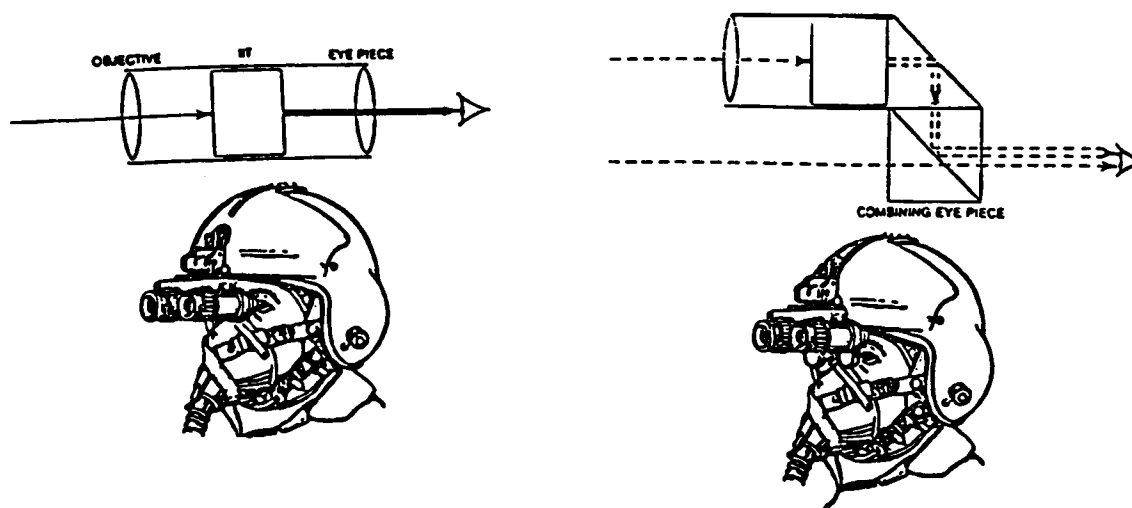


Figure 2-8
TYPES OF THIRD GENERATION NIGHT VISION GOGGLES

The type I, typified by ANVIS, has "direct view optics and are used primarily in helicopters. The ANVIS goggles, as depicted in Figure 2-9 have a flip up feature to enable normal unobstructed unaided field of view (FOV). With the goggles in the down position the goggles provide an aided field of view (FOV) of approximately 40 degrees.

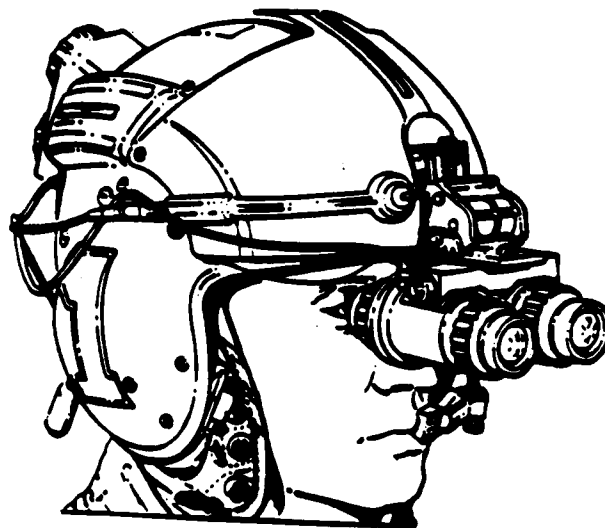


Figure 2-9
ANVIS NIGHT VISION GOGGLES

The type II design incorporates a folded optical pathway and utilizes a combiner block to present the image to the eye. The type II design was developed for fighter/attack jet aircraft to permit direct viewing of FLIR imagery presented in a heads up display (HUD). A direct viewing capability is essential in some aircraft because the HUD is not visible with NVGs (a function of wavelength of the HUD phosphor). Without the direct viewing capability, a pilot would be forced to look around the goggles to see the HUD.

Another important advantage of the Type II design is the fact that the combiner is not only relatively transparent, it is significantly smaller than the tube assembly and thus results in less obstruction of the unaided FOV. This particularly enhances the pilot's ability to see inside the cockpit to monitor essential flight instruments, an especially important feature in the high speed, highly dynamic flight regime of fighter/attack aircraft. The GEC Avionics Cats Eyes, depicted in Figure 2-10, are the most widely used type II goggle.

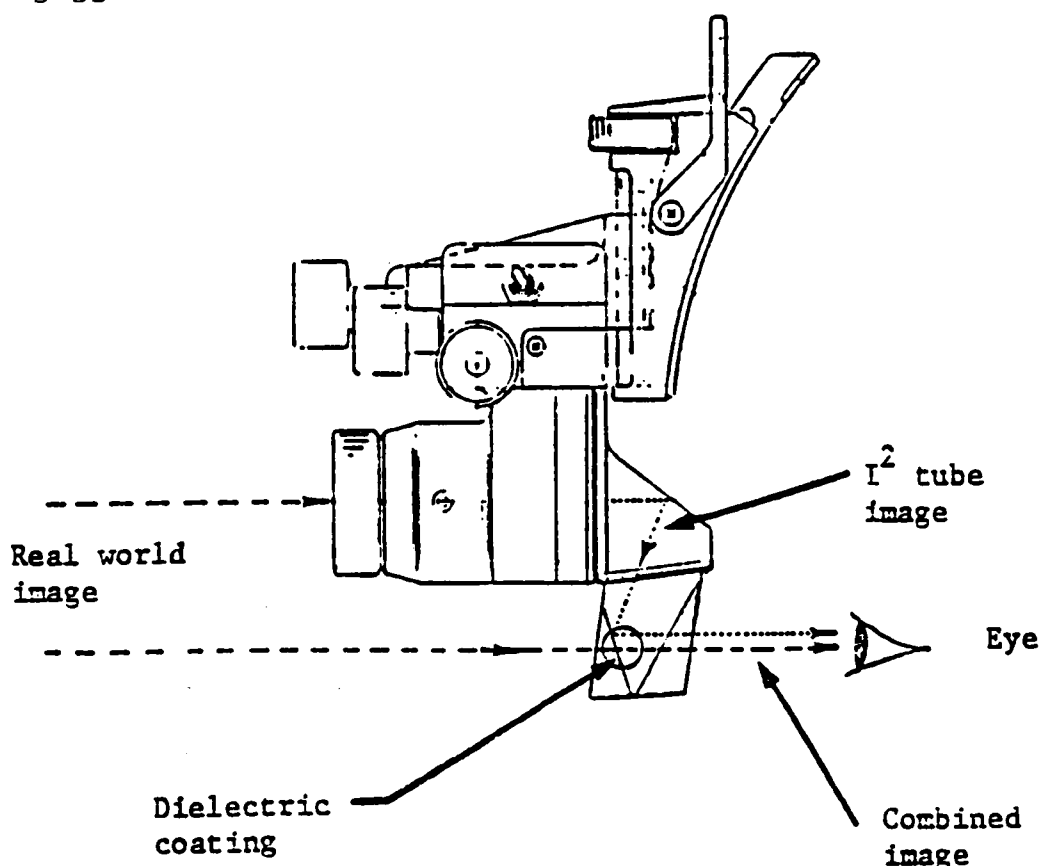


Figure 2-10
CATS EYE NIGHT VISION GOGGLES

THERMAL DETECTION THEORY

The other primary group of night imaging devices, forward looking infrared (FLIR), emerged during the Vietnam era and utilized a completely different type of technology. NVGs image visible light and near IR energy reflected from the surface of objects (reflective contrast). FLIR technology is based on the fact that all objects warmer than absolute zero emit "heat" in the form of IR energy. The rate of emission, or radiation of this thermal energy differs depending upon the composition of the object. In large part and in simple terms, thermal energy is absorbed during daylight hours and dissipated during night hours. Atmospheric conditions including cloud cover and ambient air temperatures affect the thermal differences and thus the radiance at which the thermal scenes can be viewed. A FLIR image is simply a computer generated picture based upon the differences in the rate of emission of IR energy by the objects in the scene (thermal contrast).

FLIR is capable of discriminating between adjacent objects with temperature differences of as little as one deg F, and can even differentiate objects of the same temperature if they emit energy at different rates. FLIR systems, like radar, are much larger and heavier than NVGs, necessitating that they be aircraft mounted as opposed to helmet mounted.

Atmospheric conditions greatly affect the transmittance and detection capability of the thermal scene. Water

molecules are the primary contributor to the absorption of thermal energy and as such determine the "windows" within the electromagnetic spectrum where IR detection is the best. Atmospheric transmittance is based on the following equation.

$$E = T_a (I/R^2)$$

where

- E = Irradiance of source at distance R
- I = Radiation Intensity of source
- R = Distance between source and location of measurement of irradiance
- T_a = Atmospheric transmittance (< unity)

As shown in Figure 2-11, 3 to 5.5 and 8 to 12 microns provide the best windows for detection. In general, the 3 to 5.5 micron window is degraded most by haze and the 8 to 12 micron window is degraded most by humidity (11).

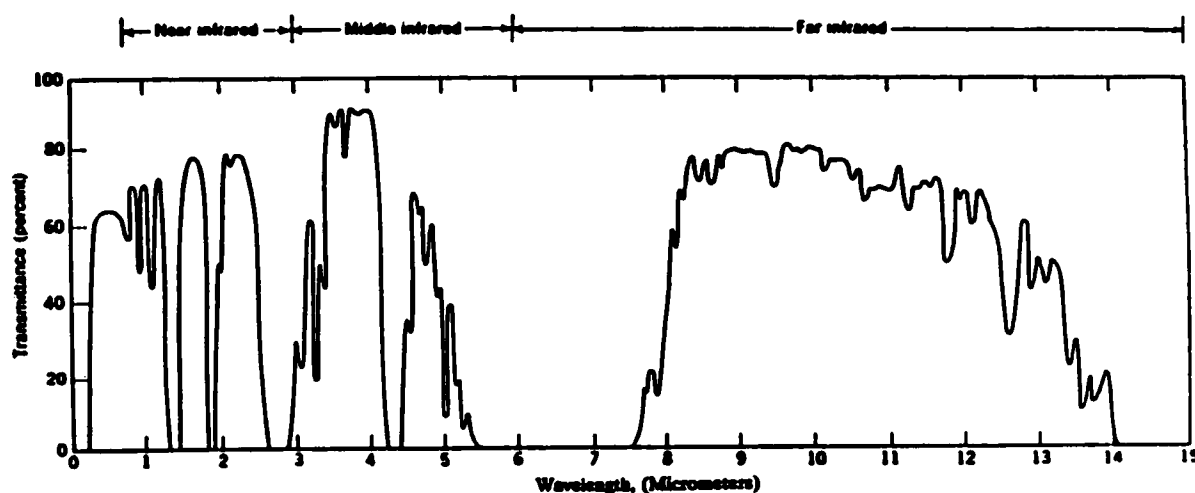


Figure 2-11
ATMOSPHERIC TRANSMITTANCE (IR WINDOWS) (4)

NVG/FLIR INTEGRATION

Because NVGs and FLIR detectors are sensitive to energy of different wavelengths (visible light and near IR of 0.6 to 0.9 microns for NVGs versus far IR at 8 to 12 microns in the case of FLIR), and the atmospheric transmission of energy varies as a function of its wavelength, the two types of systems are complimentary. That is, each can function well under certain conditions in which the other does not. For instance, NVGs are much more effective in humid conditions, and FLIR is much more effective in conditions of smoke, haze, or brownout. Having both systems is highly desirable because it affords a capability which is much greater than that provided by either system alone.

Both NVGs and FLIR have monochromatic images and are limited in resolution and FOV, all of which constitute significant deficiencies when compared to normal day vision. For instance, monochromatic imagery obviates the use of color contrast, an important modality for object detection and recognition.

CHAPTER III

NVG CHARACTERISTICS AND PHENOMENA

GEC Cats Eye NVGs possess certain specific visual characteristics related to their limited resolution, FOV, and automatic gain control. In addition the near IR energy to which NVGs are most sensitive has somewhat different properties as compared to visible light. These factors combine to produce certain effects, limitations and illusions not ordinarily encountered with unaided vision. NVG effects include limitations in estimating or judging altitude, distance, object clearance, aircraft closure rates, terrain or object obscuration, and undetected meteorological conditions (12).

RESOLUTION

Although resolution can be described in a number of ways, visual acuity facilitates comparisons in operational terms and is the terminology with which most people are familiar. The best visual acuity with NVGs is usually about 20/40, however, these levels of acuity are characteristic of relatively high levels of illumination that are rarely achieved in the cockpit. It is important to remember that visual acuity of 20/40 is only one half as good as normal 20/20 day vision, but is five times better than the best unaided night vision (20/200 to 20/400 depending upon the illumination level).

Lower light levels are more frequently encountered in actual operational conditions, but goggle acuity can also be adversely affected by incompatible sources of cockpit lighting and/or windscreen transmission losses. Even under laboratory conditions, goggle performance will be degraded enough to yield only about 20/80 vision at a light level equivalent to mean starlight.

Although the vision afforded with NVGs or FLIR provides a significant enhancement in operational capability, the acuity provided does not permit the employment of true daytime tactics. This is because the limitations in resolution have an adverse effect on altitude, distance and depth perception, as well as target detection and identification ranges. For example, an object visible at 20 kilometers with 20/20 vision would not be seen beyond 10 kilometers with 20/40 acuity or beyond 5 kilometers with 20/80 acuity (1).

Tests conducted by the Naval Air Developmental Center (NADC) identified an effect which alters the pilot's perception of distance when viewing a FLIR image through the HUD with NVGs. Both the FLIR and NVGs are registered one to one with the outside world; however, the fact that these images are displayed in front of the pilot's eye at a given distance can create a condition known as instrument myopia as shown in Figure 3-1. In order to accommodate the image on the FLIR and NVGs, the eye perceives the displayed image as being further away than it actually is (13).

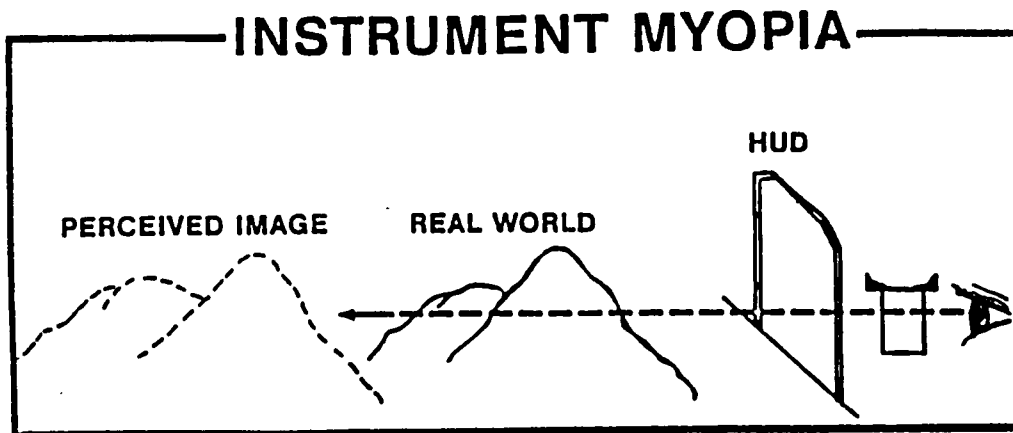


Figure 3-1
INSTRUMENT MYOPIA

FIELD OF VIEW

Currently available NVGs typically have a circular FOV ranging from 30 to 40 degrees. This is much less than the roughly 200 degrees horizontal by 120 degree vertical FOV afforded by the unaided eye. Since spatial orientation is primarily a function of peripheral vision, the limited FOV of NVGs significantly affect this capability (1).

To compensate for the deficient FOV, a pilot using NVGs must maintain an aggressive scan to increase the effective field of regard (FOR). An effective scanning technique is essential for maintenance of good situational awareness, spatial orientation and altitude awareness (12). However, the specific physiologic costs of this active scan include increased pilot task loading and physical fatigue (1).

ALTITUDE, DISTANCE, AND DEPTH PERCEPTION

Judgements of distance and depth are made with visual cues ordinarily categorized as either binocular or monocular. Binocular cues include stereopsis (vision in both eyes), vergence (tendency of both eyes to focus at a single point), and accommodation (the automatic adjustment of both eyes when focusing on object at various distances). The majority of depth perception with NVGs is presumably derived from monocular cues such as relative size, motion parallax (relative motion), size and shape constancy, interposition, texture gradient, and linear perspective. Size constancy, particularly of familiar cultural objects, is an especially powerful cue. Most monocular cues are degraded by the limited visual acuity afforded by NVGs. The result is a significant decrease in distance and depth perception compared to normal day vision, particularly at lower light levels where goggle resolution is reduced .

Problems of distance and depth perception are compounded by anything which negatively impacts resolution or contrast of the scene. Common examples are water, snow covered or low contrast terrain, low ambient illumination, unfavorable moon position, dense cultural lighting, and incompatible cockpit lighting resulting in increased canopy glare.

Water is virtually invisible to NVGs unless there is some surface texture present (boat wakes, whitecaps, spray, etc.). A frequent cause of spatial disorientation with NVGs has been

the reflection of stars by water. There have also been situations where pilots have seen through still water to the bottom of a shallow lake without detecting the presence of the water itself. With rare exception, flight over water must be conducted as if the aircraft were in instrument meteorological conditions (IMC) while incorporating an altitude buffer between the aircraft and surface.

It is well known to aviators that, even in daylight, terrain which is uniformly covered with snow usually provides insufficient cues for effective altitude or distance estimation. With NVGs the problem is aggravated by the limited resolution of the intensified imagery. Quite the opposite effect can occur if there are sufficient rocks, trees, or other features protruding through the snow cover. The high contrast of the dark winter vegetation set against the snow white ground can greatly enhance perception of altitude and distance (14). However, unless clearly discernible objects providing adequate size constancy cues are present, a mission flown over snow covered landscape will need to be conducted as if in IMC.

Other low contrast terrain, such as desert with limited foliage, may also provide inadequate cues for effective distance estimation. This is particularly true in the Arabian Desert where there are large areas almost totally devoid of any significant features or contrast. Even worse, the horizon and terrain are often obscured by fine sand and particulate

matter suspended in the lower atmosphere. Visibility can be very marginal in the daytime and almost nonexistent at night. Again the limited resolution of NVGs, especially at lower light levels, exaggerates this problem.

Flight from a well illuminated area into a shadow can pose a specific hazard if the aviator fails to recognize that a marked change in the light level has occurred. Foreshadowing, the obscuration of near terrain by a more distant ridge or mountain when flying toward a low lying sun, has long been recognized as a significant hazard during daytime (primarily at dawn or dusk). This same effect is even more likely, and much more treacherous, during NVG flight toward the moon when it is positioned at a relatively low angle above the horizon, or flight toward bright skyglow during twilight.

Although lower light levels of illumination are much more frequently involved, very high light levels can also cause a degradation of resolution. Because GEN III tubes are designed to maximize performance in low light, there is a tendency for the image to "wash out," or lose contrast at high light levels. The result is a very bright image with reduced contrast compared to the imagery obtained at lower light levels.

In addition to this loss of contrast, some tubes possess fixed pattern noise, or "honeycomb" (also apparent at high light levels). In a situation with well illuminated, highly

reflective, but low contrast scenery, there may be so little contrast in the image to the terrain that it can't successfully compete with the honeycomb. In this instance the terrain actually becomes invisible until objects or features with greater contrast are encountered.

Anything which increases contrast will tend to improve distance and depth perception. Foliage is particularly effective because chlorophyll is highly reflective to near IR energy, especially in comparison to dirt, concrete, pavement, or rocks. Even small bushes and deciduous trees are readily distinguishable as a consequence of the chlorophyll content of their foliage. However, size difference between bushes and trees are generally not so apparent. There is a relative deficiency of obvious identifying characteristics for vegetation of different sizes, and this can create a very misleading size constancy illusion if the aircrew is unfamiliar with the area. The tendency is to fly at an altitude that makes the vegetation look about the same size as it ordinarily does. Particularly hazardous is flight over terrain covered with trees, because the inclination is to fly low enough to make the bushes appear as large as trees (12).

NIGHT ILLUMINATION

To provide a better understanding of illumination and how it is measured, it is necessary to first define (15) the following terms:

1) Illumination (lux): The act of illuminating or state of being illuminated. Commonly referred to as the measure of luminance an object supplies or reflects.

2) Candela: A unit of luminous intensity equal to $\frac{1}{60}$ of the luminous intensity per square centimeter of a blackbody radiating at the temperature of solidification of platinum (2,046 deg K).

3) Luminance: The luminous intensity per unit projected area of a given surface viewed from a given direction and has the units of one candela per square meter (cd/m^2).

4) Lumen (lm): The unit of luminous flux in the International System, equal to the luminous flux emitted in a solid angle of one steradian by a uniform point source having an intensity of one candela.

5) Lux: The International System unit of illumination, equal to one lumen per square meter (lm/m^2).

With a basic understanding of these definitions one can derive that the luminance, or luminous flux, produced or reflected by an object is measured in "lax". It has been determined that an average of 0.0022 lax is the minimum illumination that must be present to safely maneuver aircraft in close proximity to the ground at night. This minimum requirement is not available by the light level produced by nature alone (starlight, airglow, zodiacal light, etc.) without the presence of sufficient moonlight. To attain the minimum light level or greater the moon must be at a

sufficient level of illumination, phase, and/or angle above the horizon. Figure 3-2 graphically depicts the light levels or "night illumination" based on moon phase and angle.

The "Light Level Planning Calendar" is one of several computer programs developed to graphically depict the light level present throughout the moon cycle. The program produces a graphic printout of the illumination present at desired locations worldwide for any desired month. The printout is based on moon phase, illumination, and angle above the horizon only and does not take into account the decreased light level present as a result of clouds, overcast layers, haze, smoke, dust, and other causes of reduced acuity. For this reason aviators must rely on their own experience to determine sufficient light levels for safe flight in reduced lighting conditions when moon phase and angle are sufficient. A light level planning calendar computer printout is shown in Figure 3-3.

The luminance of an area based on moon position or cultural lighting can have a very negative effect on scene resolution and altitude and distance perception. This effect is a function of the NVG auto-brilliance control which is a feature designed to maintain constant image luminance. Any bright light source will result in a reduction of goggle gain sufficient to keep the total image brightness within preset limits thereby making it difficult to distinguish the distance to objects due to reduced illumination.

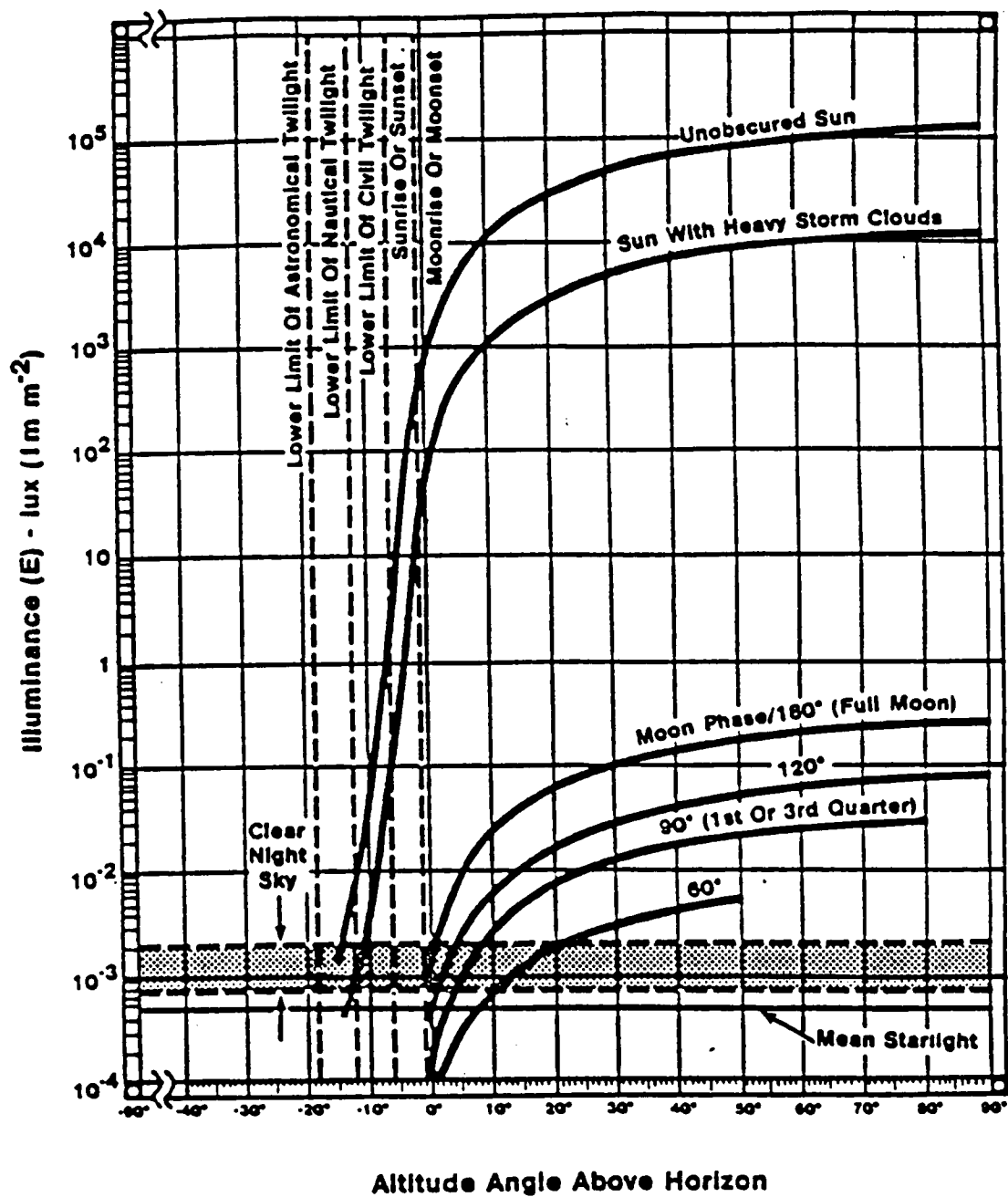


Figure 3-2
ILLUMINANCE BASED ON MOON PHASE
AND ANGLE ABOVE THE HORIZON

Start: 1 Dec 1994 1700
 Step: 31 Dec 1994 0800
 Time Zone: -5 CDT/EST

Daylight Savings Time: NO
 Boundary Value = 0.0022 lux

Lat: 38°17.3'
 Long: 76°25.0'
 Var: 10.0"W

For	Moon	Sun	Min	1700	1800	1900	2000	2100	2200	2300	2400	0100	0200	0300	0400	0500	0600	0700	0800	For	Moon	Sun
PM on	R/S	set	2400																	AM on	R/S	rise
1 Dec	S1552	1641	1%	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	2 Dec	R0629	0709
2 Dec	S1647	1641	0%	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	3 Dec	R0736	0710
3 Dec	S1748	1641	2%	XXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	4 Dec	R0836	0711
4 Dec	S1854	1640	7%	XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	5 Dec	R0929	0712
5 Dec	S2002	1640	14%	XXXXXXXXXXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	6 Dec	R1014	0713
6 Dec	S2109	1640	23%	-----XXXXXXXXXXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	7 Dec	R1054	0714
7 Dec	S2215	1640	33%	-----+++++++XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	8 Dec	R1128	0715
8 Dec	S2317	1640	43%	-----+++++++XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	9 Dec	none	0716
9 Dec	none	1640	53%	-----+++++++XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	10 Dec	S0016	0716
10 Dec	R1231	1640	63%	-----+++++++XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	11 Dec	S0112	0717
11 Dec	R1301	1641	72%	-----+++++++XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	12 Dec	S0210	0718
12 Dec	R1332	1641	80%	-----+++++++XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	13 Dec	S0306	0719
13 Dec	R1404	1641	87%	-----+++++++XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	14 Dec	S0401	0719
14 Dec	R1440	1641	93%	++++-----XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	15 Dec	S0456	0720
15 Dec	R1518	1641	97%	++++-----XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	16 Dec	S0548	0721
16 Dec	R1601	1642	99%	++++-----XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	17 Dec	S0639	0721
17 Dec	R1649	1642	100%	++++-----XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	18 Dec	S0726	0722
18 Dec	R1740	1642	99%	#####++++-----XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	19 Dec	S0810	0723
19 Dec	R1835	1643	96%	#####++++-----XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	20 Dec	S0850	0723
20 Dec	R1932	1643	91%	#####++++-----XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	21 Dec	S0927	0724
21 Dec	R2031	1644	84%	#####++++-----XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	22 Dec	S1001	0724
22 Dec	R2132	1644	76%	#####++++-----XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	23 Dec	S1034	0725
23 Dec	R2233	1645	67%	#####++++-----XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	24 Dec	S1107	0725
24 Dec	R2336	1645	56%	#####++++-----XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	25 Dec	none	0726
25 Dec	none	1646	45%	#####++++-----XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	26 Dec	R0042	0726
26 Dec	S1219	1647	34%	#####++++-----XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	27 Dec	R0148	0726
27 Dec	S1258	1647	24%	#####++++-----XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	28 Dec	R0257	0727
28 Dec	S1342	1648	15%	#####++++-----XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	29 Dec	R0406	0727
29 Dec	S1432	1649	7%	#####++++-----XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	30 Dec	R0514	0727
30 Dec	S1528	1649	2%	#####++++-----XXXXXXXXXX#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	31 Dec	R0617	0727
Date	R/S	Sun	Min																	Date	R/S	Sun
		set	2400	1700	1800	1900	2000	2100	2200	2300	2400	0100	0200	0300	0400	0500	0600	0700	0800			rise

.... indicates Sun above horizon ##### indicates Moon below horizon
 ---- indicates the Moon is at least 20 percent illuminated and at least 30 degrees above the horizon
 ++++ indicates Moonlight Level greater than or equal to 0.0022 lux but moon not 20% illum or not 30 deg above horizon
 XXXX indicates Moonlight Level less than 0.0022 lux and moon not 20% illum or not 30 deg above horizon or neither

Figure 3-3
 LIGHT LEVEL PLANNING CALENDAR

Moon position is especially critical when larger areas of its surface are illuminated. If looking towards the moon or an area of dense cultural lighting, the light source(s) will be very prominent but the resolution of any unlit objects or terrain will be adversely affected and they may even be partially or totally obscured. Altitude and distance estimation can be profoundly impaired, or nonexistent. As previously stated, an identical effect can occur when flying toward highly reflective terrain under conditions of high ambient illumination. Less reflective or shadowed features may not be visible at all.

Moon position also has another important effect on scene definition which is related to terrain shadowing. With the moon at or below the horizon it, of course, provides no illumination. This condition is termed "mean star light." When the moon is positioned overhead, there will be few if any shadows, and terrain features may be much less apparent. This effect is especially noticeable with low contrast terrain when the moon is full, or nearly full. Given the right combination of conditions, all perception of contour may be lost, producing an illusion of perfectly flat terrain, when in fact there may be quite a bit of vertical development.

There is a tendency for bright, red or IR light sources to be particularly confounding in distance estimation. Because of the sensitivity of NVGs, the relative brightness of a light source in an intensified image tends to give the

impression that the light is much closer than it really is. This effect is a particular problem in judging distance or closure rates of other aircraft because the lights are visible at much greater distances than the actual aircraft, particularly in low light conditions. The distance estimation error in this situation may be on the order of tens of kilometers. Flight in shadows tends to enhance these light source effects, because of the increase in goggle gain which occurs in response to the reduction in total scene illumination. Experienced aircrew learn to look around the goggles to view light sources with their unaided vision in order to better determine the correct distance to the source.

Situations in which there are significant differences in the illumination or reflectivity of different parts of a scene is termed obscuration. Portions of a scene less lit or less reflective will be relatively poorly visualized. Even in a situation with uniform lighting, smaller objects and anything which has very low contrast or reflectivity may not even be visible, especially if the overall level of illumination is not good.

Shadowing and foreshadowing is a very common and potentially dangerous cause of obscuration. This is because nighttime shadows contain very little light (illumination equivalent to mean star light or less) in comparison to shadows experienced during daylight. GEN II NVGs are especially limited in their performance in shadows. A number

of mishaps have occurred as a consequence of flight or descent into an area of shadowing with the subsequent loss of visual references.

UNDETECTED METEOROLOGICAL CONDITIONS

Since NVGs are primarily sensitive to near IR energy, and the near IR is poorly reflected by moisture, a particular hazard exists when flying in weather conducive to the formation of clouds or fog. Dense clouds or fog are readily apparent with aided vision, especially clouds silhouetted against a clear sky. However, thin clouds or fog may actually be invisible with NVGs, because not enough energy is reflected from their surface to create an image in the goggles. Of more significance, if the terrain is obscured by unseen clouds, collision with the ground can and has occurred.

WINDSCREEN TRANSMISSIVITY

The transmission of IR energy by windscreens and cockpit windows can be a significant problem. Designed to transmit visible light, many cockpit transparencies do not perform as well in the near infrared spectrum, and the transmissivity of some are very poor. Since NVGs (particularly GEN III) are primarily sensitive to near IR energy, this can result in a serious reduction in goggle performance. Like the decreased visual performance resulting from incompatible cockpit lighting, the effect of decreased windscreen transmissivity may not be apparent to the aircrew.

MOUNTING AND ADJUSTMENT PROCEDURES

In addition to the many extrinsic factors which influence NVG performance, mounting and adjustment errors are both common and capable of producing significant losses in visual performance. Optimal vision with NVGs cannot be obtained unless the optical axes of the tubes are precisely aligned with the optical axes of the eyes. Unfortunately, it is common to find situations in which the helmet mount and/or the aviator's adjustment procedures have resulted in an incorrect positioning with a significant loss in visual acuity and depth perception.

Misadjustment of either the objective focus or diopter adjustment can also produce seriously deficient vision. It is therefore imperative that proper mounting and adjustment procedures be followed in order to prevent a potentially serious degradation of visual performance.

NVG fitting, adjustment, and preflight assessment are the single most important phase of training. The importance of precise and correct positioning and focusing of NVGs, and the physiological inability of the visual system to quantitate acuity without an appropriate resolution target has already been emphasized. Research demonstrates that only about 30% of experienced aircrew adjust their NVGs well enough to achieve nominal acuity (20/40) without using an effective resolution chart in a controlled environment. Vision of 20/60, 20/80 or worse is more common. Cats Eye NVGs can be adjusted fore and

aft, up and down, tilted, and the interpupillary distance (IPD - Spacing Between The Eyes) can be set as shown in Figure 3-3.

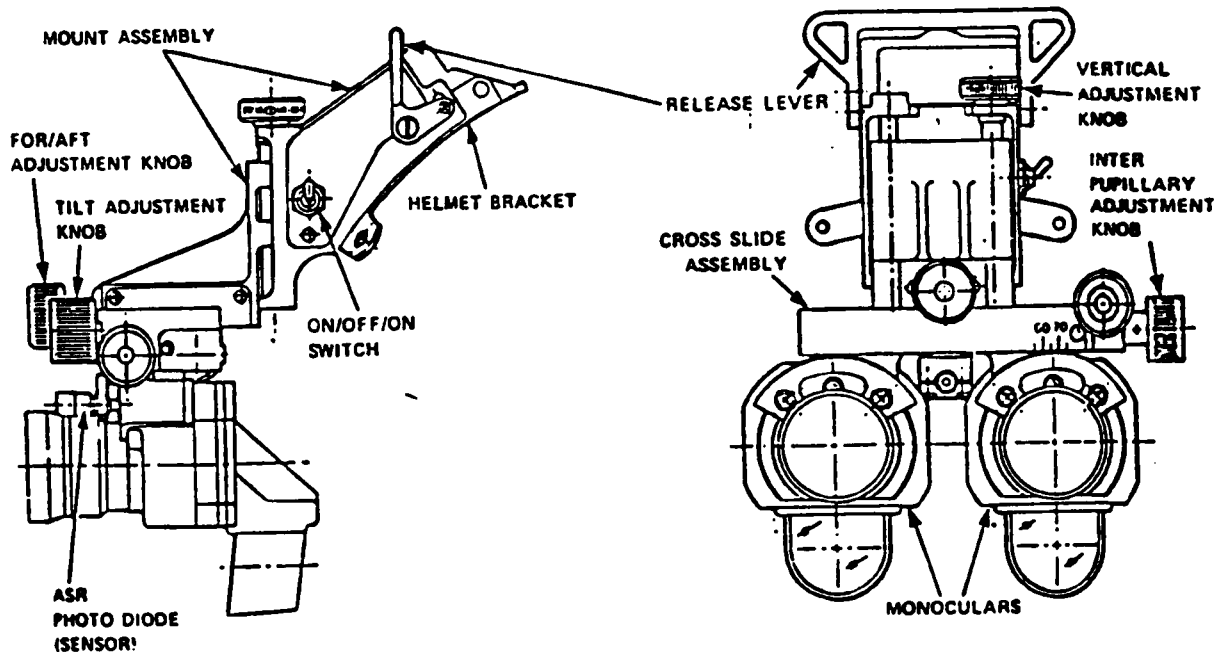


Figure 3-4
CATS EYE ADJUSTMENTS

The resolution chart depicted in Figure 3-4 is composed of nine square wave gratings which are equivalent to an acuity range from 20/35 to 20/100. The gratings are randomly arranged in either a vertical or horizontal orientation, and the chart can be rotated to any of four positions.

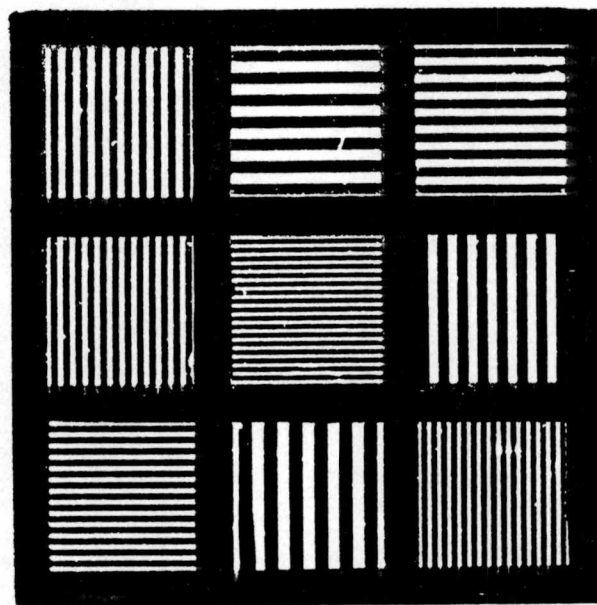


Figure 3-5
VISUAL RESOLUTION CHART

The concept is to periodically change the orientation of the chart, and thus the position and orientation of the individual grids, so the aviators do not become accustomed to a particular pattern. Acuity is determined by counting the number of grids that can be seen well enough to determine the orientation of the lines. For example, seeing 8 of the 9 grids is indication of an acuity of 20/40, seven grids is equivalent to 20/45 vision, etc.

NVG DEMONSTRATION LAB

The NVG demonstration lab uses a terrain board in a dark room to demonstrate the effects of different moon phases, elevation and azimuth; various lighting effects including cultural lighting; and to illustrate the differences between

normal and low contrast terrain and water. The terrain board and dark room combination has proven particularly effective, because many effects can be demonstrated very dramatically by simply changing the position or intensity of illumination while aircrew watch with NVGs. Experience has shown that this modality is even more convincing than a similar presentation utilizing actual intensified imagery on video.

SUMMARY

There are a tremendous variety of NVG misperceptions and illusions. In general, any effect experienced during daylight can and many times also occur during NVG use. However, with NVGs the image intensification process tends to intensify the illusions as well as the ambient light. In addition to the more familiar daytime phenomena are the NVG specific effects related to the properties of near IR energy and the limited resolution, FOV, and the goggle automatic gain control. Of these factors, resolution and the effects of automatic gain control are the most influential.

Among the environmental factors, low ambient illumination, poor terrain contrast and light source effects are easily the most important. Any deficiency in goggle performance which affects vision will have an effect on susceptibility to misperceptions and illusions. Additionally, incompatible cockpit lighting, helmet mounting problems and misadjustments also attribute to reduced acuity and perception. Their effect on visual performance is often not

recognized, and because the resulting degradation of vision has the potential of enhancing virtually all other illusions and misperceptions.

CHAPTER IV

TEST PILOT SCHOOL CURRICULUM

The prospective Test Pilot/WSO/Engineer, many of whom have never been exposed to NS, must be fully aware of specific hazards that exist when NS are evaluated and used operationally. As such, extensive academic briefs and test pilot school standard operating procedures (SOP) must be developed to ensure the NS evaluation exercise is conducted in the safest possible manner.

Evaluation/Demo flights must be developed which include such factors as target and aircraft characteristics, terrain features, and the contrast between prospective targets and their backgrounds. The methodology must also stress the human factors aspects of the man-machine interface, especially display size, image quality, and the effect of interior and exterior aircraft lighting on night vision devices.

SOP/SAFETY REQUIREMENTS

Obvious hazards exist any time aircraft are operated in close proximity to the ground. Aircrew concentration on flight tasks during maneuvering flight is paramount since any unrecognized downward deviation in flight path angle can be catastrophic. The reduced visual cues available during night operations greatly multiply these hazards and as such must be strictly addressed.

To ensure the safe operation of the night systems evaluation exercise, it is necessary to develop standard operating procedures (SOP) that enable the exercise objectives to be met in a safe and timely fashion. In recent years various test and operational organizations that operate aircraft with NS have developed detailed operating procedures (16,17,18,19,20,21,22) based on the hazards associated with NS characteristics and phenomena. Such procedures are also based on lessons learned from past incidents and accidents. Researching operating procedures from test and operational organizations alike enable the development of procedures tailored to the operations characteristic of test pilot schools to be assessed from a broad prospective.

Night system standard operating procedures are guidelines which dictate not only aircrew currency, crew rest, and designation requirements, but also weather, lumination, and altitude restrictions and requirements as well. Therefore, since most prospective evaluators likely have limited knowledge of NS characteristics and phenomena, the SOP should begin with several basic definitions associated with test pilot school specific NS operations. The Standard Operating Procedures developed for test pilot school specific requirements is outlined in the following sections and presented in Appendix A.

NVG Aircrew Qualification/Training Requirements

Test Pilot School instructors designated NVG aircrew must be knowledgeable of not only the hazards involved with operating on night vision goggles, but the characteristics and phenomena that affect their use. Additionally, realizing that the low altitude maneuvering of jet aircraft at night is a very dynamic environment, it is imperative that designated NVG aircrew have sufficient tactical jet experience to ensure safe low altitude operations.

With the advent of reduced operating budgets for test pilot schools worldwide, it is unlikely that multiple jet aircraft equipped with NVG compatible cockpits will be available to execute an NVG exercise. At best, a few sufficiently equipped aircraft of a single type (example: F/A-18 at the U.S. Naval Test Pilot School) will be available. Additionally, the opportunity to select instructors who are NVG qualified in the type aircraft to be utilized during the exercise is not likely.

With these thoughts in mind, a step-by-step qualification process is necessary to ensure sufficient safety margins exist. Aircrew should first and foremost be fleet experienced tactical jet aviators with a minimum of 100 hours in the type aircraft the exercise is to be conducted. Following these minimum flight requirements aircrew may then receive a basic NVG qualification (NVGQ) following an approved operational or in house training syllabus. To ensure aircrew have been

sufficiently exposed to the many hazards presented in previous chapters, aircrew should also receive safety training available at NVG demonstration labs equipped with an eye lane and terrain board. The in house training syllabus should be patterned after fleet training but be limited to the high altitude environment (i.e. above 3,000 ft AGL). The initial qualification should also limit flight to a minimum of 3,000 ft AGL to ensure sufficient aircrew familiarization with the NS environment. Once a minimum of 10 hours on NVGs has been acquired and a "High Altitude" standardization flight has been flown, aircrew may then receive the NVGI(H) designation (NVG Instructor Qualified [High Altitude - >3,000 ft AGL]) which allows the aircrew to instruct exercise events above 3,000 ft AGL. The high altitude designation should be maintained until 25 hours NVG time has been attained and a "Low Altitude" standardization flight has been flown. Aircrew may then receive an NVGI qualification (NVG Instructor Qualified [Low Altitude - >500 ft AGL]). Table 4-1 summarizes the NVG instructor qualification requirements.

Table 4-1
NVG INSTRUCTOR QUALIFICATION REQUIREMENTS

TYPE	QUALIFICATION	TRAINING	MINIMUM ALTITUDE (AGL)
NVGQ	Fleet Tactical Air Experienced	Fleet Qualified With 2 IUT Flights	3,000
	Minimum Exercise Aircraft Time: 100 Hours	Completed Fleet Training With 1 IUT Flight	
	Completed NVG Demonstration Lab Simulation	4 Flight IUT Training Syllabus Complete (Tab A)	
NVGI (H)	NVGQ Requirements Met	"High" Altitude NVGI Stan Flight Complete (TAB A)	3,000
	Minimum NVG Time: 10 Hours		
NVGI	NVGQ Requirements Met	"Low" Altitude NVGI Stan Flight Complete (Tab A)	500
	Minimum NVG Time: 25 Hours		

Aircrew Currency And Crew Day Requirements

Once NVG instructor qualified, aircrew must maintain a minimum level of currency to ensure the continual safe operation of aircraft during NS instruction. As such the following criteria should be strictly adhered to:

- * Minimum of 1 day flight in the evaluation aircraft in the previous 15 days.
- * Minimum of 1 NVG flight in the evaluation aircraft within the previous 30 days to act as NVGI/NVGI(H).

Additionally, aircrew flying low altitude evaluation flights should have:

- * Flown approved low level route during daylight hours within the previous 60 days to operate on NVGs below 3,000 ft AGL.

Due to the limited flight responsibilities of the prospective evaluators (students) on the evaluation flight there should be no minimum requirements established.

Crewmembers involved in NVG operations should closely monitor their crew rest and be cognizant of the degrading effects in performance associated with changes in circadian rhythm during the shift to and from night operations. The following limitations shall be observed by all crewmembers participating in NVG operations.

NVG Instructors:

- * 12 hrs max from first scheduled event to final land time.
- * 12 hrs from land time to first scheduled event the following day.
- * Instructor aircrew should not be scheduled for more than 4 consecutive nights involving NVG operations.

Students:

- * 15 hrs max from first scheduled event (class or flight) to final land time with no flight the following day.

All Crewmembers:

- * Maximum of 2 flights per day when involved in NVG operations.

Weather Requirements

As previously discussed NVG performance is degraded based on the deterioration of ambient light conditions. Weather conditions shall be thoroughly assessed prior to any NVG flight. Areas of fog or rain shall be avoided whenever possible regardless of moon phase. Overcast conditions, rain,

fog, and blowing dust can severely degrade NVG performance and should be briefed, approached, and treated as a mean starlight or inadvertent IMC condition, whichever is applicable. Weather minimums are established as follows:

- * Operations above 3,000 ft AGL
 - Normal school SOP night minimums.
- * Operations below 3,000 ft AGL
 - School SOP night minimums to include:
 - 3000/5 along entire low (<3,000 ft AGL) altitude portion of the flight.

* **Note:** Ceilings can reduce ambient light conditions to unacceptable levels regardless of moon phase and elevation. NVG flight may continue beneath broken or overcast ceilings at the discretion of the Pilot In Command. In no case will NVG flights be conducted with weather observed or measured at less than 3000/5.

Moon Conditions

The NVG Light Level Planning Calendar Computer Program should be used to determine percent of lunar illumination, angle of the moon above the horizon, and LUX level for all flights involving NVG operations. The data obtained from this program must be tempered with sound judgement since the program does not adjust for the degrading effects of cloud cover, humidity, haze, dust, smoke, low moon angle, terrain, and shadowing on the operation of the NVGs. The following ambient light and lunar condition requirements should apply.

* Operations above 3,000 ft AGL

- No minimums.

* Operations below 3,000 ft AGL

- Minimum 0.0022 LUX.

Preflight Planning/Briefing Items

In addition to the normal preflight planning procedures outlined in most aircraft operating flight manuals and the NVG briefing guide, the following additional requirements should be mandatory:

- * Careful review of the route of flight will be conducted to identify areas of known sources of bright ambient lighting conditions. These areas should be avoided whenever possible.

- * Possible hazards to flight including power lines, towers, significant terrain, and towns should be thoroughly briefed prior to flights utilizing local low level routes.

- * The following is a summary of the required briefing items:

- NVG donning and doffing procedures.
- NVG operation and adjustments.
- Location and operation of aircraft interior and exterior lighting systems.
- NVG failures.
- Bird strike
- Radar altimeter usage
- Emergency procedures during NVG operations.
- Pertinent astronomical data (sunset, moonrise, moonset, moon angle, moon azimuth, predicted ground illumination)
- Depth perception, visual illusions, physiological effects.
- Crew coordination during NVG operations.

- Course rules.
- Hotseat procedures.

Preflight/Prelaunch Procedures

In addition to the aircraft flight manual preflight and prelaunch procedures, the following NVG procedures should apply:

- * Engage and disengage CATS EYES NVGs to helmet several times to ensure disengagement can be performed quickly and easily. There should be no binding present during disengagement. Ensure both batteries supply sufficient power. Inflight NVG "Donning" and "Doffing" procedures and crew coordination must be briefed.

- * With NVGs attached to the helmet, adjust NVGs to the optimum position. Adjust tubes for proper distance between the eyes, proper distance from each eye, elevation, vertical alignment and focus prior to the take off point.

- * Protective caps for NVG lenses should not be carried in the cockpit to reduce the potential of Foreign Object Damage (FOD).

- * While preflighting the cockpit, ensure all NVG lights are operable and that filters are installed and not distorted.

- * When not being worn, NVGs should be stored in the NVG case. At no time should the NVGs be put into or taken from the cockpit when not inside the carrying case.

- * An operable flashlight should be a part of each aircrew member's personal survival equipment. While an NVG filter is desirable in flight, aircraft preflight is hindered by the dim blue-green light. Preflight with NVG filtered flashlight is not advisable. A standard white or red lens flashlight is acceptable for use in flight, recognizing that usage is incompatible with the NVGs, providing care is taken not to adversely affect the NVGs of the pilot at the controls.

Taxi/Takeoff Procedures

Taxiing with NVGs may be conducted at the instructor pilot's discretion. Takeoffs while wearing NVGs is not

recommended and should be prohibited. Inform tower of NVG operations especially if taxi with the taxiway lights out is desired. Tower will accommodate lighting requests for the airfield whenever possible. Prior coordination is normally required for most airfields, particularly if exclusive use of the airport traffic area is desired.

Enroute Procedures

All crew members must be equipped for flight with operable NVGs. Except for conducting normal donning and doffing procedures, NVG flight operations should not be conducted until both crewmembers are configured with operating and properly adjusted NVGs. For the purposes of demonstration, an instructor may have the other crew member secure NVG operation momentarily. The following procedures should be adhered to:

- * The minimum altitude to Don/Doff NVGs should be 1,500 ft AGL for low altitude flight and 3,000 ft AGL for high altitude flight. Baro altitude hold, if available, should be selected and a minimum airspeed of 250 KIAS should be maintained during the Donning/Doffing procedure.

- * Constant two-way ICS communication must be maintained between all crew members while conducting NVG operations.

- * If ambient lighting or NVG performance degrades to the point where critical aircraft performance or attitude parameters (altitude, airspeed, vertical speed and attitude) can not be determined accurately and confidently, the NVG phase of the flight should be terminated.

- * If at any time either crew member is not certain of aircraft performance parameters, if either crew member's interpretation of visual phenomenon critical to safe operation is not clear, or if either crew member becomes disoriented, an immediate wings level climb to a safe flight envelope should be initiated.

* Minimum enroute airspeed should be 250 KIAS. This airspeed provides enough energy to zoom climb in the majority of tactical jet aircraft, remove goggles, and eject if necessary.

* Formation flight should be prohibited except in situations where an emergency aircraft requires an external configuration check. If such a situation arises, extreme care should be utilized during the rendezvous to ensure aircraft closure rates are controlled.

Simulated Weapons Delivery Procedures

VMC weather restrictions should apply for all types of simulated weapons deliveries. Due to the high potential for target fixation while operating with NVGs, all simulated air to ground delivery profiles must be thoroughly briefed prior to flight. The aircraft software radar altimeter setting should be positioned at 10% below release altitudes if available. NVG air-to-ground deliveries should be limited to the profiles in Table 4-2.

Table 4-2
MINIMUM SIMULATED WEAPONS DELIVERY PROFILES

Dive Angle (degrees)	Min Roll-in (ft AGL)	Min Release Alt (ft AGL)	Min Alt (ft AGL)
0	500	500	500
15	4000	2000	1000
30	10000	5500	3000
40	12000	8000	4000

To perform simulated deliveries, an NVGI(H) or NVGI designated pilot should be present in the aircraft. In no

case should the aircraft descend below the minimum altitude of the NVGI qualified pilot (500 or 3,000 ft AGL). Extreme care should be exercised during pop-up (15 deg) dive and normal dive deliveries. Should any disorientation occur, an immediate abort should be required.

Over Water Operations

Due to the greatly reduced depth perception cues incurred during flight over non reflective terrain such as water, the minimum altitude during extended low altitude over water flight operations should be 1,000 ft AGL.

Landings

Landings with airfield lights secured should be allowed when light level is at a minimum of 0.0022 lux. A low altitude pass down the runway with the landing light on should be made prior to performing touch and go landings to ensure the landing area is clear.

Ejection

Because ejection while wearing NVGs is prohibited, absolute coordination between crew members is required. Prior to takeoff, command ejection shall be set in the briefed position and remain there for the entire flight. Ejection procedures should be reviewed at the "hold short" position, including discussion of where each crew member will throw their goggles in the event of ejection. In the event of an immediate ejection situation, the call "GOGGLES, GOGGLES,

GOGGLES" should be made prior to any "EJECTION" call. In a controlled ejection situation, every attempt should be made to stow NVGs in the protective case to avoid possible injuries.

NVG Instructor Training Syllabus

A pilot instructor under training (IUT) new to NVG flight, without previous instructor qualifications or with less than 25 hours NVG time should complete the IUT training syllabus. These flights should be flown with a qualified NVG instructor pilot. The IUT should demonstrate proficiency in each familiarization (FAM) flight before proceeding to the next flight. The syllabus consists of 4 flights for a total of 6 hours of NVG flight.

NVG/DEMONSTRATION LAB PRE-BRIEF

Prospective evaluators must be familiar with the numerous NVG characteristics and phenomena and their effects on aircraft target engagement capabilities. Specifically, NVG resolution, FOV, and FOR need to be fully understood as do the reduced altitude, distance, and depth perception cues. Additionally, the effects of weather and undetected meteorological conditions as well as the effects of lumination on visual acuity should be well defined. Aircraft interior and exterior lighting, canopy glare and transmissivity need to be presented to give the prospective evaluators the tools they will need to adequately assess new technological developments as they come on line.

To ensure NVG hazards are easily recognizable, the night demonstration lab should also be incorporated into the initial NVG evaluation syllabus. The terrain board that "Nite Labs" use to display the effects of moon angle and illumination, and the effects of cultural lighting give the prospective evaluators a first hand view of potentially dangerous effects prior to actual flight.

With these thoughts in mind the initial NS brief should expose the prospective evaluators to NVG characteristics, lighting requirements and phenomena, and prepare them for the "Nite Lab" simulation. The "Pre-Brief" handout and briefing overheads are presented in Appendix B and outlined below.

- * Purpose -- To introduce NVG specific terms, characteristics, and phenomena, and to provide exposure to NVG terms and factors that affect their use.

- * Principle Of Operation -- Amplify "Reflected" light energy

- * NVG History

- Starlight Scope
- Gen I
- Gen II
- Gen III

- * Current NVG Types

- Type I (ANVIS)
- Type II (Cats Eyes)

- * Cats Eye Adjustments

- * Image Intensifier Details

- IIT Housing
- Photocathode
- Microchannel Plate (MCP)
- Phosphor Screen
- Collimating Lens/Combiner

- * Illumination
 - Natural Light Sources
 - } Moon
 - } Airglow
 - } Starlight
 - } Zodiacal Light
 - } Gengenschein
 - } Aurora
 - } Noctilucent Clouds
 - Other Light Sources
 - } Cultural Lighting
 - } Head/Tail Lights
- * Interior and Exterior Cockpit Lighting Requirements
- * Moon Factors
 - Moon Phase, Elevation, Azimuth
- * Effects of Light
- * Illusions
 - Scintillation
 - Fog
 - Depth Perception
 - Shading
 - Edge Glow
 - Bright Spots
 - Dark Spots
 - Honeycomb
 - Instrument Myopia
 - Shadowing
- * Atmospheric Conditions
 - Clouds
 - Indication Of Clouds
 - Fog
 - Blowing Sand And Dust
- * Terrain Features
 - Luminance
 - Contrast
 - Poor Contrast
 - Texture
 - Water
- * Human Factors Concerns
 - NVG Comfort And Fit
 - External/Internal Eye And Head Movement
 - FOV/FOR Analysis
 - Neck Strain/Fatigue
 - NVG Adjustment

NVG EVALUATION EXERCISE

The evaluation exercise should be centered around the ability to use passively (NVG and FLIR) and actively (Radar) detect emissions within the electromagnetic spectrum. Focusing on the electromagnetic spectrum reinforces both the advantages and disadvantages and the specific capabilities of both passive and active systems. Most test pilot schools have exercises centered around Radar and FLIR systems; therefore, the exercise should incorporate both to show how they compliment each other, but be centered around NVG characteristics, phenomena, and test requirements.

NVG Evaluation Exercise Brief

The academic environment typical of Test Pilot Schools worldwide do not always allow exercises to coincide with the background information obtained during academic classes or informational briefs like that presented in the previous section. Weeks, or in some cases months, may pass before an exercise is conducted following the academic preparation. As such, some information may require repeating to ensure the prospective evaluators are adequately prepared to conduct the exercise. Additionally an NVG exercise may linger over several months since there may only be 8 to 10 nights a month where the desired illumination is sufficient ($> 0.0022 \text{ lax}$) to conduct low altitude NVG operations.

The exercise brief should begin with an overview of the electromagnetic spectrum, concentrating on the limited portion

that lends itself towards passively detected emissions. A complete understanding of the visible portion of the spectrum and the wavelengths that produce various colors is important to the overall understanding how the NVGs are designed to enhance certain wavelengths while inhibiting the passage of others. Since the exercise is designed around the entire spectrum, an overview of why FLIR systems are designed to operate within a specific portion of the far IR portion of the spectrum should be presented. The absorption of common gases (H_2O , CO_2 , etc.) and the IR "windows" they create is a key requirement in FLIR design. Basic FLIR design and different types also expose the prospective evaluator to various designs and how they are used by the operator.

Next, basic NVG illumination requirements, specifically the moon and its phases, need to be reviewed. The light level planning calendar, based on moon phase, azimuth, and elevation should be presented.

A basic understanding of how different objects reflect light, specifically in the near IR portion of the spectrum, will give the prospective evaluators a basic understanding of why NVGs operate within the 0.6 to 0.9 micron range. A review of NVG history and how current NVG technology enhances ambient light should then be presented. Since the evaluation is concentrated on NVG capabilities to enhance ambient light levels in the visible and near IR portions of the spectrum, NVG phenomena and limitations should also be reviewed.

With a basic understanding of how NVG technology has evolved from the starlight scope to current systems that incorporate radars to actively process cm wavelength emissions and NVG and FLIR systems to passively process 0.6 to 0.9 and 8 to 12 micron wavelength emissions, the prospective evaluators should begin to look into the future at systems each may one day be evaluating. One such concept might be a system that incorporates a helmet tracking system connected to a line of sight turret which is capable of processing and fusing together FLIR and I² images and presenting them to the aircrew via an integrated visor (23). An example of the conceptual design is presented in Figure 4-1.

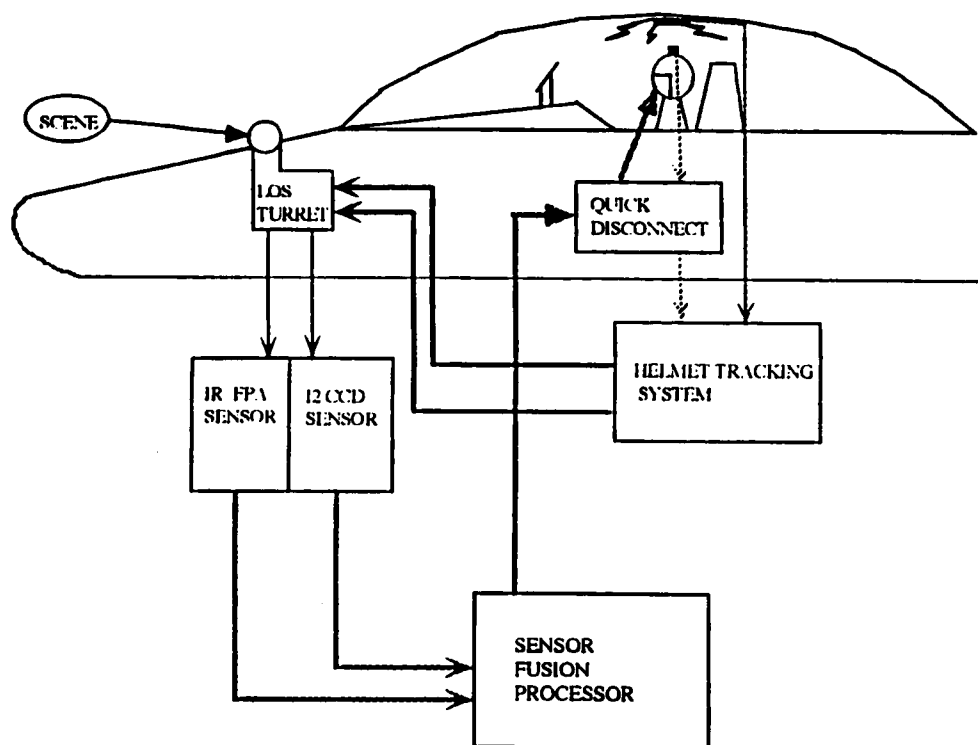


Figure 4-1
CONCEPTUAL NIGHT VISION DESIGN (23)

The "Evaluation Brief" handout and briefing overheads are presented in Appendix C and outlined below.

- * Electromagnetic Radiation Spectrum Overview
- * Optical Spectrum
- * Frequency Band / Wavelength Overview
- * Visible And IR Spectrums
- * FLIR / IR Spectrum Requirements
 - Atmospheric Absorption By Common Gases
 - IR "Windows"
 - Affect Of Water Vapor On Atmospheric Transmissivity
 - Simple FLIR System
 - FLIR System Types
- * NVG / Visible and Near IR Spectrum Requirements
 - Moon Factors
 - Light Level Planning Calendar
 - Illumination Of The Moon
 - Spectral Reflectivity Of Objects
- * NVG History / Concept Of Operation
 - Starlight Scope
 - Gen I Series Intensifiers
 - Gen II Series Intensifiers
 - Gen III Series Intensifiers
 - ANVIS
 - Cats Eyes
 - Comparisons
 - Cats Eye Adjustments
- * NVG Image Intensifier Details
 - Photocathode Function
 - Microchannel Plate Function And Design
 - Phosphor Screen Function
 - Collimating Lens / Combining Optics
- * NVG Phenomena
 - Shading
 - Edge Glow
 - Bright Spots
 - Dark Spots
 - Honeycomb
 - Windscreen / Canopy Transmissivity
 - Instrument Myopia
 - Shadowing

- * Human Eye, Second And Third Generation IIT Response
- * Exploitation Of The Electromagnetic Spectrum
Based On Current Technology
- * Future System Possibilities
 - Simple Helmet Tracking System
 - Dual Sensor
 - Conceptual Night Vision Design
 - Integrated Helmet Technology
 - Example Of A Fused Image

NVG Evaluation Exercise Flight

The evaluation flight should use the previously presented technological advancements that allow use of passively and actively detected emissions within the electromagnetic spectrum (i.e. radar, FLIR, NVG). Utilizing these systems to prosecute simulated air-to-ground and air-to-air targets gives the prospective evaluators a first hand look at the systems individual and combined capabilities. Additionally, NVG helmet interface, interior and exterior aircraft lighting requirements, windscreen / canopy transmissivity, and NVG FOV and FOR can be qualitatively evaluated for their effect on mission tasks throughout the evaluation flight.

The prospective evaluators will have the opportunity to see the importance of properly adjusted NVGs and practice adjustment procedures. They should also ensure that they are able to quickly don and remove the NVGs in the event of an emergency. Finally, the importance of comfort and fit can be assessed during all flight regimes including maneuvering flight where aircraft longitudinal accelerations can exceed seven g's.

Interior and exterior cockpit lighting configurations and the effect of cockpit lighting intensities and incompatible warning and caution lights can be assessed. Additionally, light leaks and readability of control and displays can be evaluated for their effect on mission tasks. Canopy and windscreen transmissivity and glare from cockpit lights can greatly affect the amount of external light transmitted to the NVGs for amplification.

Specific NVG characteristics such as FOV and FOR can be assessed for mission suitability. Blooming, comet trails, scintillation, honeycomb effects, and other NVG phenomena can be assessed for their effect on NVG resolution at various altitudes, airspeeds, and g loadings.

Each of the varying requirements, characteristics, and phenomena will be assessed during high or low altitude flights. Whether a high (> 3,000 ft AGL) or low (> 500 ft AGL) flight is flown will depend on weather or instructor qualification as outlined in the NVG standard operating procedures. Each flight is included as an enclosure in the exercise briefing handout presented in Appendix C.

CHAPTER V

CONCLUSIONS

Night systems (NS) are playing an ever increasing role in the warfighting capabilities of armed forces world wide. NS developed for airborne use were defined as any system primarily designed or utilized to enhance a crewmember's ability to operate his aircraft utilizing VMC techniques during periods of darkness. The ability to see and therefore maneuver at night through technological advancements in Forward Looking InfraRed (FLIR) and image intensification (I²), specifically night vision goggle, devices has lead to the development of unique offensive and defensive tactics.

Although initially used exclusively in helicopters, NVGs are now seeing service in all types of military aircraft. As NS technology for use in aircraft has evolved, so has the desire to augment existing and future designs with the ability to prosecute enemy targets from passively detected emissions within the electromagnetic spectrum that cannot be detected by the naked eye at night. Cockpit and system display designers must now meet specification requirements for NVG compatible cockpit and external lighting, windscreens, and displays. As such, evaluation specifications and requirements of the NS themselves and the aircraft and cockpits in which they are used must be assessed to ensure fleet aircrew have the best

and safest systems current technology can make available. At present, an instructional test program to expose prospective evaluators to night system requirements, characteristics, and phenomena in tactical jet aircraft is non-existent.

This thesis briefly illustrated NVG theory and history, outlined specification and test criteria, and presented a complete test pilot school curriculum to expose prospective Test Pilots, Weapons System Operators, and Engineers to NS test techniques with an emphasis on NVGs, and NVG/cockpit lighting compatibility. Extensive academic briefings and test pilot school standard operating procedures were developed to ensure the night systems evaluation exercise is conducted in the safest possible manner. The integration of NS into the total aircraft weapon system was addressed. A methodology for addressing NVG specific questions were developed which included such factors as target and aircraft characteristics, terrain features, and the contrast between prospective targets and their backgrounds. The methodology stressed the human factors aspects of the man-machine interface, especially display size, image quality, and NVG compatibility. Finally, an evaluation/demonstration flight was developed which exposed the prospective evaluator to NVG phenomena, hazards, and operational requirements, and the NS assessment techniques many may use during their flight test careers.

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APPENDICES

APPENDIX A
TEST PILOT SCHOOL STANDARD OPERATING PROCEDURES

**TEST PILOT SCHOOL
STANDARD OPERATING PROCEDURES**

GENERAL

1. The enhanced night systems associated with NVG compatible aircraft create unique physiological and environmental concerns which must be recognized and addressed to ensure that mission parameters are developed in an organized and safe manner. Accordingly, this section provides guidance and standardization to optimize training and exercise instruction while strictly adhering to the highest standards of aviation safety.

DEFINITIONS

2. Cats Eyes - NVGs employing third generation intensifier tubes and "see through" technology designed for use with the HUD / FLIR display. Cats Eyes are the only NVGs authorized for use by aircrew in most jet aircraft.

3. Circadian Rhythm - Normal daily cycle of over 50 physiological functions, affected by approximately 40 environmental variables, which tend to regulate each individual to function at their peak during the day.

4. Degoggle - The act of removing NVGs from a crewmember's helmet and/or returning them to the stowed position.

5. Donning - The act of connecting NVGs to a crewmember's helmet.

6. LUX - A measure of illumination; specifically the illuminance produced from the flux of one lumen against a surface. LUX levels may restrict the conduct of Night Systems (NS) operations under certain conditions.

7. Night Systems (NS) - Any system primarily designed or utilized to enhance a crewmember's ability to operate his aircraft utilizing VMC techniques during periods of darkness. For the purpose of this order, NS shall include but not be limited to NVG and FLIR devices.

8. Night Vision Goggle Qualified (NVGO) - An instructor pilot that has met all of the flight requirements and applicable academic and flight training requirements as delineated in section III.

9. Night Vision Goggle Instructor Qualified (NVGI) - An instructor pilot who is qualified to instruct exercise events as delineated in section III to a minimum altitude of 500 ft AGL.

10. Night Vision Goggle Instructor "High" Qualified (NVGI(H))
- An instructor pilot who is qualified to instruct exercise events as delineated in section III to a minimum altitude of 3,000 ft AGL.

NVG AIRCREW QUALIFICATION/TRAINING REQUIREMENTS

Instructor Pilots

11. NVGQ

a. Qualification Requirements:

1. Only fleet tactical air experienced pilots will be designated fixed wing NVG aircrew.
2. Minimum evaluation aircraft time: 100 hrs.
3. Completed "NVG NITE Lab" simulation.

b. Training Requirements:

1. Fleet Qualified with 2 TPS IUT flights,
or
2. Completed Fleet Replacement Squadron (RAG) training syllabus with 1 TPS IUT flight,
or
3. Completed the 4 flight TPS IUT training syllabus listed in Tab A.

c. Minimum Altitude: 3,000 ft AGL .

12. NVGI(H)

a. Qualification Requirements:

1. NVGQ requirements met.
2. Minimum NVG time: 10 hrs.

b. Training Requirements:

1. TPS "High Altitude" NVGI stan flight
Complete

c. Minimum Altitude: 3,000 ft AGL.

13. NVGI

a. Qualification Requirements:

1. NVGQ requirements met.
2. Minimum NVG time: 25 hrs.

b. Training Requirements:

1. TPS "Low" Altitude NVGI stan flight
complete.

c. Minimum Altitude: 500 ft AGL.

Students

14. Completion of "NITE Lab" simulation desired but not required.

AIRCREW CURRENCY

Instructor Currency

15. Minimum of 1 day flight in the evaluation aircraft in the previous 15 days.

16. Minimum of 1 NVG flight in the evaluation aircraft within the previous 30 days to act as NVGI/NVGI(H).

17. Flown approved low level during daylight hours within previous 60 days to operate on NVGs below 3,000 ft AGL.

Student Currency

18. There are no minimum requirements established for student currency.

CREW DAY/FLIGHT LIMITATIONS

19. Crewmembers involved in NVG operations shall closely monitor their crew rest and be cognizant of the degrading effects in performance associated with changes in circadian rhythm during the shift to and from night operations. The following limitations shall be observed by all crewmembers participating in NVG operations.

NVGO/NVGI(H)/NVGI Instructor Requirements

20. 12 hrs max from first scheduled event to final land time.

21. 12 hrs from land time to first scheduled event the following day.

22. Instructor aircrew will not be scheduled for more than 4 consecutive nights involving NVG operations.

Students

23. 15 hrs max from first scheduled event (class or flight) to final land time.

24. No flight the following day.

All Crewmembers

25. Maximum of 2 flights per day when involved in NVG operations.

NVG FLIGHT REQUIREMENTS

Equipment

26. Minimum essential equipment to conduct night low and high altitude flights shall be per fleet operating instruction and the aircraft flight manual. Additionally, the following equipment will be required for the conduct of NVG flights.

Cats Eyes NVGs, Both Crewmembers

27. Night Vision Goggles (NVGs) are to be the MK-IV "CATEYES", adapted to the GENTEX HGU-66/85 helmets. Use of any other night vision goggle is not authorized without approval of the Commanding Officer.

28. **Warning:** NVGs are light intensifiers. Serious damage and/ or premature failure may result if NVGs are operated in bright ambient conditions (i.e. daylight, over major cities at night, or within enclosed rooms with lights on). Care should be taken to avoid these hazardous situations.

Aircraft

29. Due to the operating frequency range of NVGs, only aircraft with NVG compatible lighting shall be used on NVG flights.

30. In addition to the equipment required by NATOPS, the following aircraft equipment are also **required** for NVG operations during:

- a. Flight above 3,000 ft AGL
 1. Anti-collision light
 2. HUD
 3. ICS
- b. Flight below 3,000 ft AGL
 1. Anti-collision light
 2. HUD (If Available)
 3. ICS
 4. Radar Altimeter (If Available)
 5. Operable INS

Weather.

31. NVG performance is degraded based on deterioration of ambient light condition. Weather conditions shall be thoroughly assessed prior to any NVG flight. Areas of fog or rain shall be avoided whenever possible regardless of moon phase. Overcast conditions, rain, fog, and blowing dust can severely degrade NVG performance and should be briefed, approached, and treated as a mean starlight or inadvertent IMC condition, whichever is applicable.

32. Weather minimums are established as follows:

- a. Operations above 3,000 ft AGL
 - School SOP night minimums.
- b. Operations below 3,000 ft AGL
 - School SOP night minimums to include:
 - 3000/5 along entire low (<3,000 ft AGL) portion of the flight.

Note: Ceilings can reduce ambient light conditions to unacceptable levels regardless of moon phase and elevation. NVG flight may continue beneath broken or overcast ceilings at the discretion of the Pilot In Command. In no case will NVG flights be conducted with weather observed or measured at less than 3000/5.

Moon Conditions.

33. The NVG Light Level Planning Calendar Computer Program shall be used to determine percent of lunar illumination, angle of the moon above the horizon, and LUX level for all flights involving NVG operations. The data obtained from this program must be tempered with sound judgement since the program does not adjust for the degrading effects of cloud cover, humidity, haze, dust, smoke, low moon angle, terrain, and shadowing on the operation of the NVGs. The following ambient light and lunar condition requirements shall apply to NVG operations.

- a. Operations above 3,000 ft AGL
 - No minimums.
- b. Operations below 3,000 ft AGL
 - Minimum 0.0022 LUX.

Aircrew Requirements.

34. All students and Non-NVG aircrew will fly in the rear cockpit for NVG fixed wing flights. The following exceptions may be approved by the Commanding Officer on a case by case basis:

- a: Prior NVG qualified evaluation aircraft pilot aircrew with a minimum of 50 hours NVG time.
- b: Prior NVG qualified Non-evaluation aircraft aircrew with a minimum of 75 hours NVG time. In such cases minimum altitude will be limited to 3,000 ft AGL.

35. Solo NVG flight by NVGI and NVGI(H) aircrew is allowed for aircrew currency purposes. 3,000 ft AGL will be the minimum altitude on solo flights regardless of aircrew qualification. Solo flight by NVGQ personnel is prohibited.

36. NVG demonstration flights with non-NVG qualified personnel may be conducted by NVGI(H) and NVGI qualified personnel that meet all currency requirements.

37. NVG flights with Non-NVG qualified personnel may be conducted by NVGQ personnel while building NVG time to the minimum 10 hours required for NVGI(H) designation. Such flights are restricted to 3,000 ft AGL and may be scheduled with tactical fixed wing TPS instructor personnel only. To ensure NVG specific issues are addressed, the NVG Fam 0 listed will be completed prior to flight.

38. A USNTPS Operations Duty Officer (radio watch) is required for all NVG operations utilizing local restricted areas and low level routes. No duty officer is required for currency flights utilizing local stereo routes at and above 3,000 ft AGL.

NVG OPERATING AREAS

39. The following areas and routes may be utilized during TPS NVG operations:

- a. Operations above 3,000 ft AGL:
 - 1. Local Operating areas
 - 2. Local Stereo Routes
- b. Operations below 3,000 ft AGL:
 - 1. Approved Low Level Routes
 - 2. Local Airfield
 - 3. Transit to and from the local airfield and approved low level routes

PREFLIGHT PLANNING/BRIEFING ITEMS

40. In addition to the normal preflight planning procedures outlined in the aircraft flight manual and the NVG briefing guide listed in Tab A, the following additional requirements are mandatory:

a. Careful review of the route of flight will be conducted to identify areas of known sources of bright ambient lighting conditions. These areas will be avoided whenever possible.

b. Power lines, towers, significant terrain, and towns will be thoroughly briefed prior to flights utilizing approved low levels.

41. The following is a summary of the required briefing items:

- a. NVG donning and doffing procedures.
- b. NVG operation and adjustments.
- c. Location and operation of aircraft interior and exterior lighting systems.
- d. NVG failures.
- e. Bird strike
- f. Radar altimeter usage
- g. Emergency procedures during NVG operations.
- h. Pertinent astronomical data (sunset, moonrise, moonset, moon angle, moon azimuth, predicted ground illumination)
- i. Depth perception, visual illusions, physiological effects.
- j. Crew coordination during NVG operations.
- k. Course rules.
- l. Hotseat procedures.

PREFLIGHT/PRELAUNCH PROCEDURES

42. In addition to the aircraft preflight and prelaunch procedures, the following NVG procedures will apply:

a. Engage and disengage CATS EYES NVGs to helmet several times to ensure disengagement can be performed quickly and easily. There should be no binding present during disengagement. Ensure both batteries supply sufficient power. Inflight NVG "Donning" and "Doffing" procedures and crew coordination must be briefed.

b. With NVGs attached to the helmet, adjust NVGs to the optimum position. Adjust tubes for proper distance between the eyes, proper distance from each eye, elevation, vertical alignment and focus prior to the take off point.

c. Protective caps for NVG lenses will not be carried in the cockpit to reduce the potential of Foreign Object Damage (FOD).

d. While preflighting the cockpit, ensure all NVG lights are operable and that filters are installed and not distorted.

e. When not being worn, NVGs will be stored in the NVG case. At no time will the NVGs be put into or taken from the cockpit when not inside the carrying case.

f. An operable flashlight will be a part of each aircrew member's personal survival equipment. While an NVG filter is desirable in flight, aircraft preflight is hindered by the dim blue-green light. Preflight with an NVG filtered flashlight is

not advisable. A standard white or red lens flashlight is acceptable for use in flight, recognizing that usage is incompatible with the NVGs, providing care is taken not to adversely affect the NVGs of the pilot at the controls.

g. Flashlight blue filters can be checked out from most paralofts for each NVG flight.

TAXI/TAKEOFF PROCEDURES

43. Taxiing with NVGs may be conducted at the instructor pilot's discretion.

44. Takeoffs while wearing NVGs are prohibited.

45. Inform tower of NVG operation. Use the term "Goggle" in call sign while conducting NVG operations.

46. Tower will accommodate lighting requests for the airfield whenever possible. Prior coordination is required, particularly if exclusive use of the airport traffic area is desired.

ENROUTE PROCEDURES

47. All crew members will be equipped for flight with operable NVGs. Except for conducting normal donning and doffing procedures, NVG flight operations will not be conducted until both crewmembers are configured with operating and properly adjusted NVGs. For the purposes of demonstration, an instructor may have the other crew member secure NVG operation momentarily.

48. The minimum altitude to Don/Doff NVGs is 1,500 ft AGL for low altitude flight and 3,000 ft AGL for high flight. Baro altitude hold (if available) will be selected and a minimum airspeed of 250 KIAS will be maintained during the Donning/Doffing procedure.

49. Constant two-way ICS communication must be maintained between all crew members while conducting NVG operations. ICS failure is an NVG mission abort criteria.

50. If ambient lighting or NVG performance degrades to the point where critical aircraft performance or attitude parameters (altitude, airspeed, vertical speed and attitude) can not be determined accurately and confidently, the NVG phase of the flight shall be terminated.

51. If at any time either crew member is not certain of aircraft critical performance parameters, or if either crew member's interpretation of visual phenomenon critical to safe

operation is not clear, or if either crew member becomes disoriented, an immediate wings level climb to a safe flight envelope shall be initiated.

52. Minimum enroute airspeed is 250 KIAS. This airspeed provides enough energy in most aircraft to zoom, remove goggles, and eject if necessary.

53. Formation flight is prohibited except in situations where an emergency aircraft requires an external configuration check. If such a situation arises, extreme care shall be utilized during the rendezvous to ensure aircraft closure rates are controlled.

SIMULATED WEAPONS DELIVERY PROCEDURES

54. VMC weather restrictions apply for all types of simulated weapons deliveries.

55. Due to the high potential for target fixation while operating with NVGs, all simulated air to ground delivery profiles must be thoroughly briefed prior to flight. The software "RADALT" bug (if available) will be set 10% below release altitudes. NVG air-to-ground deliveries are limited to the profiles in Table I.

Table I
MINIMUM SIMULATED WEAPONS DELIVERY PROFILES

Dive Angle (degrees)	Min Roll-in (ft AGL)	Min Release Alt (ft AGL)	Min Alt (ft AGL)
0	500	500	500
15	4000	2000	1000
30	10000	5500	3000
40	12000	8000	4000

56. To perform simulated deliveries, an NVGI(H) or NVGI designated pilot must be present in the aircraft. In no case shall the aircraft descend below the minimum altitude of the NVGI qualified pilot (500 or 3,000 ft AGL). Extreme care should be exercised during pop-up (15 deg) dive and normal dive deliveries. Should any disorientation occur, an immediate abort is required.

OVER WATER OPERATIONS

57. The minimum altitude during extended low altitude over water flight operations is 1,000 ft AGL.

LANDINGS

58. Landings with airfield lights secured is allowed when light level is at a minimum of 0.0022 lux. A low altitude pass down the runway with the landing light on will be made prior to performing touch and go landings to ensure the landing area is clear.

EMERGENCIES

Ejection.

58. Because ejection while wearing NVGs is prohibited, absolute coordination between crew members is required. Prior to takeoff, command ejection shall be set in the briefed position and remain there for the entire flight. Ejection procedures will be reviewed at the "hold short" position, including discussion of where each crew member will throw his goggles in the event of ejection. In the event of an immediate ejection situation, the call "GOGGLES, GOGGLES, GOGGLES" will be made prior to any "EJECTION" call. In a controlled ejection situation, every attempt will be made to stow NVGs in the protective case to avoid possible injuries.

FIXED WING NVG INSTRUCTOR TRAINING SYLLABUS

59. Pilot IUTs new to NVG flight, without previous instructor qualifications or with less than 25 hours NVG time must complete the TPS IUT training syllabus (Tab A). These flights must be flown with a qualified NVG instructor pilot. The IUT must demonstrate proficiency in each FAM flight before proceeding to the next flight. The instructor pilot must sign the NVG qualification sheet after each FAM flight is completed. The syllabus consists of 4 flights for a total of 6 hours of NVG flight.

INSTRUCTOR NIGHT VISION GOGGLE QUALIFICATION (NVGQ) SHEET

Rank/Name _____ SSN _____

1. Preflight Requirements:

A. NVG FAM 0: _____
Date NVG Instructor

B. I have read the sections concerning night vision device flight in the local governing flight SOP.

C. I have read the NIGHT VISION GOGGLE STANDARD OPERATING PROCEDURES.

Pilot's Signature

Date _____

2. NITE Lab training: _____
Date _____

3. IUT FAM Flights:

DateInstructorStatus/NVG time

A. IUT FAM 1: _____

B. IUT FAM 2: _____

C. IUT FAM 3: _____

D. IUT FAM 4: _____

4. TPS NVG instructional flights is qualified to act as pilot in command on (NVGO designation).

A. Recommended	Date	NVG Instructor
----------------	------	----------------

B. Recommended _____
Date Senior FW Instructor

C. Recommended _____
Date CFI

D. _____ is designated a qualified pilot for NVG flights (NVGQ) and is authorized to act as pilot in command of TPS NVG aircraft during NVG operations.

Date _____

Director

E. Noted.

Date _____

Operations Officer

F. Filed.

Date _____

Schedule Writer

NVG INSTRUCTOR NVGI(H) AIRCRAFT QUALIFICATION SHEET

1. Qualification consists of one high altitude standardization flight with a qualified instructor pilot in that aircraft and 10 hrs NVG time for NVGI(H) designation. The qualification flight can be concurrent with one flown in the NVG IUT syllabus.

2. _____ has met all the requirements to act as an instructor pilot and is designated an NVGI(H) in the evaluation aircraft (Total hours of _____ as of _____).

A. Recommended _____
Date _____ NVG Instructor

B. Recommended _____
Date _____ Senior FW Instructor

C. Recommended _____
Date _____ CFI

D. _____ is designated a qualified instructor pilot for NVG flights (NVGI(H)) and is authorized to act as pilot in an instructional role of TPS evaluation aircraft during high altitude NVG operations.

Date _____ Director

E. Reviewed _____
Date _____ Operations Officer

F. Noted _____
Date _____ Schedule Writer

G. Filed _____
Date _____ Log and Records

NVG INSTRUCTOR NVGI AIRCRAFT QUALIFICATION SHEET

1. Qualification consists of one low altitude standardization flight with a qualified instructor pilot in that aircraft and 25 hrs NVG time for NVGI designation. The qualification flight can be concurrent with one flown in the NVG IUT syllabus.

2. _____ has met all the requirements to act as an instructor pilot and is designated an NVGI in the evaluation aircraft (Total hours of _____ as of _____)

A. Recommended _____
Date _____ NVG Instructor

B. Recommended _____
Date _____ Senior FW Instructor

C. Recommended _____
Date _____ CFI

D. _____ is designated a qualified instructor pilot for NVG flights (NVGI) and is authorized to act as pilot in an instructional role of TPS evaluation aircraft during low altitude NVG operations.

_____ Date _____ Director

E. Reviewed _____
Date _____ Operations Officer

F. Noted _____
Date _____ Schedule Writer

G. Filed _____
Date _____ Logs and Records

TPS NVG FAMO SYSTEMS BRIEF

BRIEF TIME: 1.5 HOUR

PREREQUISITES: NONE

1. The Fixed Wing NVG FAM Systems Brief is designed to give the new TPS NVG instructor an introduction to NVG operations.

TOPICS OF DISCUSSION

- *Basic description of NVGs work
- *Cockpit lighting modifications
- *CATS EYES combiner type vs ANVIS see through type
- *Goggle performance/limitations as a function of ambient light conditions
- *Route and checkpoint planning considerations
- *Goggle failure modes
- *Ejection considerations
- *Discussion of results and lessons learned
- *Training syllabus
- *NVG donning and doffing procedures
- *Physiological factors
- *Dark room FAM
- *Cockpit Brief (Lighting modifications, instrument scan)

NVG BRIEFING GUIDE

1. WEATHER
 - A. CLOUD COVERAGE
 - B. VISIBILITY
 - C. ILLUMINATION/MOON ANGLE/MOON RISE, MOON SET TIMES
2. NVG PREFLIGHT
 - A. CHECK ALL ADJUSTMENTS
 - B. HELMET FIT AND SECURITY
 - C. PRACTICE EMERGENCY DISCONNECT
 - D. CHECK BOTH BATTERIES FOR PROPER OPERATION
 - E. NVG COMPATIBLE FLASHLIGHT

WARNING: TURNING ON GOGGLES IN BRIGHT LIGHTING SHOULD BE AVOIDED

3. NVG COCKPIT PREFLIGHT
 - A. NVG STOWAGE
 - B. WINDSCREEN/CANOPY CLEAN INTERIOR AND EXTERIOR
 - C. CHECK NVG LIGHTING
4. BEFORE TAKEOFF
 - A. ATTACH CATS EYES TO HELMET AND ADJUST TO PROPER FIT, FUNCTION, AND SECURITY
 - B. CHECK COCKPIT FOR LIGHT LEAKS
5. TAKEOFF
 - A. NWLO AND TAKEOFF SPEED/DISTANCE
 - B. ABORT SPEED/CRITERIA
6. AIRBORNE NVG CHECK
 - A. DONNING PROCEDURES:
 - SELECT BARO ALT HOLD AND MAINTAIN 250 KIAS MIN
 - MIN DONNING ALTITUDE 3,000 FT AGL FOR HIGH SORTIES AND 1,500 FT AGL FOR LOW SORTIES
 - BOTH AIRCREW "GOGGLE UP" SIMULTANEOUSLY
 - B. CHECK FOR SCINTILLATION AND IDENTIFY CAUSE
 - C. ESTABLISH SCAN PATTERN
 - D. DETERMINE SUFFICIENT ILLUMINATION
 - E. EXTERIOR LIGHTING AS DESIRED
 - F. COCKPIT LIGHTING AS NECESSARY
 - G. WINDSCREEN TRANSMISSIVITY
7. MISSION
 - A. SEE SPECIFIC MISSION BRIEF
8. NVG SAFETY
 - A. BATTERY FAILURE
 - B. NVG FAILURE
 - C. HELMET FIT
 - D. LANDINGS
 - E. EJECTION
9. NVG TRAINING RULES

NVG TRAINING RULES

1. THE TPS FIXED WING NIGHT VISION GOGGLE SOP IS THE GOVERNING DOCUMENT FOR ALL NVG FLIGHTS. A THOROUGH KNOWLEDGE OF THE SOP IS MANDATORY PRIOR TO ANY NVG FLIGHT.

- ILLUMINATION AND WEATHER ACCEPTABLE FOR REGIME OF FLIGHT. DO NOT PRESS THE LIMIT!

- INSTRUCTORS:

- Minimum of 1 day flight in the evaluation aircraft in the previous 15 days.
- Minimum of 1 NVG flight in the evaluation aircraft within the previous 30 days to act as NVGI/NVGI(H).
- Flown approved low level during daylight hours within previous 60 days to operate on NVGs below 3,000 ft AGL.

- ROUTE STUDY TO INCLUDE TERRAIN, TERRAIN CONTRAST, OBSTRUCTIONS, AMBIENT LIGHTING, SIGNIFICANT TERRAIN, AND INHABITED AREAS.

- GOGGLES DONNED ABOVE 1,500 FT AGL FOR LOW ALTITUDE FLIGHTS OR 3,000 FT AGL FOR HIGH ALTITUDE FLIGHTS.

- NVG MINIMUM ALTITUDE 500 FT AGL FOR LOW ALTITUDE FLIGHT AND 3,000 FT FOR HIGH ALTITUDE FLIGHT.

- FLIGHT BELOW 3,000 FT AGL REQUIRES AN OPERATIVE INS, HUD, RADAR ALTIMETER AND ICS COMMUNICATION.

- LOSS OF SITUATIONAL AWARENESS WILL BE TRANSMITTED IMMEDIATELY

- DESCENTS TO LOW LEVEL

- NAV MASTER MODE UNTIL AT OPERATING ALTITUDE
- MONITOR RATE OF DESCENT
- DO NOT BREAK THE MINUTE TO LIVE RULE
- "CHECK ROD/PULL UP" (NOSE ABOVE THE HORIZON) BROADCAST AND ACKNOWLEDGED IF EITHER OCCUPANT PERCEIVES AN "EXTREMIS" SITUATION.

- RADALT WILL BE USED AS PRIMARY ALTITUDE WARNING AND SET 10% BELOW NVG MIN ALT (450 FT FOR LOW LEVEL PORTION OF HOP IF APPLICABLE).

- MINIMUM AIRSPEED 250 KIAS

- MINIMUM AIRSPEED DURING LOW LEVEL PORTION OF FLIGHT 300 KIAS

- NVGs SHOULD BE REMOVED PRIOR TO EJECTION

- NO MORE THAN 4 DAYS CONSECUTIVE NVG OPERATIONS. 12 HOUR CREW DAY MAX FOR INSTRUCTOR PILOT'S AND 15 HOUR MAX FOR STUDENTS. 12 HOURS REST REQUIRED PRIOR TO CREW DAY.

- KNOCK IT OFF DURING LOW ALTITUDE FLIGHT FOR:

- INADVERTENT IFR
- NORDO/ICS FAILURE
- VERTIGO
- BREAKING THE "MINUTE TO LIVE RULE"
- NVG FAILURE
- ANY UNSAFE CONDITION

NVG IUT FAM 1

BRIEF TIME: 2.0 HOUR

PREREQUISITES: FAM0 SYSTEMS BRIEF, NITE LAB SIMULATION

FLIGHT TIME: 1.5 HOUR DUAL

CREW: NVG INSTRUCTOR FRONT SEAT / IUT REAR SEAT

BRIEF

1. ENSURE QUALIFICATION SHEET PREFLIGHT REQUIREMENTS ARE MET.
2. SOLICIT QUESTIONS ON NVG OPERATION AND PROCEDURES.
3. NVG BRIEFING GUIDE TO INCLUDE:

MISSION

1. DEMONSTRATE/INTRODUCE
 - COURSE RULES
 - NVG FOCUSING ADJUSTMENT PROCEDURES
 - INTERIOR LIGHTING CONFIGURATIONS
 - EXTERIOR LIGHTING CONFIGURATIONS
 - DEPTH PERCEPTION CUES
 - GROUND TAXI
 - OBSERVE NVG PHENOMENON
 - SIMULATED BOMBING RUNS
 - LAYDOWN
 - 20/30/40 DEG ROLLINS

DEBRIEF

1. PROBLEM AREAS.
2. FAM 2.

NVG IUT FAM 2

BRIEF TIME: 1.5 HOUR

PREREQUISITES: FAM 1

FLIGHT TIME: 1.5 HOUR DUAL

CREW: IUT FRONT SEAT / NVG INSTRUCTOR REAR SEAT

BRIEF

1. SOLICIT QUESTIONS ON NVG OPERATION AND PROCEDURES.
2. NVG BRIEFING GUIDE TO INCLUDE:

MISSION (1 OR 2 BELOW)

1. DEMONSTRATE/INTRODUCE
 - COURSE RULES
 - NVG FOCUSING ADJUSTMENT PROCEDURES
 - INTERIOR LIGHTING CONFIGURATIONS
 - EXTERIOR LIGHTING CONFIGURATIONS
 - DEPTH PERCEPTION CUES
 - GROUND TAXI
 - OBSERVE NVG PHENOMENON
 - SIMULATED BOMBING RUNS
 - LAYDOWN
 - 20/30/40 DEG ROLLINS

2. LOCAL STEREO ROUTE IF DESIRED

DEBRIEF

1. PROBLEM AREAS.
2. FAM 3.

NVG IUT FAM 3

BRIEF TIME: 1.5 HOUR

PREREQUISITES: FAM 2

FLIGHT TIME: 1.5 HOUR DUAL

CREW: IUT FRONT SEAT / NVG INSTRUCTOR REAR SEAT

BRIEF

1. SOLICIT QUESTIONS ON NVG OPERATION AND PROCEDURES.
2. NVG BRIEFING GUIDE TO INCLUDE:

MISSION (1 OR 2 BELOW)

1. DEMONSTRATE/INTRODUCE
 - COURSE RULES
 - NVG FOCUSING ADJUSTMENT PROCEDURES
 - INTERIOR LIGHTING CONFIGURATIONS
 - EXTERIOR LIGHTING CONFIGURATIONS
 - DEPTH PERCEPTION CUES
 - GROUND TAXI
 - OBSERVE NVG PHENOMENON
 - SIMULATED BOMBING RUNS
 - LAYDOWN
 - 20/30/40 DEG ROLLINS

2. LOCAL STEREO ROUTE IF DESIRED

DEBRIEF

1. PROBLEM AREAS.
2. FAM 4.

NVG IUT FAM 4 / "HIGH" ALTITUDE STANDARDIZATION FLIGHT

BRIEF TIME: 1.5 HOUR

PREREQUISITES:

IF FAM 4: FAM 3

IF "HIGH" ALT STAN: REQUIREMENTS OF NVG SOP SECTION III MET

FLIGHT TIME: 1.5 HOUR DUAL

CREW: IUT FRONT SEAT / NVG INSTRUCTOR REAR SEAT

BRIEF

1. SOLICIT QUESTIONS ON NVG OPERATION AND PROCEDURES.
2. NVG BRIEFING GUIDE TO INCLUDE:

MISSION

1. GROUND
 - NVG HELMET INTERFACE
 - ADJUSTMENT PROCEDURES
 - ABILITY TO QUICKLY DON AND REMOVE GOGGLES
 - COMFORT
 - INTERIOR LIGHTING CONFIGURATIONS
 - EFFECT OF COCKPIT LIGHTING INTENSITIES
 - INCOMPATIBLE WARNING AND CAUTION LIGHTS
 - READABILITY OF CONTROLS
 - CANOPY TRANSMISSIVITY AND GLARE
 - LIGHT LEAKS
 - NVG PERFORMANCE WITH HUD
 - EXTERIOR LIGHTING CONFIGURATIONS/INTENSITIES
 - QUALITATIVE MEASURE OF NVG FIELD OF VIEW (FOD)
 - QUALITATIVE MEASURE OF NVG FIELD OF REGARD (FOR)
 - GROUND TAXI
 - FEASIBILITY OF TAXI ON UNLIT TAXIWAYS
 - DEPTH PERCEPTION CUES
2. TAKEOFF (TAKEOFF WITH NVGs IS PROHIBITED)
3. AREA FAM
 - DONNING PROCEDURES (3,000 FT AGL MINIMUM)
 - FIT
 - SCAN TECHNIQUES
 - OBSERVE NVG PHENOMENON
 - BLOOMING
 - COMET TRAILS
 - HONEYCOMB EFFECTS
 - EXTERNAL LIGHTING EFFECTS (MOON, STARS, CULTURAL)
 - NVG RESOLUTION
 - RESOLUTION VS. AIRSPEED
 - RESOLUTION VS. ALTITUDE
 - RESOLUTION VS. G
 - AIR-TO-AIR TARGET ENGAGEMENT CAPABILITY
4. TARGET ENGAGEMENT CAPABILITY
 - RADAR/FLIR DESIGNATION TO LEVEL LAYDOWN
 - RADAR/FLIR DESIGNATION TO 20 DEG DIVE
 - RADAR/FLIR DESIGNATION TO 30 DEG DIVE
 - RADAR/FLIR DESIGNATION TO 40 DEG DIVE
5. HIGH ALTITUDE MISSION UTILITY (15,000 FT MSL / 400 KIAS)
 - NAV/RADAR DESIGNATE NON-RADAR REFLECTIVE TARGET
 - PERFORM FLIR HANDOFF AND UPDATE DESIGNATION
 - TRANSITION TO VISUAL 40 DEG DIVE DELIVERY
6. RTB (DEGGOGGLE ABOVE 3,000 FT AGL)

DEBRIEF

1. PROBLEM AREAS.
2. SIGN OFF NVGQ/NVGI (H) QUALIFICATION PAPERWORK AS APPLICABLE

NVG IUT "LOW" ALTITUDE STANDARDIZATION FLIGHT

BRIEF TIME: 1.5 HOUR

PREREQUISITES: REQUIREMENTS OF NVG SOP SECTION III MET

FLIGHT TIME: 1.5 HOUR DUAL

CREW: IUT FRONT SEAT / NVG INSTRUCTOR REAR SEAT

BRIEF

1. SOLICIT QUESTIONS ON NVG OPERATION AND PROCEDURES.
2. NVG BRIEFING GUIDE TO INCLUDE:

MISSION

1. GROUND

- NVG HELMET INTERFACE
 - ADJUSTMENT PROCEDURES
 - ABILITY TO QUICKLY DON AND REMOVE GOGGLES
 - COMFORT
- INTERIOR LIGHTING CONFIGURATIONS
 - EFFECT OF COCKPIT LIGHTING INTENSITIES
 - INCOMPATIBLE WARNING AND CAUTION LIGHTS
 - READABILITY OF CONTROLS
 - CANOPY TRANSMISSIVITY AND GLARE
 - LIGHT LEAKS
 - NVG PERFORMANCE WITH HUD
- EXTERIOR LIGHTING CONFIGURATIONS/INTENSITIES
- QUALITATIVE MEASURE OF NVG FIELD OF VIEW (FOD)
- QUALITATIVE MEASURE OF NVG FIELD OF REGARD (FOR)
- GROUND TAXI
 - FEASIBILITY OF TAXI ON UNLIT TAXIWAYS
 - DEPTH PERCEPTION CUES

2. TAKEOFF (TAKEOFF WITH NVGs IS PROHIBITED)

3. AREA FAM

- DONNING PROCEDURES (1,500 FT AGL MINIMUM)
- FIT
- SCAN TECHNIQUES
- OBSERVE NVG PHENOMENON
 - BLOOMING
 - COMET TRAILS
 - HONEYCOMB EFFECTS
 - EXTERNAL LIGHTING EFFECTS (MOON, STARS, CULTURAL)
- AIR-TO-AIR TARGET ENGAGEMENT CAPABILITY

4. HIGH ALTITUDE MISSION UTILITY (15,000 FT MSL / 400 KIAS)

- NAV/RADAR DESIGNATE NON-RADAR REFLECTIVE TARGET
- PERFORM FLIR HANDOFF AND UPDATE DESIGNATION
- TRANSITION TO VISUAL 40 DEG DIVE DELIVERY

5. LOW LEVEL MISSION UTILITY

- NVG RESOLUTION
- RESOLUTION VS. AIRSPEED
- RESOLUTION VS. ALTITUDE
- RESOLUTION VS. G
- NAVIGATION CAPABILITY
- TERRAIN AVOIDANCE
- TARGET DETECTION MAX RANGE
- TARGET ENGAGEMENT CAPABILITY
 - PERFORM RADAR LEVEL LAYDOWN
 - PERFORM RADAR POP-UP ATTACK

6. MEDIUM ALTITUDE RTB

- A/A FEASIBILITY
- MED ALT TARGET NAV CAPABILITY

- 7. LANDINGS
 - FEASIBILITY OF CONDUCTING LIGHTS OUT LANDINGS

DEBRIEF

- 1. PROBLEM AREAS.
- 2. SIGN OFF NVGI QUALIFICATION PAPERWORK AS APPLICABLE

APPENDIX B
TEST PILOT SCHOOL NVG PRE-BRIEF/LAB
EXERCISE HANDOUT AND BRIEF

**TEST PILOT SCHOOL
NIGHT VISION GOGGLE (NVG) LAB BRIEF**

I. BACKGROUND

There are many physiological and NVG specific factors that aircrew experience when utilizing Night Vision Goggles in aircraft equipped for their employment. The Night Vision Lab allows many of these effects to be experienced under a controlled (i.e. non-flight related) environment. As such, much can be learned about hazards associated with NVG usage with varying moon angles and flight into and away from moonlight or twilight conditions. Mean star light, cultural lighting, and various moon phases with varying moon illumination will be addressed. NVG hazards such as shadowing, scintillation, and objects with low contrast will also be introduced.

II. PURPOSE

The purpose of this lab is to introduce Night Vision Goggle specific terms and flight characteristics to TPS student personnel prior NVG flight operations.

III. OBJECTIVES

The objectives of this lab is to provide exposure to fixed wing and rotary wing night vision goggle terms and specific factors that affect their use.

Specific areas to be addressed include:

- a. **Principle of Operation** - Amplify "Reflected" Light.
- b. **Natural Light Sources**
 1. Moon - The major source of night illumination. The amount of illumination is dependent on phase and elevation.
 2. Airglow - Light reflected from clouds (primarily cultural lighting).
 3. Starlight
 4. Zodiacal Light - A luminous tract in the sky seen in the west after sunset or in the east before sunrise and thought to be the light reflected from a cloud of meteoric matter revolving around the sun.
 5. Gegenschein - A faint, elliptical patch of light in the night sky thought to be a reflection of sunlight by meteorological material in space.
 6. Aurora - A radiant emission from the upper atmosphere that occurs sporadically over the middle and high latitudes of both hemispheres in

the form of luminous bands or streamers caused by the bombardment of the atmosphere with charged solar particles that are being guided along the earth's magnetic lines of force.

7. Noctilucent Clouds - High altitude clouds visible during the short nights of summer.

c. Components and Operation

1. Objective Lens - Focuses scene on photocathode.
2. Intensifier Tube - A vacuum tube that changes light to electrons, boosts them, and converts the amplified signal back to a visible scene.
 - Photocathod - Emits electrons when light strikes it.
 - Microchannel Plate (MCP) - A thin glass wafer with about 2 million microscopic channels lined with lead. Electrons entering the microchannels strike the walls, which release more electrons with each impact. Thousands of electrons typically exit the MCP for each one entering.
 - Phosphor Screen - A coating on the exit window that glows when struck by electrons. A positive charge of several thousand volts accelerates the electrons from the MCP to the phosphor screen.
3. Combiner Glass (Cats Eyes only) - Inverts/rotates the image and presents it to the eye at a 1:1 magnification.

d. Adjustments

1. Vertical
2. Interpupillary Distance (IPD)
3. Fore/Aft
4. Tilt
5. Focus

e. Field of View (No Peripheral Vision)

1. Anvis - 40 deg
2. Cats Eyes - 30 deg

f. Resolution - Limited by intensifier tube design and ambient light.

1. Even under optimum conditions, the ability to resolve small targets is limited. **Thin, non-reflective targets, such as wires or some towers, are invisible.**
2. If light is too dim resolution degrades. If light is too high, automatic control circuits decrease the gain, again lowering resolution.

g. Visual Acuity

1. Optimum acuity is limited to 20/40.
2. Objects appear farther away than they are.
3. No color contrast.

h. NVG Phenomena

1. Scintillation - A symptom of low ambient light; the lower limit of the goggles' capability has been reached.
2. Shading - The inability to obtain a full image; it begins at the edge and progresses inward.
3. Edge Glow - Also begins at the edges and progresses inward. It is detected by covering one lens to block incoming light.
4. Bright spots - Caused by pinholes in phosphor screen.
5. Dark spots - Caused by deficient channels in the MCP or dust inside the intensifier tube.
6. Honeycombing - Fixed pattern noise caused by high light conditions.

i. Peripheral Cues - Are "Minimal"

j. Scan Into Turns - Continual scan is required to compensate for narrow field of view, especially into turns.

k. Depth Perception - The lack of peripheral cues and monochromatic image cause poor depth perception.

l. Dive Angle - NVGs provide no perception of dive angle. Rely on the HUD pitch ladder for attitude information (fixed wing only).

m. Scan - There is a natural tendency to fixate on individual objects. Proper scan takes concentrated effort.

n. Terrain Masking (Shadowing)

1. High terrain in the distance can obscure lower hills closer to the aircraft, particularly if the high terrain is between the aircraft and a light source.
2. Rough or mountainous terrain can cast long shadows that completely obscure targets, checkpoints, and deadly flight hazards. One should plan to fly on the lighted side of valleys and not risk flying into an unseen ridgeline in an attempt to avoid a threat.

o. **Illusions**

1. Resolution improves as altitude is decreased. The lower you get, the more comfortable you feel.
2. Objects appear farther away than they are. Bushes can be mistaken for trees.

p. **Night Adaptation** - Recovery of night adaptation after NVG use is faster than from day adaptation.

q. **Eye Fatigue** - Due primarily to incorrect adjustment.

r. **Twilight**

1. Civil - From sunset until the sun is 6 deg below the horizon.
2. Nautical - From sunset until the sun is 12 deg below the horizon.
3. Astronomical - From sunset until the sun is 18 deg below the horizon.
4. The glow of nautical twilight is enough to mask terrain features, especially when flying into the sun.

s. **Moon Factors** - Moon phase, elevation, and azimuth significantly affect NVG performance.

1. A minimum of 20% moon illumination is required for good contrast and resolution.
2. Low moon angle causes shadowing, and creates glare problems when looking into it.
3. Having the moon at your back enhances scene illumination. Moon azimuth is an important consideration when selecting target area tactics and run-in headings.

t. **Light Level Planning Calendar** - Gives sunrise, sunset, moonrise, moonset, and graphic presentation of light level, moon phase, and moon elevation data for a given location and time period.

u. **Cultural Lighting** - Lights show up extremely well with NVGs, and can dramatically change the appearance of populated areas. Bright lights wash out the surrounding scene, although the lighted area is enhanced.

v. **Headlights** - Headlights on highways parallel to course can be very distracting, and can also cause scene washout.

w. **Atmospheric Conditions**

1. Clouds

- Decrease illumination and cause shadows.
- Broken layers cause variations in perceived ground texture. Terrain can appear heavily forested when actually darkened by shadows.
- An overcast will reduce illumination below what is needed for NVG operations.

2. Indication of Clouds - Degrading NVG image quality, loss of moon and stars, and scintillation indicate clouds.

3. Fog - Reduce light and blocks the NVG image. The chance of fog occurring increases as the temp/dewpoint spread decreases.

4. Blowing Sand and Dust - Degrade the NVG scene dramatically.

x. **Terrain Factors**

1. Luminance - Is a measure of how much light an object reflects.

2. Contrast - Is a determinant of NVG ability to discern terrain features. It is the difference in luminance between objects.

3. Poor Contrast - Contrast is wavelength dependent. Terrain with good contrast definition in the day may have little or no contrast at night.

4. Texture - Enhances the ability to discern details. Shadows give dimension to rolling terrain, and features with vertical development stand out more than flat landmarks.

5. Water - **NVG flight over water is not recommended due to the absence of a discernable horizon and lack of contrast in low sea states.** Accomplish overwater flight on instruments.

y. **Human Factors**

- Comfort and Fit
- External and Internal Eye and Head Movement and FOV Analysis
- Neck Strain/Fatigue
- NVG Adjustment

IV. REFERENCES

A. Aircraft Operating Manual

B. TPS Night Vision Goggle SOP

C. "Electro-Optical Systems Test and Evaluation",
Airborne Systems Course Textbook, USNTPS,
01 June 1981.

- D. USNTPS Systems Test Manual (Preliminary)
- E. "Night Attack Test Requirements Analysis", TACAIR
TECHNOLOGY DEPARTMENT, NAWC, October 1987.

V. SCOPE

- A. One 1.0 hr Brief
- B. One 45 minute lab period.
- C. No TEST PLAN.

VI. REPORT

No Reporting Requirements

“TEST PILOT SCHOOL NIGHT VISION GOGGLE PRE-BRIEF”

NIGHT VISION GOGGLE (NVG) LAB BRIEF

PURPOSE -- TO INTRODUCE NIGHT VISION GOGGLE (NVG) SPECIFIC TERMS, CHARACTERISTICS, AND PHENOMENA, AND TO PROVIDE EXPOSURE TO NVG TERMS AND FACTORS THAT AFFECT THEIR USE.

PRINCIPLE OF OPERATION -- TO AMPLIFY "REFLECTED" LIGHT ENERGY.

NVGs

TYPES

HOW THEY WORK

ILLUMINATION

VISUAL EFFECTS

CATS EYES

MISCELLANEOUS

NVG HISTORY

- EVOLVED OVER THE LAST 20 YEARS
 - STARLIGHT SCOPE
 - GEN I
 - GEN II
 - GEN III
- DESIGNED TO ENHANCE DETECTION EVASION AND TERRAIN MASKING
- INTRODUCED INTO MILITARY SERVICE IN VIETNAM, 1965

STARLIGHT SCOPE

- INITIAL IMAGE INTENSIFIER
- VERY LARGE AND CUMBERSOME
- REQUIRED COVERT IR LIGHT SOURCE TO ILLUMINATE DESIRED AREA TO BE VIEWED
- THE BEST ATTAINABLE ACUITY LESS THAN 20/100
- DEEMED UNSATISFACTORY FOR AVIATION USE

NVG - GEN I SERIES INTENSIFIERS

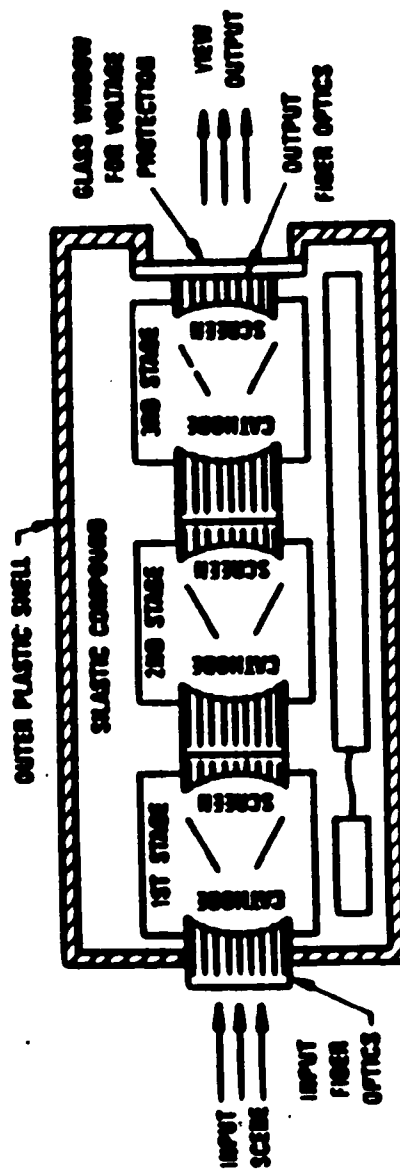
FEATURES:

- TYPICAL GAIN OF 25K (ELECTRONS AMPLIFIED 25K TIMES)
- USED A THREE STAGE CASCADE AMPLIFIER
- ELECTRON PICTURE CREATED USING
ELECTROSTATIC AMPLIFICATION
- 10,000 HOURS RELIABILITY

DRAWBACKS:

- BULK WAS MOST SIGNIFICANT DRAWBACK
- TUBES TOO LARGE FOR AIRCRAFT USE
- BATTERIES TOO HEAVY
- REQUIRED AC TO DC CONVERTER
- BRIGHT LIGHTS CAUSED PHOSPHOR SCREEN
TO DEVELOP BLACK "BURN" MARKS

NVG - GEN I SERIES INTENSIFIERS



NVG - GEN II SERIES INTENSIFIERS

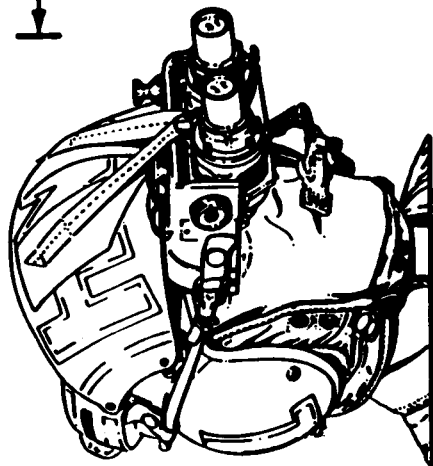
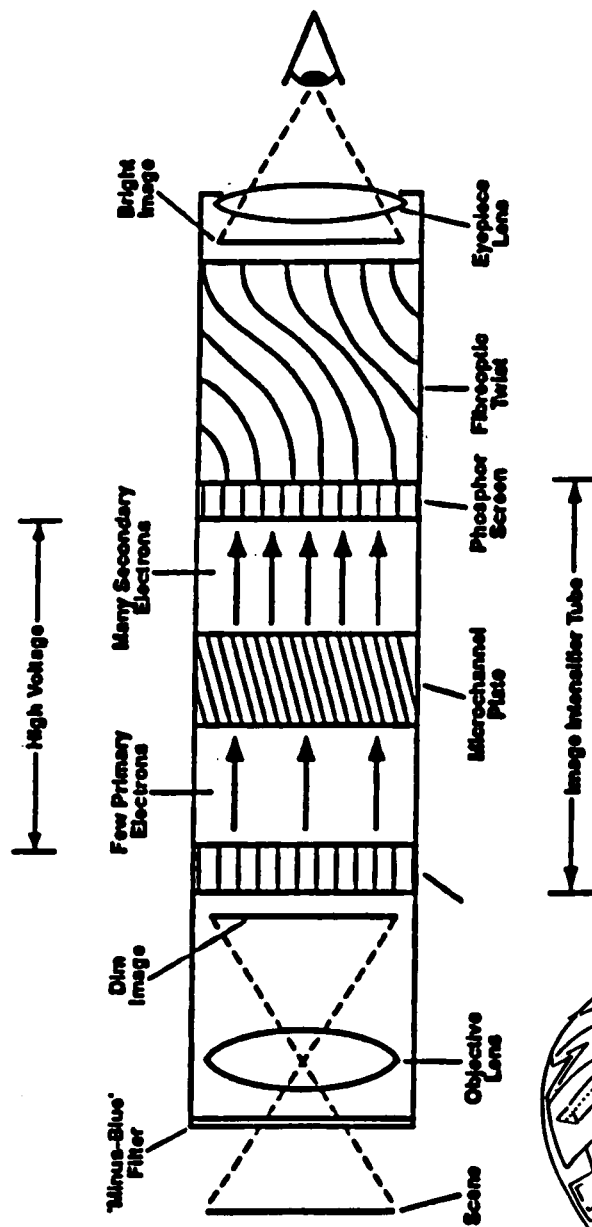
FEATURES:

- RESULTED FROM 70s SEMICONDUCTOR TECHNOLOGY
- ELECTRONS IMMEDIATELY HIT MICROCHANNEL PLATE
- MICROCHANNEL PLATE ONLY 1MM THICK
- 1.5 MILLION TINY TUBES IN MICROCHANNEL PLATE
- USED MUCH LESS POWER
- COULD NOW BE FITTED ON HELMETS FOR USE IN AIRCRAFT

DRAWBACKS:

- LIMITED USEFUL OPERATING RANGE (1/4 MOONLIGHT MIN)
- LESS INTENSIFICATION THAN GEN I (15K vs 25K)
- POORER RESOLUTION THAN GEN I
- TUBE LIFE REDUCED TO 3,000 HOURS

NVG - GEN II SERIES INTENSIFIERS



NVG - GEN III SERIES INTENSIFIERS

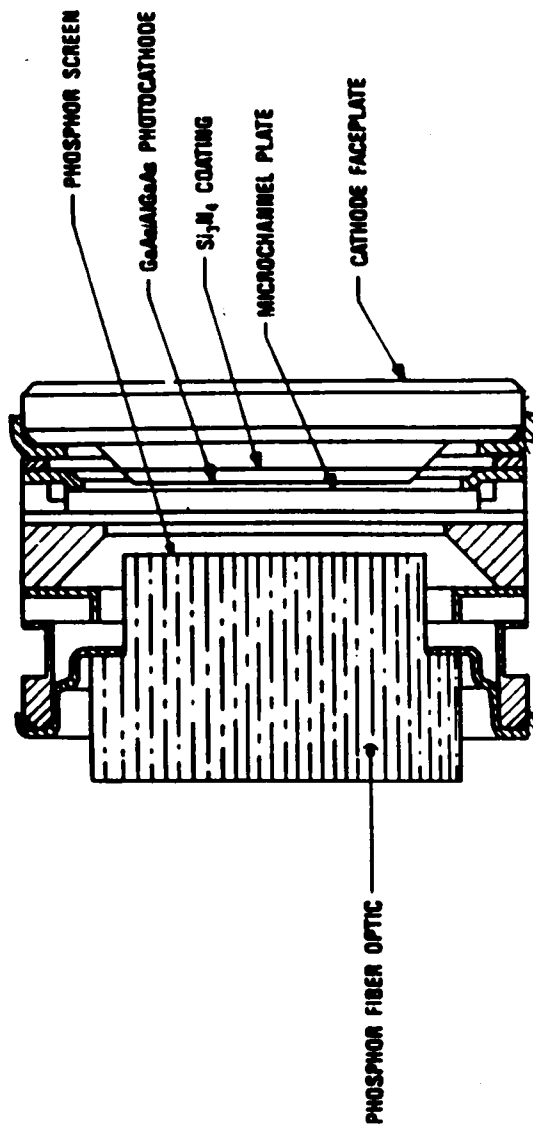
FEATURES:

- OPERATE UNDER STARLIGHT CONDITIONS
- PHOTOCATHODE 5X MORE SENSITIVE THAN GEN II DUE TO THE INCORPORATION OF GALLIUM ARSENIDE (GaAs) WHICH IS GROWN IN A HERMETICALLY SEALED ENVIRONMENT
- GAIN UP TO 30,000
- TUBE LIFE UP TO 10,000 HOURS

DRAWBACKS:

- REQUIRES 5 DAYS TO GROW GaAs PHOTOCATHODE
- 85% INDUSTRIAL PRODUCTION SUCCESS RATE FOR GaAs PHOTOCATHODE

NVG - GEN III SERIES INTENSIFIERS

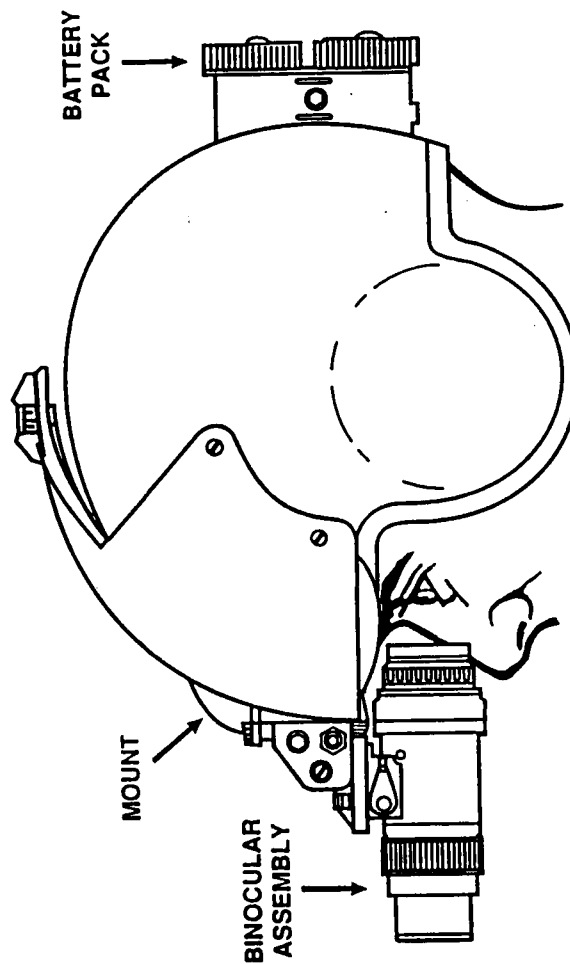


CURRENT NVG TYPES

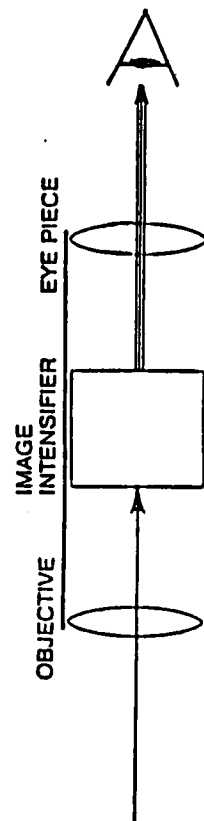
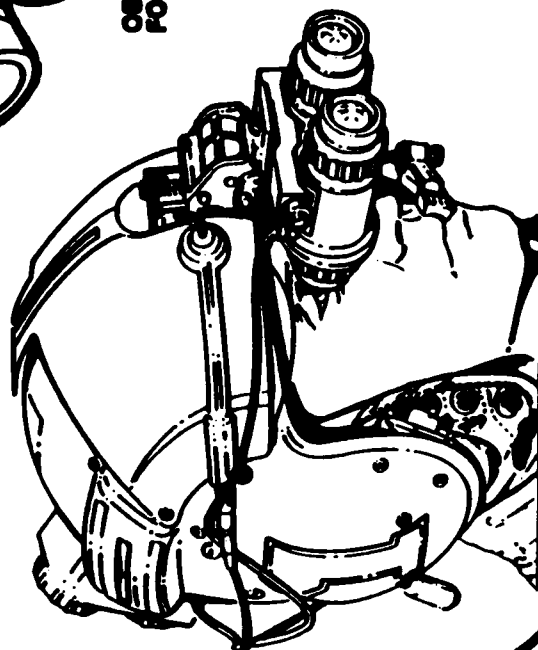
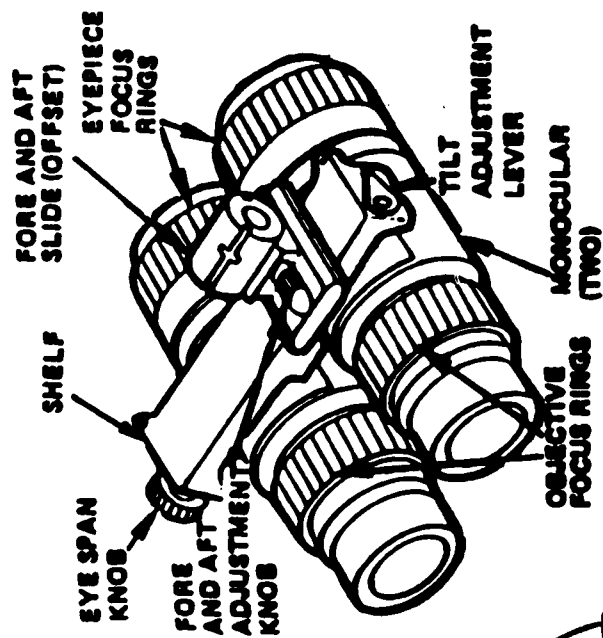
- NVGs HAVE BECOME AN INTEGRAL PART OF NIGHT OPERATIONS IN MANY ROTARY AND FIXED-WING (JET) AIRCRAFT.
- THIRD GENERATION (GEN III) NVGs ARE CLASSIFIED AS EITHER...
 - TYPE I -- WHICH HAVE DIRECT VIEW OPTICS AND ARE USED PRIMARILY IN HELICOPTERS, OR....
 - TYPE II -- WHICH INCORPORATE A FOLDED OPTICAL PATHWAY AND UTILIZES A COMBINER BLOCK TO PRESENT THE IMAGE TO THE EYE AND ARE USED PRIMARILY IN JET AIRCRAFT
- TO ALLOW FOR COMPATIBLE COCKPIT LIGHTING NVGs INCORPORATE AN OPTICAL FILTER TO INHIBIT PASSAGE OF LIGHT BELOW A GIVEN WAVELENGTH. THESE OPTICAL FILTERS ARE DIVIDED INTO 2 CLASSES WHICH INCLUDE...
 - CLASS A: 0.625 MICRON FILTERS
 - CLASS B: 0.665 MICRON FILTERS

ANVIS (Aviator's Night Vision Imaging System) **NVGs**

- MOST COMMON TYPE I NVG - CONSIST OF THREE
MAJOR COMPONENTS

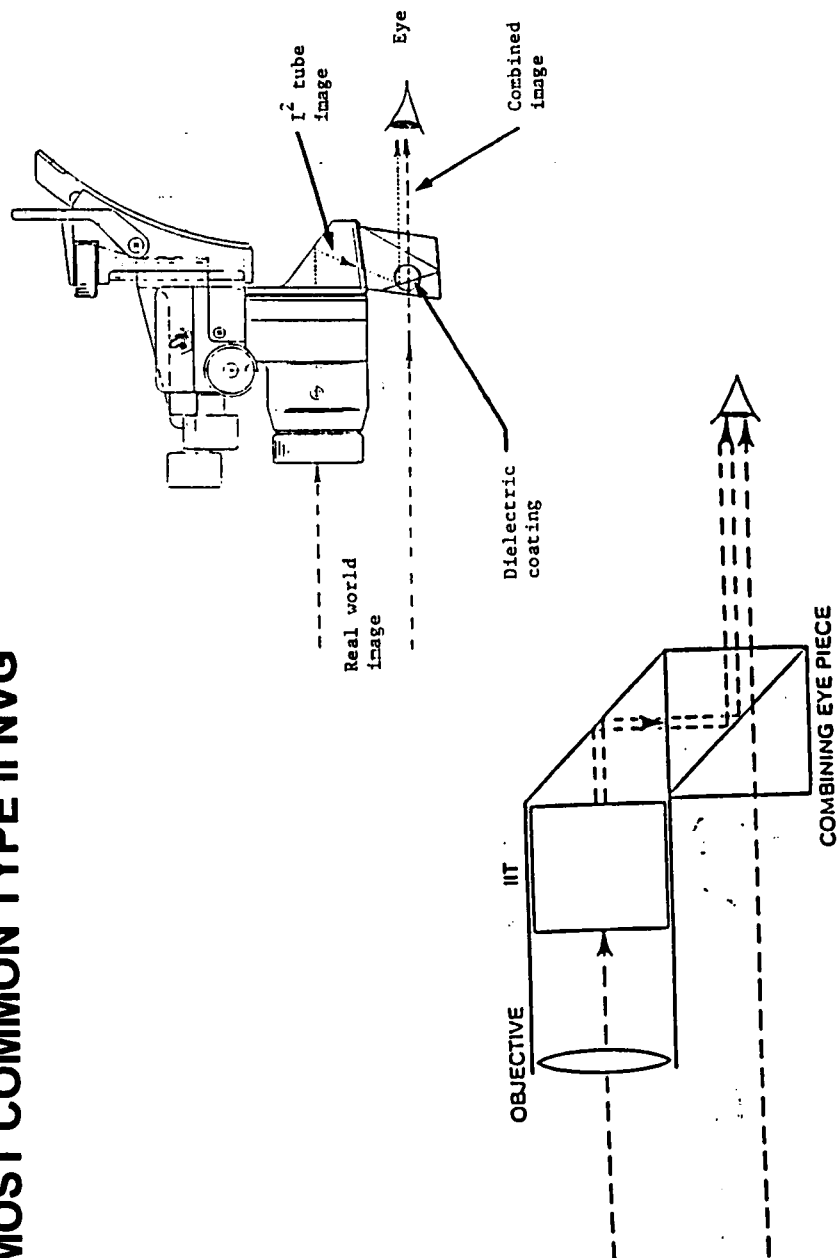


ANVIS NVGS

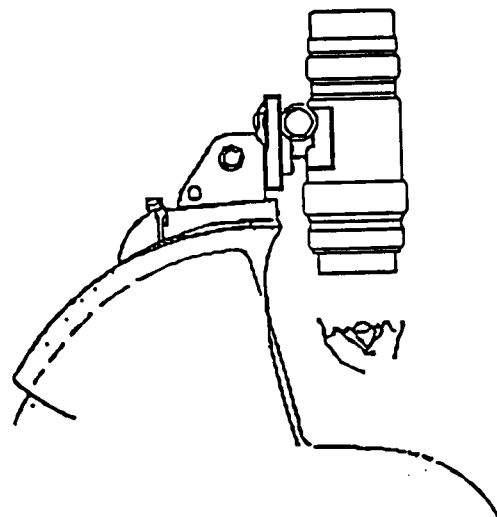


CATS EYES NVGS

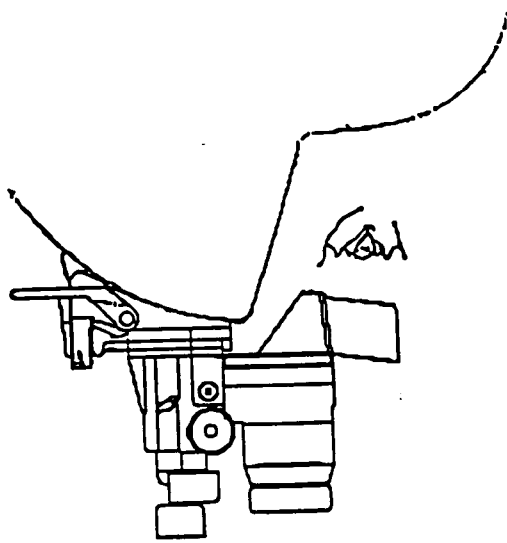
- MOST COMMON TYPE II NVG



NVG TYPE I AND TYPE II COMPARISON



ANVIS



CATS EYE

FIELD OF VIEW 30 DEG SEMI-CIRCULAR

ACUITY (OPTIMAL CONDITIONS) 20/40

WEIGHT 820 GRAMS

FIELD OF VIEW 40 DEG CIRCULAR

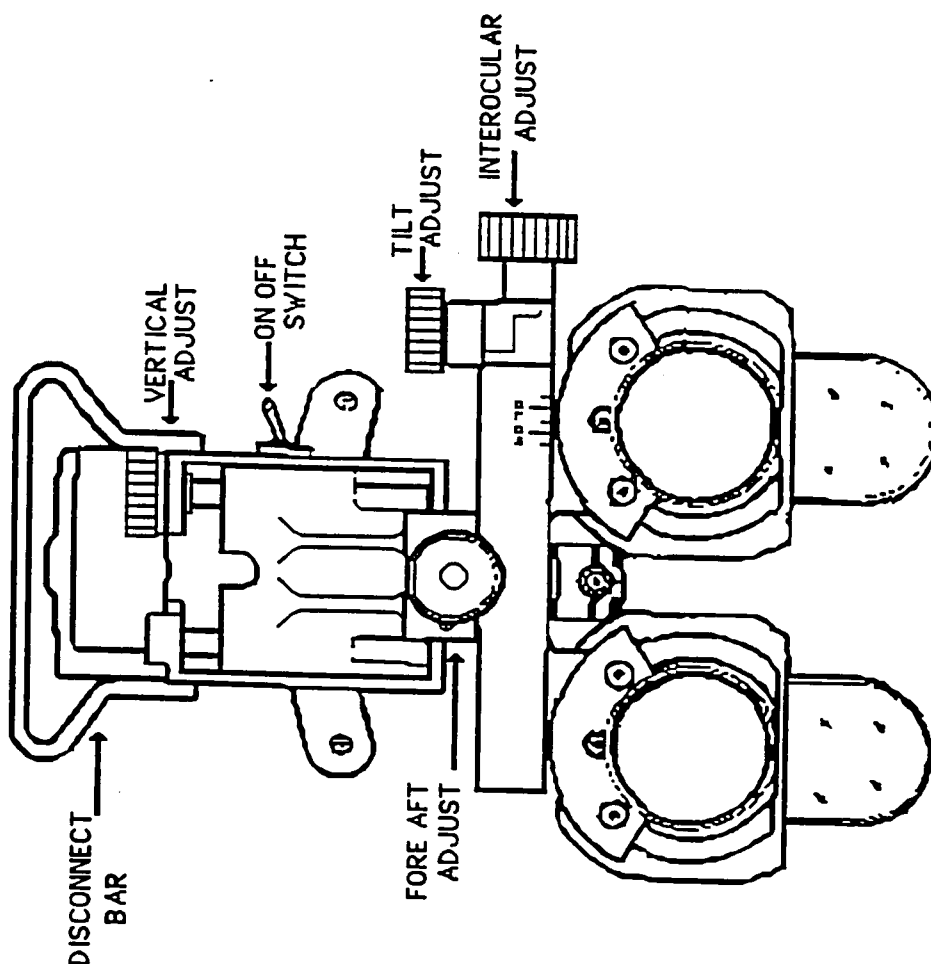
ACUITY (OPTIMAL CONDITIONS) 20/40

WEIGHT 600 GRAMS

CATS EYE GOGGLES

- COMBINER TYPE NVGs
- INTEGRAL POWER SOURCE
- HEAVY (ABOUT 1.75 LBS)
 - NOT EJECTION SAFE
- DELICATE DESIGN
 - REQUIRES FREQUENT BORESIGHTING
- EXPENSIVE (ABOUT \$40K/PAIR)

CATS EYE ADJUSTMENTS



NVG IMAGE INTENSIFIER DETAILS

- IMAGE INTENSIFIER TUBE (IIT) HOUSING
- FIELD LENS:
 - FOCUSES LIGHT INTO IIT
- PHOTOCATHODE
 - TURNS LIGHT INTO ELECTRONS
- MICROCHANNEL PLATE (MCP)
 - AMPLIFIES ELECTRONS
- PHOSPHOR SCREEN
 - RECREATES IMAGE WITH AMPLIFIED ELECTRONS
- COLLIMATING LENS/COMBINER
 - DISPLAYS IMAGE TO OPERATOR

IIT COMPONENT FUNCTIONS

TUBE HOUSING:

- CONTAIN AND PROTECT THE IIT TUBE AND POWER SUPPLY
- PROVIDE MOUNTING FOR OBJECTIVE LENS AND EYEPIECE STRUCTURE
- HOLD THE IIT ASSEMBLY ONTO THE GOGGLE STRUCTURE
- CONTAINS THE NITROGEN PURGE
- PROVIDE EMI SHIELDING OF THE IIT AND POWER SUPPLY

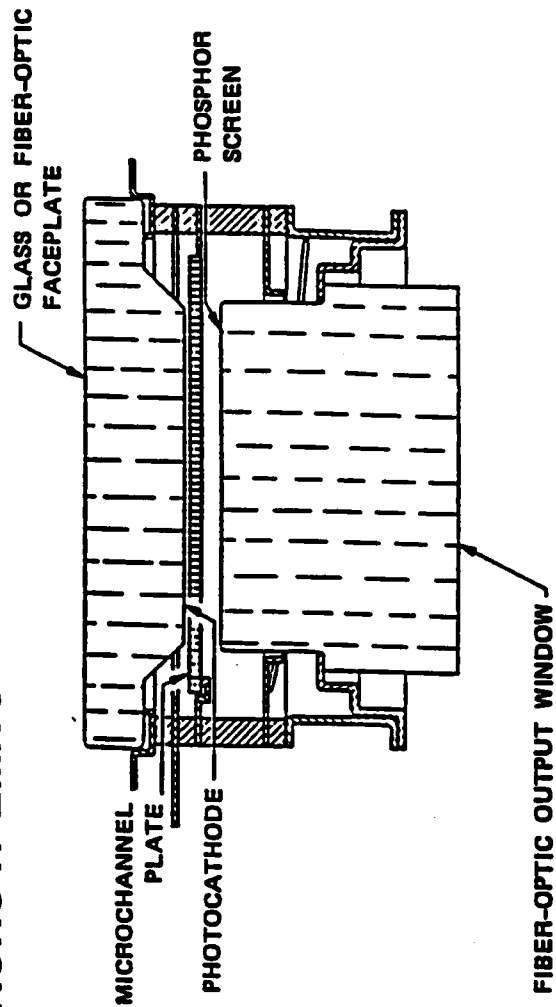
POWER SUPPLY:

- CHANGES THE BATTERY VOLTAGE (3 VDC) INTO:
 - -800 VDC FOR THE PHOTOCATHODE
 - +600 VDC FOR THE OUTPUT OF THE MCP
 - +6000 VDC FOR THE PHOSPHOR SCREEN

PHOTOCATHODE FUNCTION

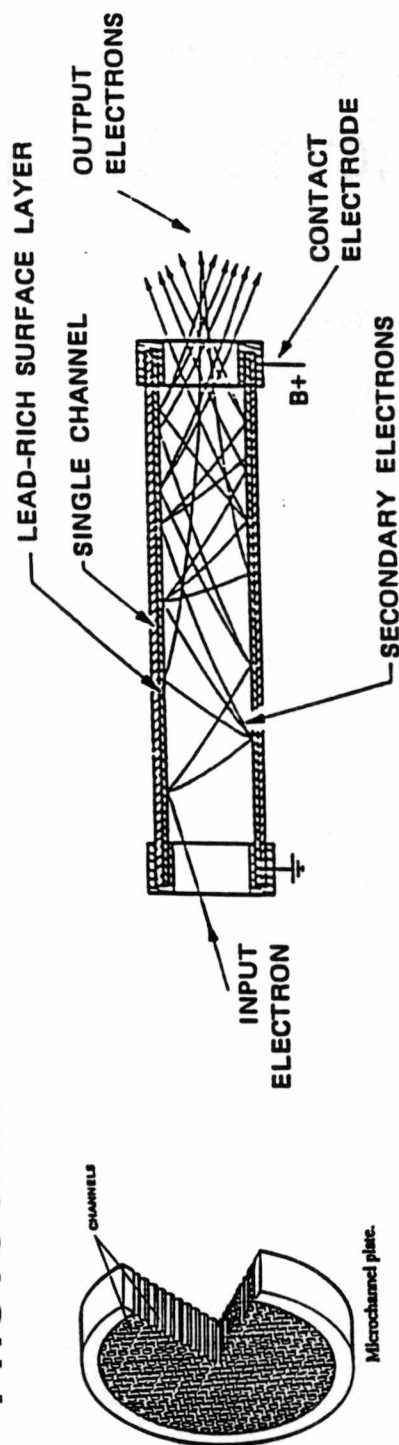
“CHANGE PHOTONS INTO ELECTRONS”

- IN GEN III TUBES THEY ARE MADE OF GALLIUM ARSENIDE (GaAs)
- IN USE, A HIGH NEGATIVE ELECTRICAL POTENTIAL IS APPLIED TO THE PHOTOCATHODE TO CAUSE IT TO ACTIVELY REPEL THE ELECTRONS IT EMITS



MICROCHANNEL PLATE FUNCTION

**“COLLECT ELECTRONS EMITTED FROM
PHOTOCATHODE AND BOOST THEIR QUANTITY”**



- ELECTRONS RELEASED FROM THE PHOTOCATHODE ENTER THE MICROCHANNELS AND BOUNCE OFF THE WALLS NEAR THE ENTRANCE (MCP IS COVERED WITH A LEAD COATING)
- ELECTRONS COLLIDING WITH THE CHANNEL WALLS KNOCK 2 OR 3 MORE ELECTRONS FREE AS THEY REBOUND (SECONDARY EMISSION)
- ELECTRONS REPEATEDLY COLLIDE WITH THE WALLS OF THE BORES AS THEY TRAVEL THROUGH MULTIPLYING IN NUMBER WITH EACH COLLISION. THOUSANDS OF ELECTRONS LEAVE EACH BORE FOR EACH ONE ENTERING.

MICROCHANNEL PLATE DESIGN

- A MCP IS BUILT UP OF GLASS FIBERS (GOOD FOR 10,000 HOURS)
- CONSTRUCTION STARTS WITH A COAXIAL ROD. THE OUTSIDE IS A HARD LEAD-RICH GLASS. THE INNER CORE IS A SOFT GLASS
- THE COAXIAL ROD IS HEATED AND STRETCHED THIN. THEN IT IS CUT INTO EQUAL LENGTHS AND THE PIECES ARE PACKED TOGETHER IN PARALLEL TO MAKE A BUNDLE
- THE BUNDLE IS FUSED TOGETHER AND STRETCHED AGAIN. THE PROCESS IS REPEATED UNTIL A BLANK CONTAINING ABOUT 2 MILLION FIBERS IS BUILT UP
- THE BLANK IS SLICED INTO THIN WAFERS, WHICH ARE PLACED INTO AN ACID BATH TO ETCH OUT THE SOFT GLASS CORES, LEAVING BEHIND A LEAD GLASS HONEYCOMB LIKE MATRIX
- THE ETCHED WAFERS ARE PLACED IN A HOT HYDROGEN FURNACE TO DERIVE A LEAD RICH LAYER IN THE LINING OF THE MICROSCOPIC BORE WALLS.

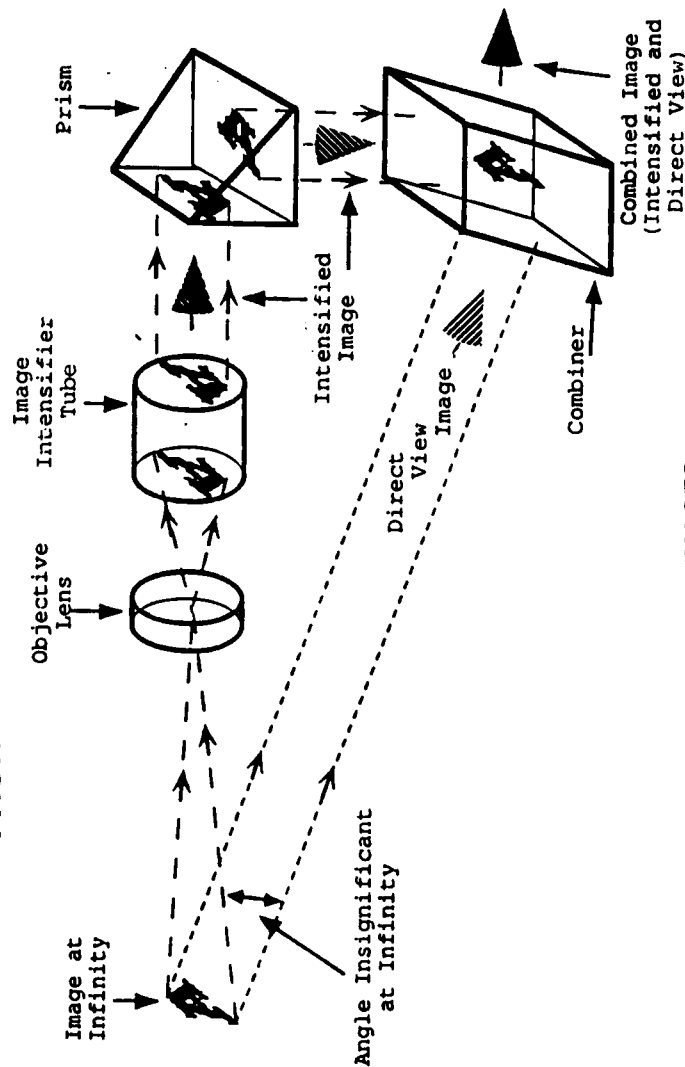
PHOSPHOR SCREEN

“RECREATES IMAGE WITH AMPLIFIED ELECTRONS”

- YELLOW-GREEN TO EXPLOIT PHOTOPIC VISION ABILITY
- RCA-1052 IN EARLY GEN III TUBES:
 - 0.530 MICRON WAVELENGTH (WARM GREEN)
- PRODUCES “SMOOTH” IMAGE
- P-20 USED IN PRODUCTION GEN II TUBES:
 - 0.560 MICRON WAVELENGTH (YELLOW-GREEN)
- CLOSELY MATCHES HUD PHOSPHER
- GREATER SCINTILLATION IN LOW LIGHT CONDITIONS
- GREATER RESOLUTION

COLLIMATING LENS / COMBINING OPTICS

"PROJECTS THE IMAGE TO OPTICAL INFINITY AND POSITIONS THE IMAGE IN FRONT OF THE USERS EYES"



- PERMITS VIEWING OF VIRTUAL AND INTENSIFIED IMAGES
- NO PARTIALLY REFLECTIVE COATING NEEDED TO DISPLAY INTENSIFIED IMAGE
- DISPLAYS INTENSIFIED IMAGE BY EXPLOITING DIFFERENCES IN REFRACTIVE PROPERTIES OF GLASS AND AIR
- PERMITS DIRECT VIEW OF VIRTUAL IMAGERY IN THE EVENT OF NVG POWER FAILURE

NVG OPERATING FEATURES

AB: AUTO BRILLIANCE CONTROL

- LIMITS ABSOLUTE MAXIMUM BRIGHTNESS OF IMAGE PRESENTED TO OPERATOR
- PREVENTS USER FROM BEING MOMENTARILY BLINDED
- PROLONGS TUBE LIFE
- CONTINUOUSLY IN-USE (NOT USER SELECTABLE)

ASR: AUTO-SCENE-REJECT

- EXTINGUISHES NVGs WHEN ALIGNED WITH IR LIGHT SOURCE
- TURNS NVGs OFF WHEN LOOKING TOWARD HUD
- ILLIMINATES HUD/NVG INCOMPATIBILITIES
- IS USER SELECTABLE (DISABLED IN THE F/A-18)

ILLUMINATION DEFINED

ILLUMINATION (lux): The act of illuminating or state of being illuminated. Commonly referred to as the measure of luminance an object supplies or reflects.

Candela: A unit of luminous intensity equal to 1/60 of the luminous intensity per square centimeter of a blackbody radiating at the temperature of solidification of platinum (2,046 deg K).

Luminance: The luminous intensity per unit projected area of a given surface viewed from a given direction and has the units of one candela per square meter (cd/m²).

Lumen (lm): The unit of luminous flux in the International System, equal to the luminous flux emitted in a solid angle of one steradian by a uniform point source having an intensity of one candela.

Lux: The International System unit of illumination, equal to one lumen per square meter (lm/m²).

NATURAL SOURCES OF ILLUMINATION

Moon - The major source of night illumination. The amount of illumination is dependent on phase and elevation.

Airglow - Light reflected from clouds (primarily cultural lighting).
Starlight

Zodiacal Light - A luminous tract in the sky seen in the west after sunset or in the east before sunrise and thought to be the light reflected from a cloud of meteoric matter revolving around the sun.

Gegenschein - A faint, elliptical patch of light in the night sky thought to be a reflection of sunlight by meteorical material in space.

Aurora - A radiant emission from the upper atmosphere that occurs sporadically over the middle and high latitudes of both hemispheres in the form of luminous bands or streamers caused by the bombardment of the atmosphere with charged solar particles that are being guided along the earth's magnetic lines of force.

Noctilucent Clouds - High altitude clouds visible during the short nights of summer.

OTHER SOURCES OF ILLUMINATION

Cultural Lighting - Lights show up extremely well with NVG's, and can dramatically change the appearance of populated areas. Bright lights wash out the surrounding scene, although the lighted area is enhanced.

Headlights - Headlights on highways parallel to course can be very distracting, and can also cause scene washout.

LIGHTING REQUIREMENTS AND LIMITATIONS

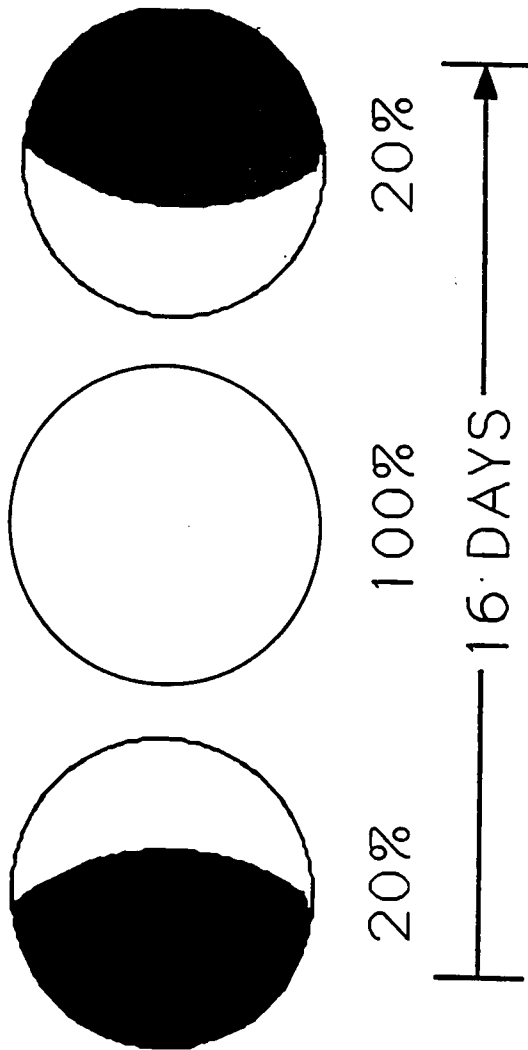
OUT-OF-COCKPIT

- INITIAL FLIGHT RULE: 20% MOON AT 30 DEGREES TO THE HORIZON
- ANY ILLUMINATION LEVEL BETWEEN MEAN STARLIGHT AND FULL MOON NAVFLIR REQUIRED IF LESS THAN A 20% MOON
- OPERATION IS POOR NEAR BRIGHT LIGHTS

IN-THE-COCKPIT

- ONLY NVG COMPATABLE GREEN PERMITTED IN COCKPIT
- WARNINGS / ANNUNCIATORS MUST BE FILTERED TO CREATE A COMPATABLE COCKPIT
- WHITE CHART / MAP LIGHTS MUST BE FILTERED
- LOOK AT THE HUD THROUGH NVG COMBINERS, DIRECTLY AT ALL OTHER INSTRUMENTS

MOON FACTORS



- Moon phase, elevation, and azimuth significantly affect NVG performance
- A minimum of 20% moon illumination is required for good contrast and resolution.
- Low moon angle causes shadowing, and creates glare problems when looking into it.
- Having the moon at your back enhances scene illumination. Moon azimuth is an important consideration when selecting target area tactics and run-in headings.

TWILIGHT DEFINITIONS

- Civil Twilight - From sunset until the sun is 6 deg below the horizon.
- Nautical Twilight - From sunset until the sun is 12 deg below the horizon.
- Astronomical Twilight - From sunset until the sun is 18 deg below the horizon.

Note: The glow of nautical twilight is enough to mask terrain features, especially when flying into the sun.

EFFECTS OF LIGHT

GAIN

- ANY LIGHT SEEN BY GOGGLES
WILL DRIVE GAIN DOWN

PROBLEM AREAS

- INSTRUMENT LIGHTS
- CONSOLE LIGHTS
- CANOPY REFLECTIONS
- PANEL REFLECTIONS

SIDE AFFECTS

- GAIN REDUCED
- DEGRADED VIEW

ILLUSIONS

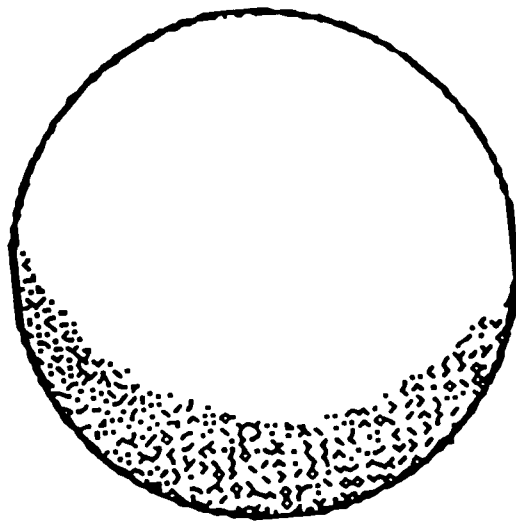
POSSIBLE ILLUSIONS / LIGHT TRICKS

SPARKLE / SCINTILLATION

FOG

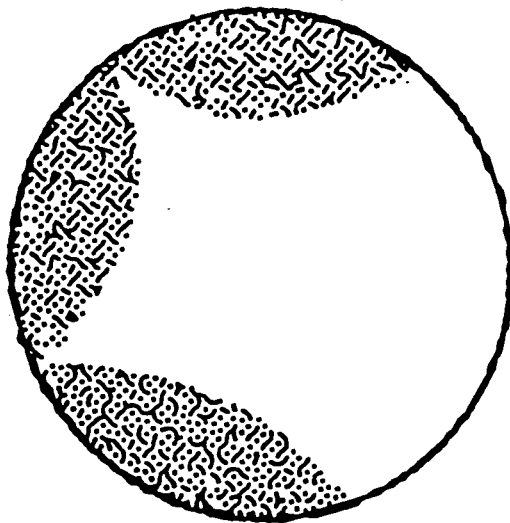
DEPTH PERCEPTION

SHADING



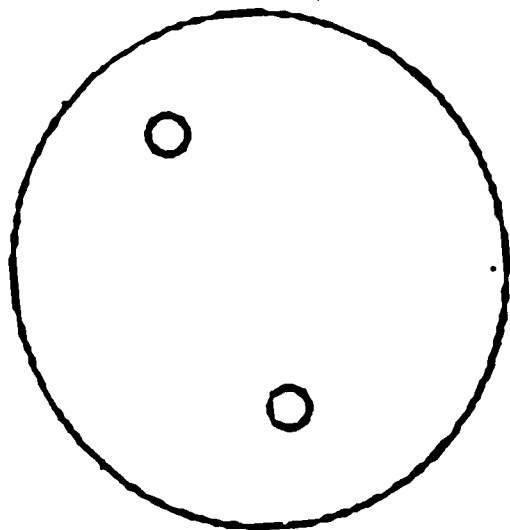
SHADING - BOTH TUBES SHOULD BE A PERFECT CIRCLE
(OR BASEBALL DIAMOND FOR CATS EYES). SHADING STARTS
ON THE EDGES AND MOVES INWARD.

EDGE GLOW



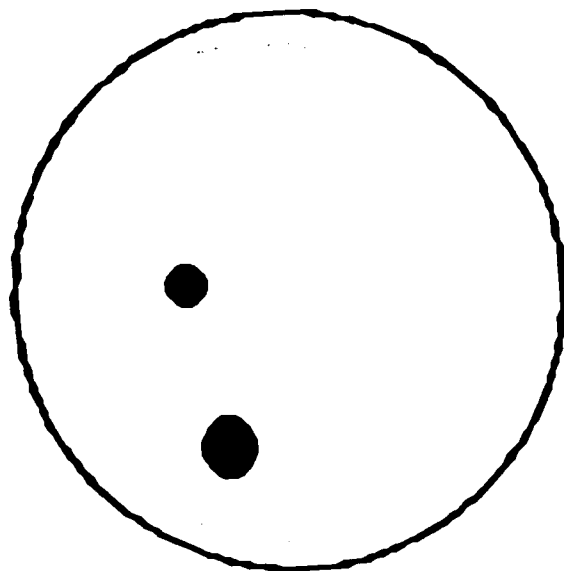
EDGE GLOW - CHECK BY BLOCKING LIGHT IN EACH LENS INDIVIDUALLY. THIS WILL BE A BRIGHT AREA IN OUTER PORTION.

BRIGHT SPOTS



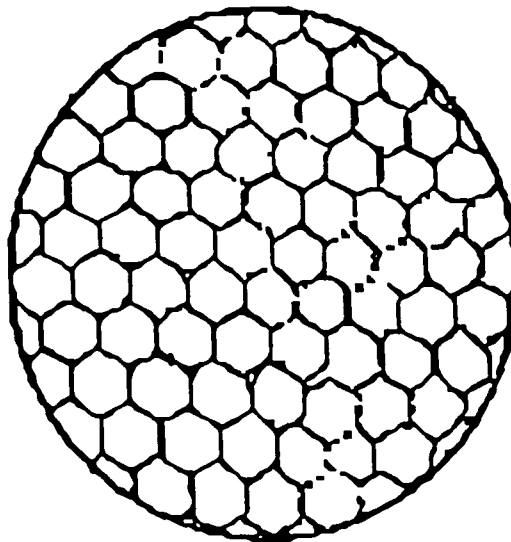
BRIGHT SPOTS - CAUSED BY PINHOLES IN PHOSPHOR.
CHECK BY COVERING EACH LENS INDIVIDUALLY.

DARK SPOTS



DARK SPOTS - BLACK MARKS CAUSED BY DEFICIENT CHANNELS
IN THE MCP. OK IF IT DOESN'T IMPAIR VISION.

HONEYCOMB

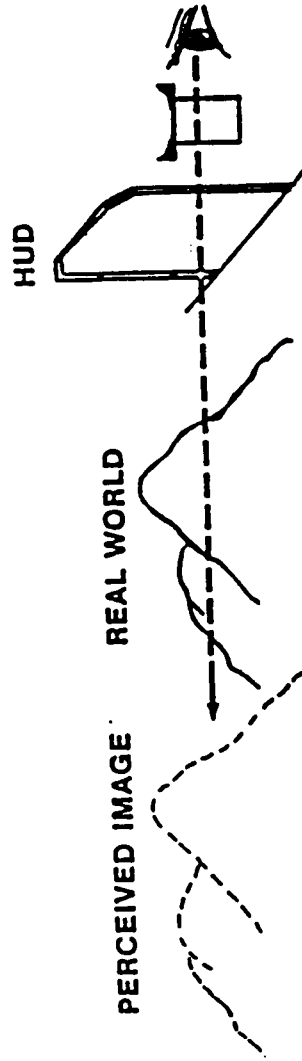


HONEYCOMB - RESULTING FROM FIXED PATTERN NOISE IN THE
MCP CAUSED BY HIGH LIGHT CONDITIONS.

WINDSCREEN/CANOPY TRANSMISSIVITY

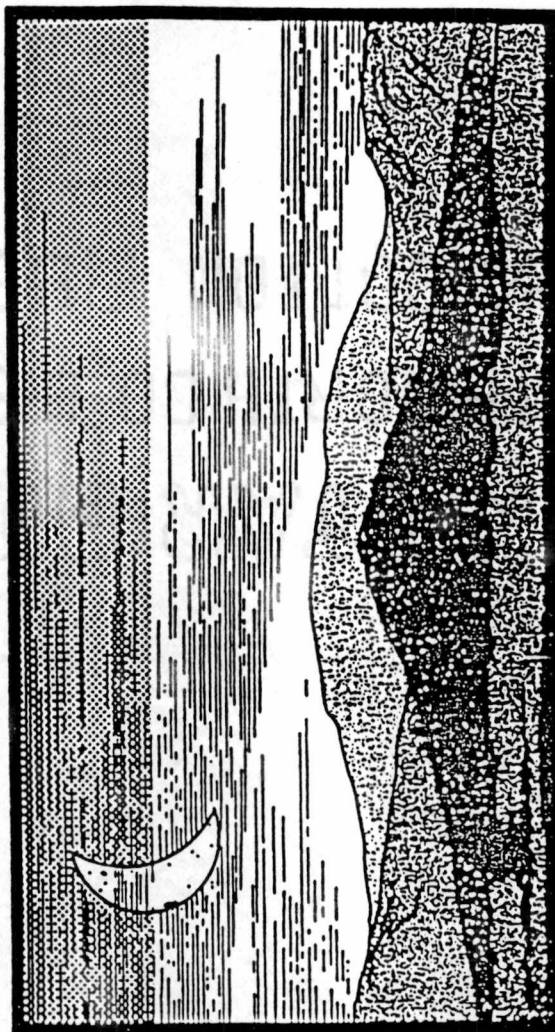
- The transmission of IR energy by windscreens and cockpit windows can be a significant problem.
- Designed to transmit visible light, many cockpit transparencies do not perform as well in the near infrared spectrum, and the transmissivity of some is very poor.
- Since NVGs (particularly GEN III) are primarily sensitive to the near IR portion of the spectrum, this can result in a serious reduction in goggle performance.
- Like the decreased visual performance resulting from incompatible cockpit lighting, the effect of decreased windscreen transmissivity may not be apparent to the aircrew.

INSTRUMENT MYOPIA



INSTRUMENT MYOPIA - In order to accommodate the image on the FLIR and NVGs, the eye perceives the displayed image as being further away than it actually is

SHADOWING



Shadowing - High terrain in the distance can completely obscure lower hills closer to the aircraft, particularly if the high terrain is between the aircraft and a light source. Rough or mountainous terrain can cast long shadows that completely obscure targets, checkpoints, and deadly flight hazards. One should plan to fly on the lighted side of valleys and not risk flying into an unseen ridgeline in an attempt to avoid a threat.

ATMOSPHERIC CONDITIONS

CLOUDS

- Decrease illumination and cause shadows.
- Broken layers cause variations in perceived ground texture.
Terrain can appear heavily forested when actually darkened by shadows.
- An overcast will reduce illumination below what is needed for NVG operations.

INDICATION OF CLOUDS

- Degrading NVG image quality, loss of moon and stars, and scintillation indicate clouds.

FOG

- Reduce light and blocks the NVG image. The chance of fog occurring increases as the temp/dewpoint spread decreases.

BLOWING SAND AND DUST

- Degrade the NVG scene dramatically.

TERRAIN FEATURES

LUMINANCE - A measure of how much light an object reflects.

CONTRAST - A determinant of NVG ability to discern terrain features. It is the difference in luminance between objects.

POOR CONTRAST - Contrast is wavelength dependent. Terrain with good contrast definition in the day may have little or no contrast at night.

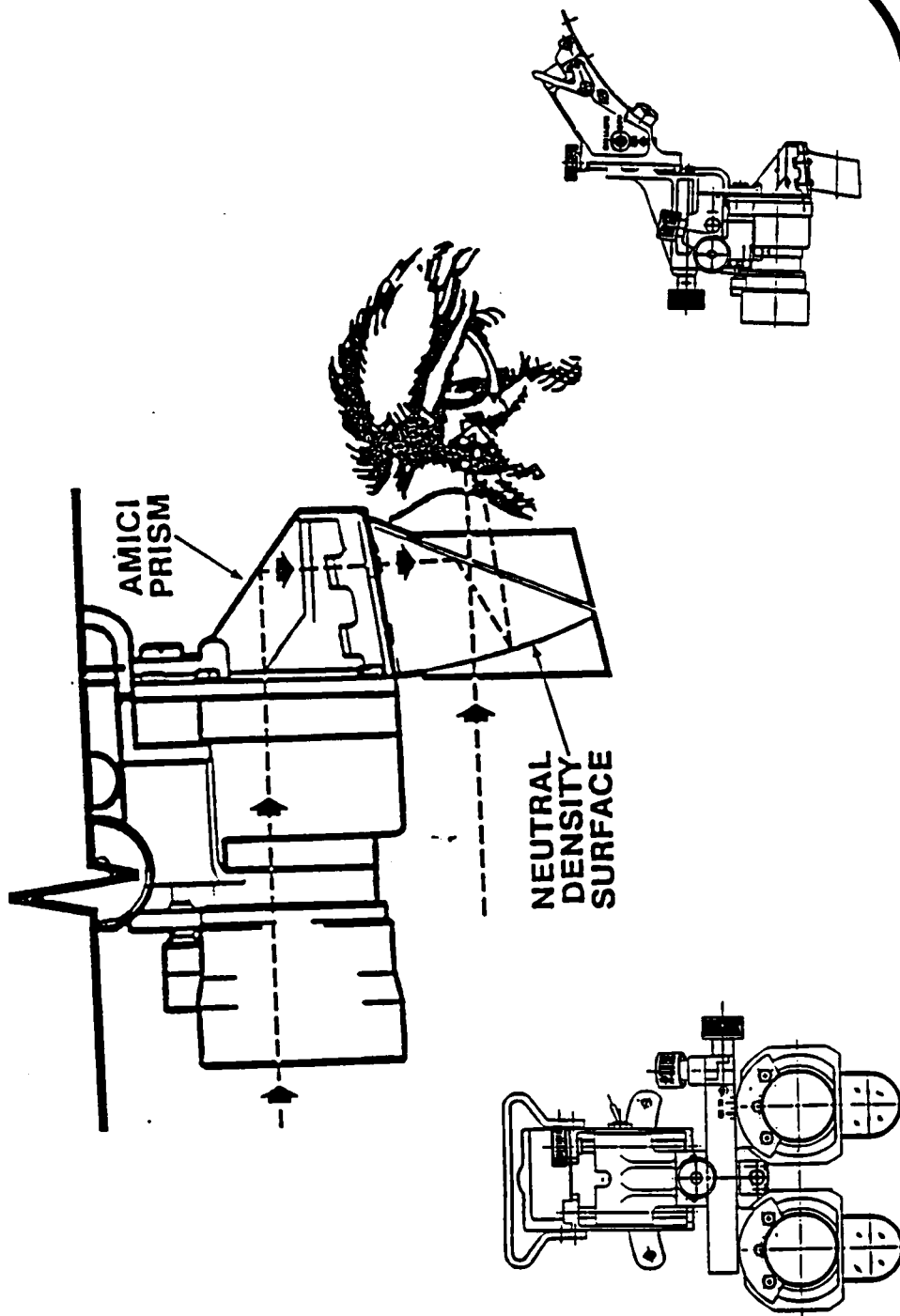
TEXTURE - Enhances the ability to discern details. Shadows give dimension to rolling terrain, and features with vertical development stand out more than flat landmarks.

WATER - NVG flight over water is not recommended due to the absence of a discernable horizon and lack of contrast in low sea states. Accomplish overwater flight on instruments.

HUMAN FACTORS CONCERNS

- NVG Comfort and Fit
- External and Internal Eye and Head Movement and FOV Analysis
- Neck Strain/Fatigue
- NVG Adjustment

CATS EYE GOGGLES



APPENDIX C
TEST PILOT SCHOOL NVG EVALUATION/DEMONSTRATION
HANDOUT AND BRIEF

**TEST PILOT SCHOOL
NIGHT VISION GOGGLE (NVG) EVAL/DEMO**

I. BACKGROUND

Reserve Forces are considering purchasing several _____ aircraft and modifying them with a Night Attack kit for the night strike fighter mission. The Night Attack equipped aircraft will be configured with a Targeting Forward Looking Infrared (TFLIR) pod and an NVG lighting modification kit to provide compatible cockpit lighting for night operations with CATS EYES Night Vision Goggles (NVGs). TPS class _____ has been tasked to assess the feasibility of incorporating a compatible NVG light modification kit into the _____ aircraft for flight with CATS EYES NVGs for the land/sea based night strike fighter mission.

II. PURPOSE

The purpose of this test is to qualitatively evaluate the feasibility of incorporating the Night Attack night lighting compatibility kit for use with the CAT's EYES NVGs to the _____ aircraft for the night strike fighter mission.

III. OBJECTIVES

The objectives of this exercise is to provide exposure to fixed wing night vision goggle operations and to night vision device cockpit compatibility evaluation techniques.

Specific areas to be evaluated include:

- a. Field of View (FOV)
- b. Field of Regard (FOR)
- c. Static/Dynamic Resolution
- d. Airspeed Effects
- e. Fault Detection/Failure modes
- f. Target Detection
- g. Target Identification
- h. Mission Utility
- i. Maximum Detection Range
- j. Maximum Identification Range
- k. Readability of Controls and Displays With NVGs Vice Without NVGs
- l. Compatibility of Cockpit Lighting
- m. Canopy Transmissivity
- n. Human Factors
 - Comfort and Fit
 - External and Internal Eye and Head Movement and FOV Analysis
 - Neck Strain/Fatigue
 - NVG Adjustment

IV. REFERENCES

- A. Aircraft Operating Manual
- B. TPS Night Vision Goggle SOP
- C. "Electro-Optical Systems Test and Evaluation",
Airborne Systems Course Textbook, USNTPS,
01 June 1981.
- D. USNTPS Systems Test Manual (Preliminary)
- E. "Night Attack Test Requirements Analysis", TACAIR
TECHNOLOGY DEPARTMENT, NAWC, October 1987.

V. PREREQUISITES

Completion of the NVG Night Lab prior to flight desired but not required.

VI. SCOPE

- A. One 1.0 hr Brief
- B. One 15 minute ground night lighting cockpit evaluation.
- C. One 1.5 hr Evaluation Flight.
- D. No TEST PLAN. The flight will be flown IAW this exercise brief in order to provide standardization. The Test Matrix and Envelope provided will be adhered to with minimal flexibility. Modifications approved by Monitor only, at least one day prior to flight.
- E.

Test Configurations

CONFIG	GEAR	FLAPS	S/B
CR	UP	AUTO	IN
PA	DN	FULL/HALF	IN

VII. METHOD OF TEST

A. Tests will be conducted IAW the exercise handout Test Matrix. Each test flight will include a 15 minute ground evaluation in a dark area of the field, NVG familiarization, and mission utility evaluation. In the event that the low altitude mission is flown, _____ low level points _____ to _____ will be utilized with a low altitude RTB and an NVG landing

demonstration. There will be no inflight low level kneeboard data recording. All inflight recording will be via voice tape recorders and Over-the-Shoulder cameras.

VIII. REPORT

A minimum of 6 paragraphs -- 2-Ground Eval -- 4-Flight Eval and a list of all deficiencies noted.

IX. SAFETY

A. This exercise is a high visibility project. There will be strict adherence to the TPS NVG SOP, and NVG EVAL exercise brief Test Matrix. Safety through Standardization. Flight briefs will be scheduled 2 hours prior to takeoff to cover all issues and to ensure proper fit of the helmet and CATS EYES night vision devices.

B. Illumination level prediction will be obtained by students prior to flight brief. Call the day prior to METRO to initiate.

C. Low levels (When applicable) will be scheduled by students or the OPS scheduler at least 2.5 hours prior to takeoff. Thorough chart study and route will be conducted.

D. Weather Mins: 3000/5 for both high and low altitude sorties.

E. Intentional Ejections with goggles are not allowed. Quick release removing of the goggles will be practiced in the flight brief and at the hold short prior to takeoff. In the event of an immediate ejection, aircrew will call, "GOGGLES, GOGGLES, GOGGLES" prior to calling for "EJECTION".

F. Minimum altitude to don and remove goggles is 3,000 ft AGL for high altitude sorties and 1,500 ft AGL for low altitude sorties with BARO Altitude hold and ATC selected.

G. No kneeboard data recording will be done by flight crew while below 3,000 ft AGL.

H. NVG Evaluation is primarily a systems integration evaluation, however, the rear cockpit evaluator will be allowed to fly the airplane on low gain tasks. High gain tasks being defined as Simulated Ground Attacks, Landings, Turns greater than 3g's, and flight at airspeeds greater than 420 KIAS.

I. Crew coordination is imperative and will be discussed in detail. Emergency procedures to be discussed will include NVG failures, ejections procedures, and bird strikes.

J. LOOKOUT - Distances can be deceiving and lights can be confusing while wearing NVGs. Be particularly aware of traffic. CATS EYES field of view is 30 degrees which necessitates greater and more frequent head movement.

K. Simulated attack profiles will be conducted IAW the Test Matrix. Avoid tendencies for target fixation.

L. MOTHERHOOD.

a. Night time - limited capability to write data and follow data cards -- Thus lots of prior study will be required especially since you did not write the test plan.

b. Be Careful!!!

c. See a Whole New World and have fun!!!!!!!

NVG "HIGH" ALTITUDE EVALUATION/DEMO FLIGHT BRIEF

BRIEF TIME: 1.5 HOUR

PREREQUISITES: NITE LAB SIMULATION COMPLETE

FLIGHT TIME: 1.5 HOUR DUAL

CREW: NVG INSTRUCTOR FRONT SEAT / STUDENT REAR SEAT

BRIEF

1. SOLICIT QUESTIONS ON NVG OPERATION AND PROCEDURES.
2. NVG BRIEFING GUIDE TO INCLUDE:

MISSION

1. GROUND
 - NVG HELMET INTERFACE
 - ADJUSTMENT PROCEDURES
 - ABILITY TO QUICKLY DON AND REMOVE GOGGLES
 - COMFORT
 - INTERIOR LIGHTING CONFIGURATIONS
 - EFFECT OF COCKPIT LIGHTING INTENSITIES
 - INCOMPATIBLE WARNING AND CAUTION LIGHTS
 - READABILITY OF CONTROLS
 - CANOPY TRANSMISSIVITY AND GLARE
 - LIGHT LEAKS
 - NVG PERFORMANCE WITH HUD
 - EXTERIOR LIGHTING CONFIGURATIONS/INTENSITIES
 - QUALITATIVE MEASURE OF NVG FIELD OF VIEW (FOV)
 - QUALITATIVE MEASURE OF NVG FIELD OF REGARD (FOR)
 - GROUND TAXI
 - FEASIBILITY OF TAXI ON UNLIT TAXIWAYS
 - DEPTH PERCEPTION CUES
2. TAKEOFF (TAKEOFF WITH NVGs IS PROHIBITED)
3. AREA FAM
 - DONNING PROCEDURES (3,000 FT AGL MINIMUM)
 - FIT
 - SCAN TECHNIQUES
 - OBSERVE NVG PHENOMENON
 - BLOOMING
 - COMET TRAILS
 - HONEYCOMB EFFECTS
 - EXTERNAL LIGHTING EFFECTS (MOON, STARS, CULTURAL)
 - NVG RESOLUTION
 - RESOLUTION VS. AIRSPEED
 - RESOLUTION VS. ALTITUDE
 - RESOLUTION VS. G
 - AIR-TO-AIR TARGET ENGAGEMENT CAPABILITY
4. TARGET ENGAGEMENT CAPABILITY
 - RADAR/FLIR DESIGNATION TO LEVEL LAYDOWN
 - RADAR/FLIR DESIGNATION TO 20 DEG DIVE
 - RADAR/FLIR DESIGNATION TO 30 DEG DIVE
 - RADAR/FLIR DESIGNATION TO 40 DEG DIVE
5. HIGH ALTITUDE MISSION UTILITY (15,000 FT MSL / 400 KIAS)
 - NAV/RADAR DESIGNATE NON-RADAR REFLECTIVE TARGET
 - PERFORM FLIR HANDOFF AND UPDATE DESIGNATION
 - TRANSITION TO VISUAL 40 DEG DIVE DELIVERY
6. RTB (DEGGGLE ABOVE 3,000 FT AGL)

DEBRIEF

NVG "LOW" ALTITUDE EVALUATION/DEMO FLIGHT BRIEF

BRIEF TIME: 1.5 HOUR

PREREQUISITES: NITE LAB SIMULATION COMPLETE

FLIGHT TIME: 1.5 HOUR DUAL

CREW: NVG INSTRUCTOR FRONT SEAT / STUDENT REAR SEAT

BRIEF

1. SOLICIT QUESTIONS ON NVG OPERATION AND PROCEDURES.
2. NVG BRIEFING GUIDE TO INCLUDE:

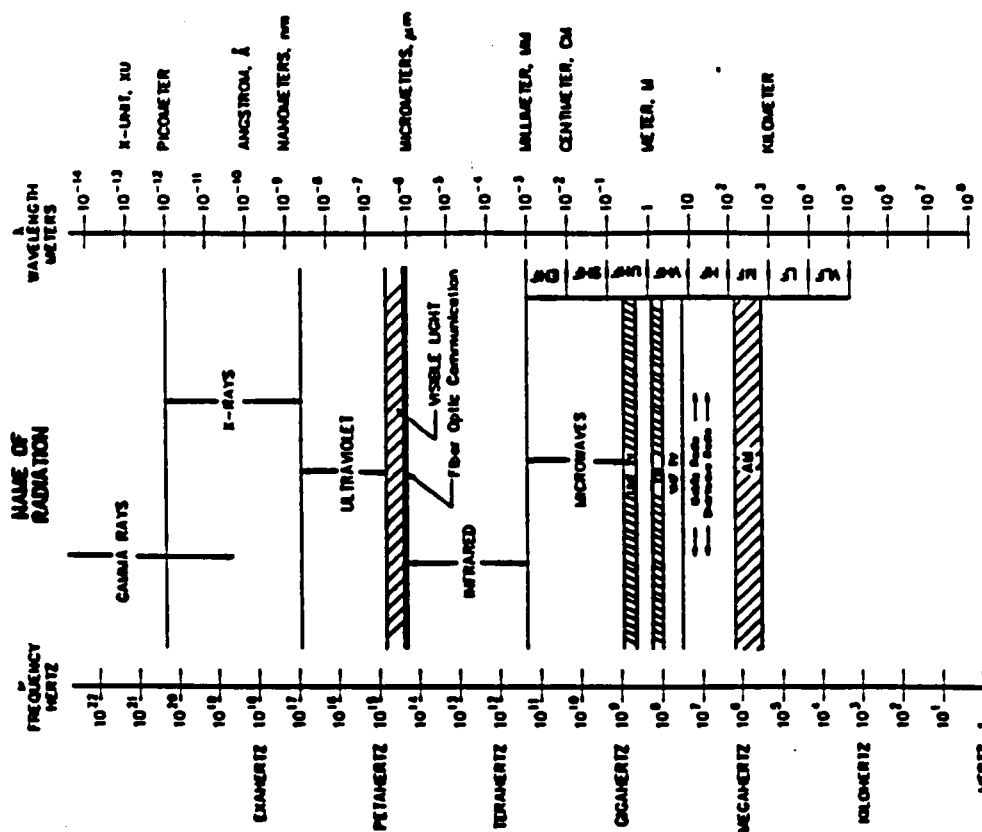
MISSION

1. GROUND
 - NVG HELMET INTERFACE
 - ADJUSTMENT PROCEDURES
 - ABILITY TO QUICKLY DON AND REMOVE GOGGLES
 - COMFORT
 - INTERIOR LIGHTING CONFIGURATIONS
 - EFFECT OF COCKPIT LIGHTING INTENSITIES
 - INCOMPATIBLE WARNING AND CAUTION LIGHTS
 - READABILITY OF CONTROLS
 - CANOPY TRANSMISSIVITY AND GLARE
 - LIGHT LEAKS
 - NVG PERFORMANCE WITH HUD
 - EXTERIOR LIGHTING CONFIGURATIONS/INTENSITIES
 - QUALITATIVE MEASURE OF NVG FIELD OF VIEW (FOD)
 - QUALITATIVE MEASURE OF NVG FIELD OF REGARD (FOR)
 - GROUND TAXI
 - FEASIBILITY OF TAXI ON UNLIT TAXIWAYS
 - DEPTH PERCEPTION CUES
2. TAKEOFF (TAKEOFF WITH NVGs IS PROHIBITED)
3. AREA FAM
 - DONNING PROCEDURES (1,500 FT AGL MINIMUM)
 - FIT
 - SCAN TECHNIQUES
 - OBSERVE NVG PHENOMENON
 - BLOOMING
 - COMET TRAILS
 - HONEYCOMB EFFECTS
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 - NAV/RADAR DESIGNATE NON-RADAR REFLECTIVE TARGET
 - PERFORM FLIR HANDOFF AND UPDATE DESIGNATION
 - TRANSITION TO VISUAL 40 DEG DIVE DELIVERY
5. LOW LEVEL MISSION UTILITY
 - NVG RESOLUTION
 - RESOLUTION VS. AIRSPEED
 - RESOLUTION VS. ALTITUDE
 - RESOLUTION VS. G
 - NAVIGATION CAPABILITY
 - TERRAIN AVOIDANCE
 - TARGET DETECTION MAX RANGE
 - TARGET ENGAGEMENT CAPABILITY
 - PERFORM RADAR LEVEL LAYDOWN
 - PERFORM RADAR POP-UP ATTACK
6. MEDIUM ALTITUDE RTB
 - A/A FEASIBILITY
 - MED ALT TARGET NAV CAPABILITY
7. LANDINGS
 - FEASIBILITY OF CONDUCTING NIGHTS OUT LANDINGS

DEBRIEF

“TEST PILOT SCHOOL NIGHT VISION GOGGLE EXERCISE BRIEF”

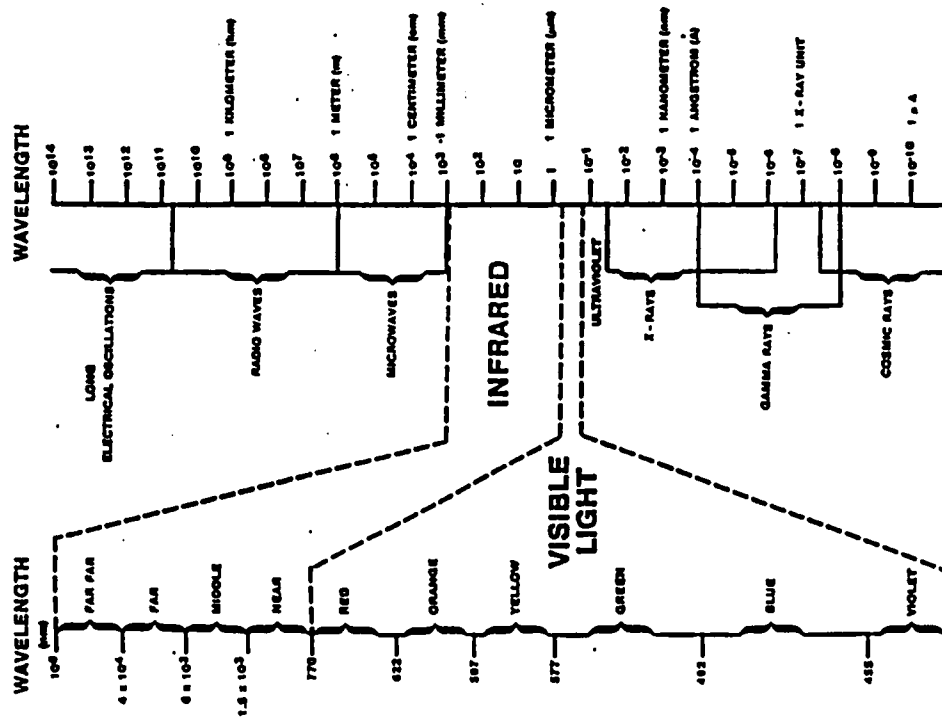
ELECTROMAGNETIC RADIATION SPECTRUM



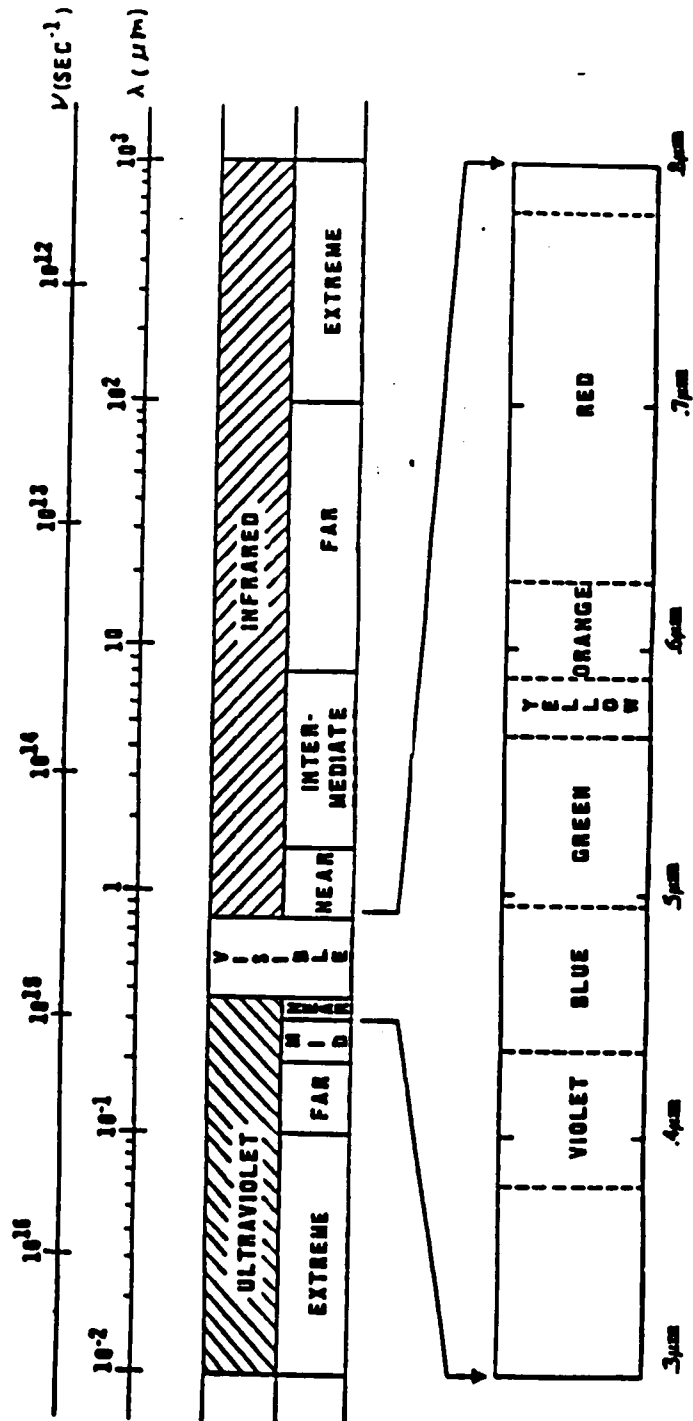
ELECTROMAGNETIC RADIATION SPECTRUM

- Only a small portion of the electromagnetic energy spectrum is detectable with sensors that are capable of passively detecting the energy that exists in the environment and producing an image that can be discerned visually.
- Millimeter and greater wavelengths require active transmitting devices such as radars to capture energy and map terrain and man-made objects that are then displayed in the cockpit.
- Passive imaging has few tactical applications below the ultraviolet wavelengths where energy is most commonly produced from astronomical and atomic reactions.
 - Such reactions are primarily detected as reflected energy from the sun, which precludes it from night applications

ELECTROMAGNETIC RADIATION SPECTRUM

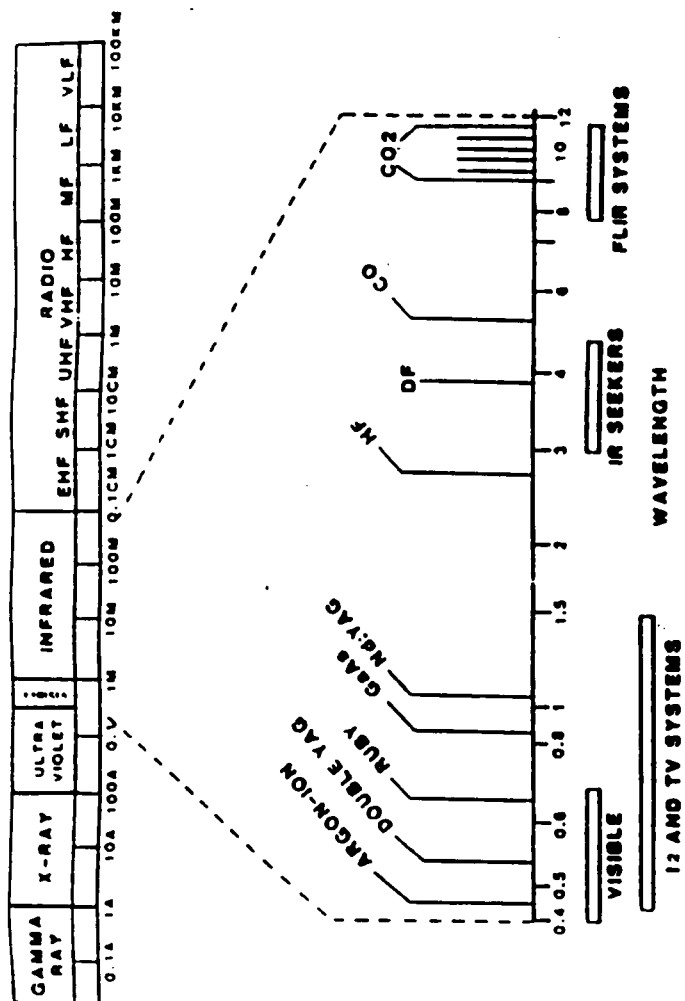


OPTICAL SPECTRUM

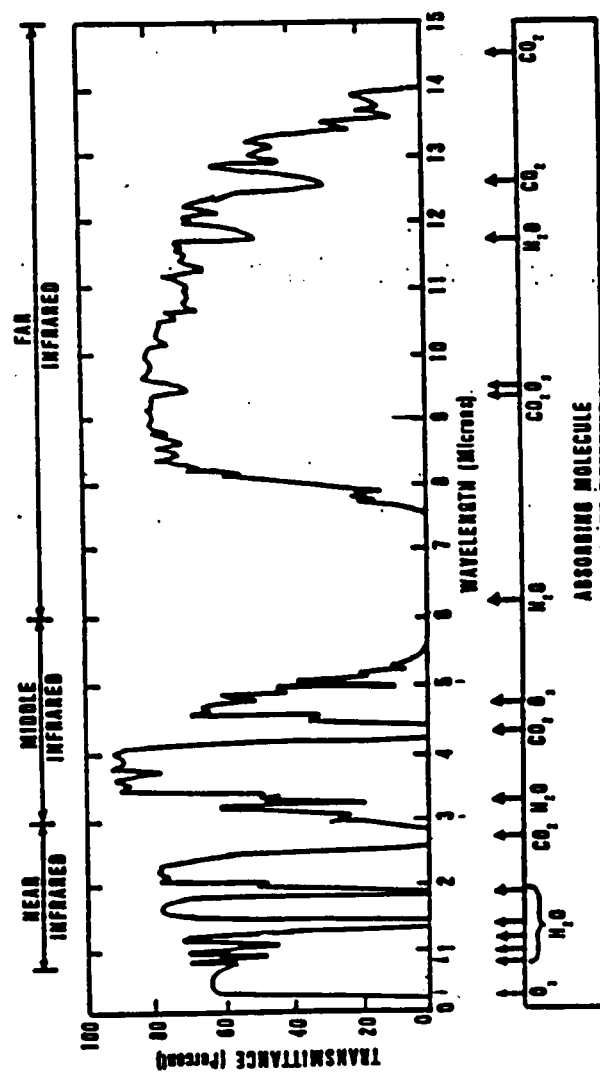


FREQUENCY BAND	WAVELENGTH	REMARKS
Ultraviolet	Below 0.40 Microns (4,000 Angstroms)	
Visible Violet Blue Green Yellow Orange Red	0.40 - 0.70 Microns 0.40 - 0.45 Microns 0.45 - 0.51 Microns 0.51 - 0.58 Microns 0.58 - 0.60 Microns 0.60 - 0.63 Microns 0.63 - 0.70 Microns	Operating Range Of Photo Camera
InfraRed (IR) Near IR Middle IR Far IR Extreme IR	0.70 - 10,000 Microns 0.70 - 1.50 Microns 1.50 - 5.6 Microns 5.60 - 1,000 Microns 1,000 - 10,000 Microns	Operating Range Of InfraRed Surveillance Using InfraRed Detectors
Hertzian (Radio) Waves EHF SHF UHF VHF HF MF LF VLF	1 mm - 1 cm 1 - 10 cm 10 cm - 1 m 1 - 10 m 10 - 100 m 100 - 1,000 m 1,000 - 10,000 m Greater Than 10,000 m	High Precision Radar High Resolution Radar Line-of-Sight Military and Commer Communications(TACAN), EW, GCI, FC. Military Comm, Long Distance Commercial Broadcasts Polar Comm, Area Cover Navigation Aids

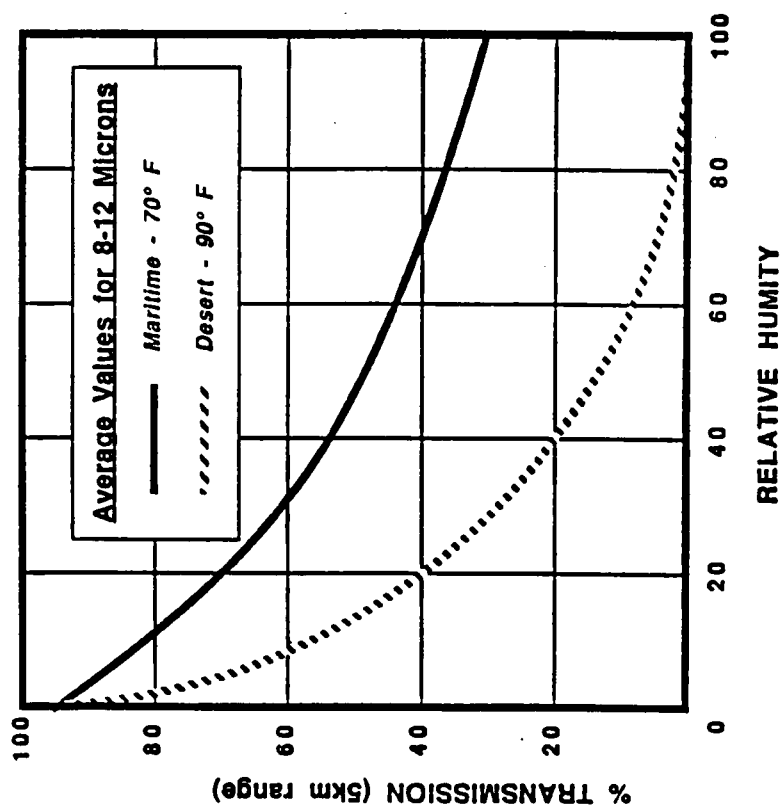
VISIBLE AND IR SPECTRUMS



INFRARED (IR) WINDOWS

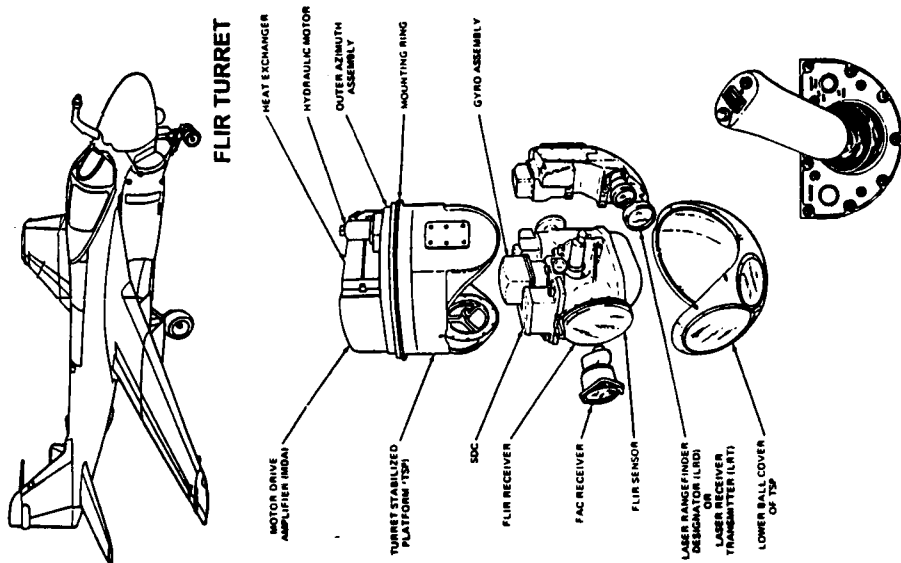


AFFECT OF WATER VAPOR ON TRANSMISSIVITY



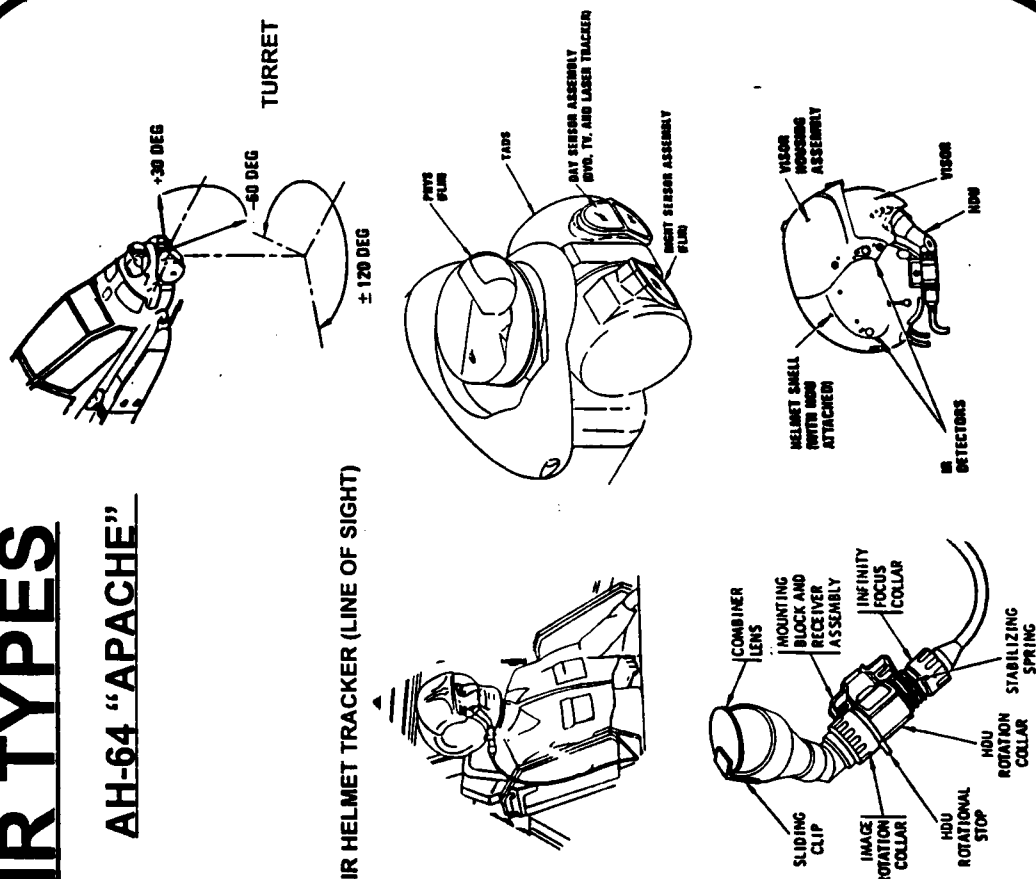
FLIR TYPES

A-6E "SWIP"



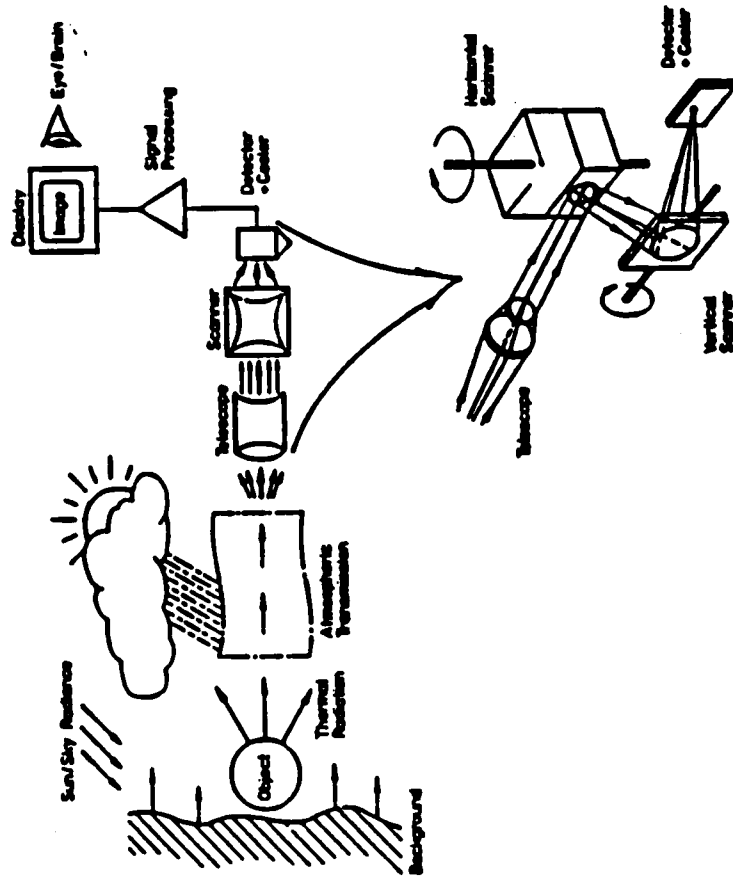
MANUAL SLEW GRIP

AH-64 "APACHE"



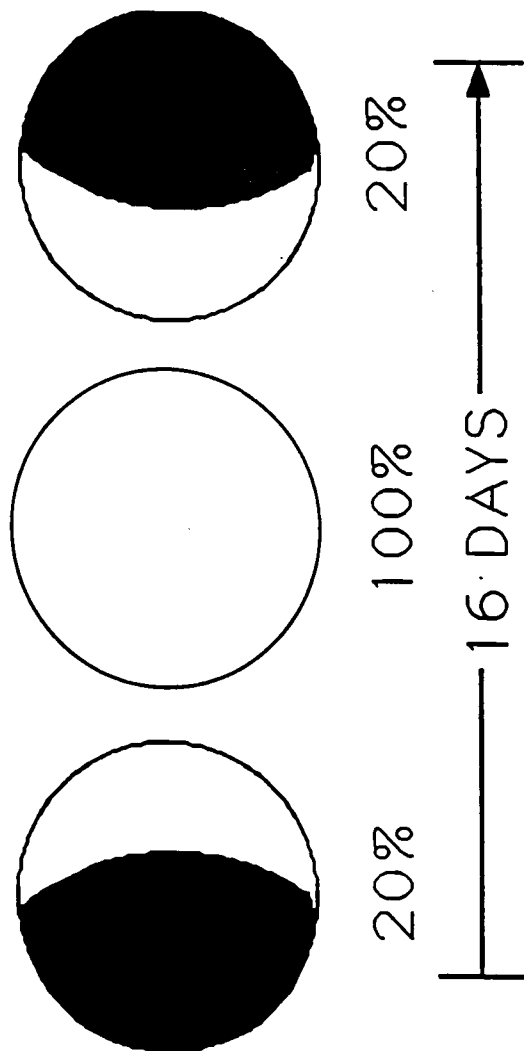
HELMET MOUNTED MONOCLE

SIMPLE FLIR SYSTEM



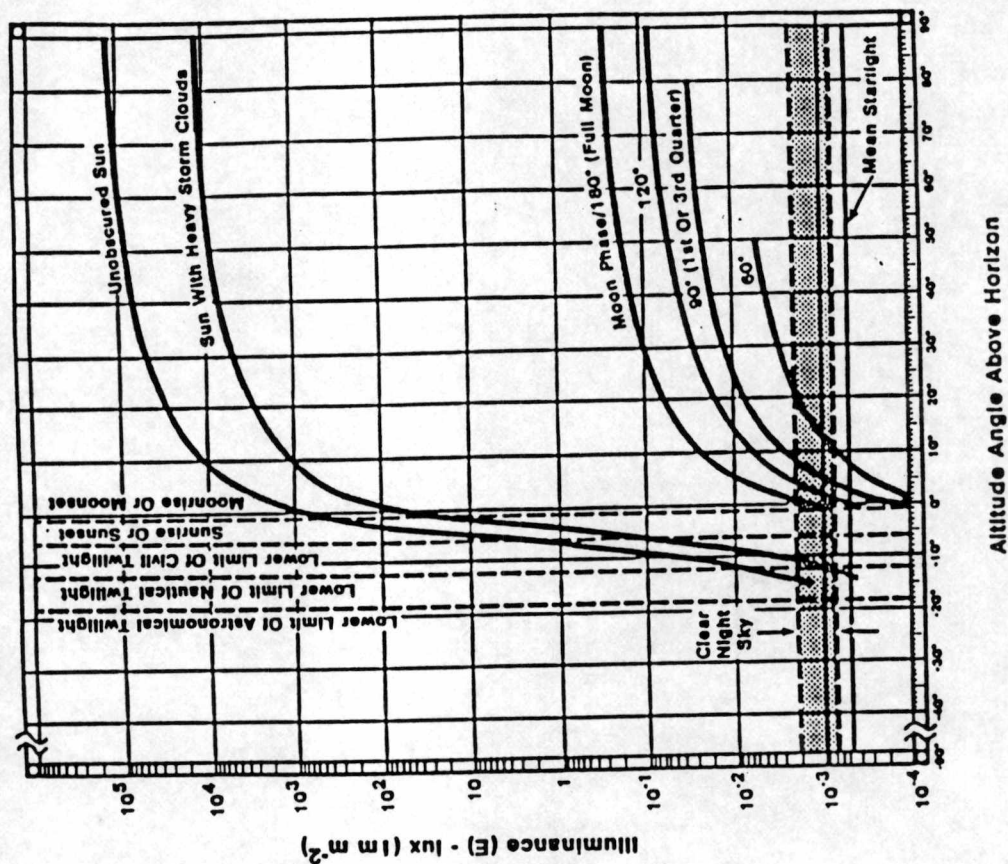
- Thermal Energy Equates To Approximately -- 270 to 300 Degrees Kelvin
- Scanner -- A Mirror Scans The Image Across A Fixed Detector. Some Scanners Have Horizontal And Vertical Scanners Dependent On The # And Arrangement Of The Detectors.
- Detectors Convert Thermal Energy Into Electrical Signals
- Signal Processing Can Take A Lot Of Forms (e.g. Light Emitting Diodes, Etc.)

MOON FACTORS



- Moon phase, elevation, and azimuth significantly affect NVG performance
- A minimum of 20% moon illumination is required for good contrast and resolution.
- Low moon angle causes shadowing, and creates glare problems when looking into it.
- Having the moon at your back enhances scene illumination. Moon azimuth is an important consideration when selecting target area tactics and run-in headings.

ILLUMINATION OF THE MOON



LIGHT LEVEL PLANNING CALENDAR

Flight Level Planning Calendar

1990-1991

Daylight Savings Time: NO

Boundary Value = 0.0022 lux

Lat: 38°17.3'
Long: 76°25.0'

Ver: 10.0°V

Start:	1 Dec 1994	1700
Stop:	11 Dec 1994	0800

31 Dec 1994 0800

Time Zone: -5 CDT/EST

For	Moan	Sun	2nd	1700	1800	1900	2000	2100	2200	2300	2400	0100	0200	0300	0400	0500	0600	0700	0800	For	Moan	Sun	
PM on	R/S	set	2640																	AM on	R/S	rise	
1	1 Dec	1552	1641	1%																2	Dec	10629	0709
2	2 Dec	1567	1641	0%																3	Dec	10736	0710
3	3 Dec	1574	1641	2%																4	Dec	10836	0711
4	4 Dec	1585	1640	7%																5	Dec	10929	0712
5	5 Dec	16002	1640	16%																6	Dec	11014	0713
6	6 Dec	16109	1640	23%																7	Dec	11055	0714
7	7 Dec	162215	1640	33%																8	Dec	11128	0715
8	8 Dec	162317	1640	43%																9	Dec	none	0716
9	9 Dec	none	1640	53%																10	Dec	112014	0716
10	10 Dec	16231	1640	63%																11	Dec	11212	0717
11	11 Dec	16101	1641	72%																12	Dec	10210	0718
12	12 Dec	16132	1641	80%																13	Dec	10306	0719
13	13 Dec	16104	1641	87%																14	Dec	10401	0719
14	14 Dec	16160	1642	99%																15	Dec	10456	0720
15	15 Dec	16160	1641	97%																16	Dec	10548	0721
16	16 Dec	16101	1642	99%																17	Dec	10639	0721
17	17 Dec	16649	1642	100%																18	Dec	10726	0722
18	18 Dec	16760	1642	99%																19	Dec	10810	0723
19	19 Dec	16183	1643	96%																20	Dec	10850	0723
20	20 Dec	161932	1643	91%																21	Dec	10927	0724
21	21 Dec	162031	1644	84%																22	Dec	11001	0724
22	22 Dec	162132	1644	76%																23	Dec	11034	0725
23	23 Dec	162233	1645	67%																24	Dec	11107	0725
24	24 Dec	162336	1645	56%																25	Dec	none	0726
25	25 Dec	none	1646	45%																26	Dec	10042	0726
26	26 Dec	16219	1647	34%																27	Dec	10148	0726
27	27 Dec	16258	1647	24%																28	Dec	10257	0727
28	28 Dec	16342	1648	15%																			

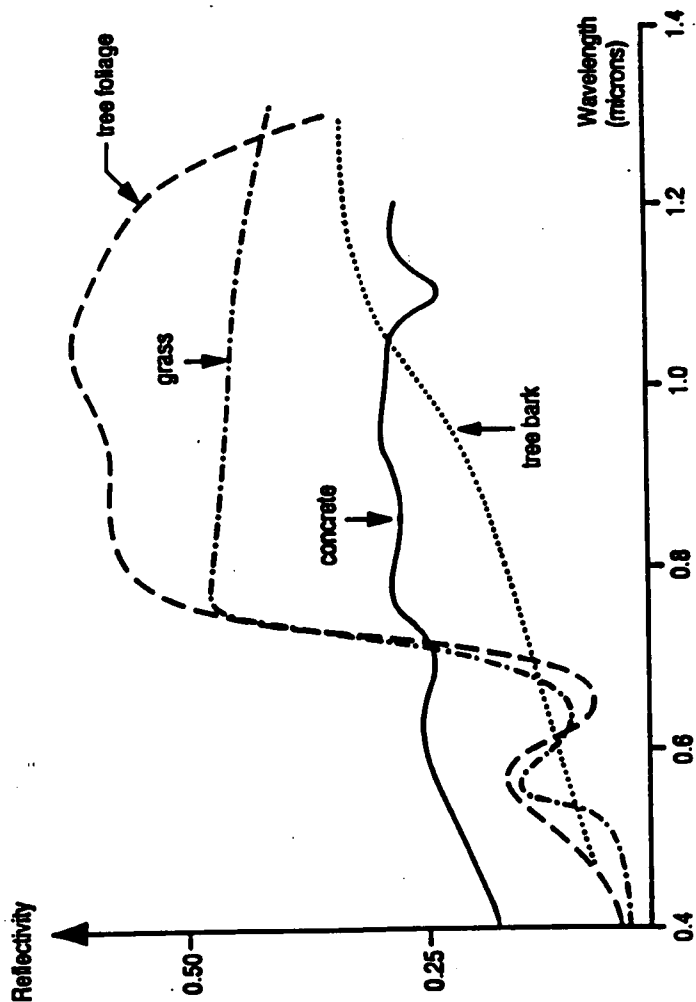
...	(nd/cates \$un above	hor/zon	###	nd/cates	Mean	hor/zon
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----- indicates sun above horizon.
 indicates moon below horizon.
 (indicates the Moon is at least 20 percent illuminated and at least 30 degrees above the horizon)

***** INDICATES THE MEAN IS AT LEAST 20 PERCENT ILLUMINATED AND AT LEAST 30 ABOVE HORIZON
***** INDICATES MEAN LIGHT LEVEL GREATER THAN OR EQUAL TO 0.0022 LUX BUT MEAN NOT 20% ILLUM OR NOT 30 DEG ABOVE HORIZON

[illegible]

SPECTRAL REFLECTIVITY OF OBJECTS



- The Chlorophyll In Tree Foliage And Grass Is Highly Reflective Compared To Concrete And/Or Tree Bark and Asphalt

STARLIGHT SCOPE

- INITIAL IMAGE INTENSIFIER
- VERY LARGE AND CUMBERSOME
- REQUIRED COVERT IR LIGHT SOURCE TO ILLUMINATE DESIRED AREA TO BE VIEWED
- THE BEST ATTAINABLE ACUITY LESS THAN 20/100
- DEEMED UNSATISFACTORY FOR AVIATION USE

NVG - GEN I SERIES INTENSIFIERS

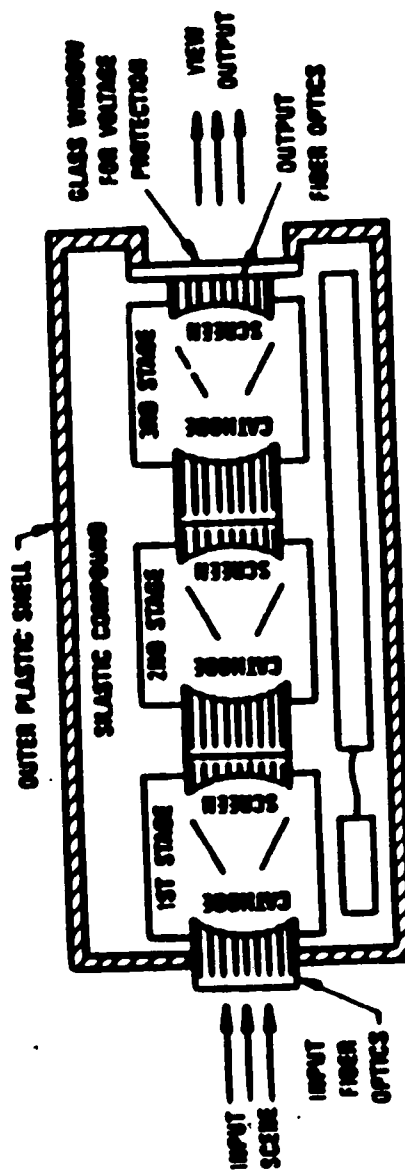
FEATURES:

- TYPICAL GAIN OF 25K (ELECTRONS AMPLIFIED 25K TIMES)
- USED A THREE STAGE CASCADE AMPLIFIER
- ELECTRON PICTURE CREATED USING
ELECTROSTATIC AMPLIFICATION
- 10,000 HOURS RELIABILITY

DRAWBACKS:

- BULK WAS MOST SIGNIFICANT DRAWBACK
- TUBES TOO LARGE FOR AIRCRAFT USE
- BATTERIES TOO HEAVY
- REQUIRED AC TO DC CONVERTER
- BRIGHT LIGHTS CAUSED PHOSPHOR SCREEN
TO DEVELOP BLACK "BURN" MARKS

NVG - GEN I SERIES INTENSIFIERS



NVG - GEN II SERIES INTENSIFIERS

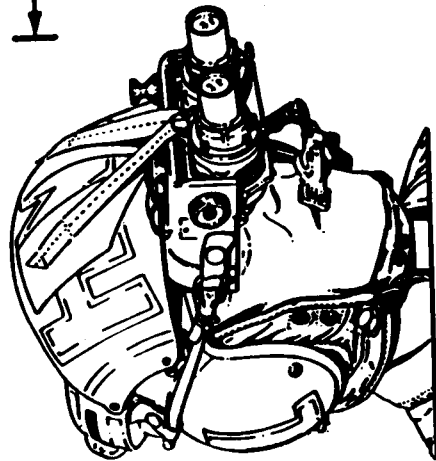
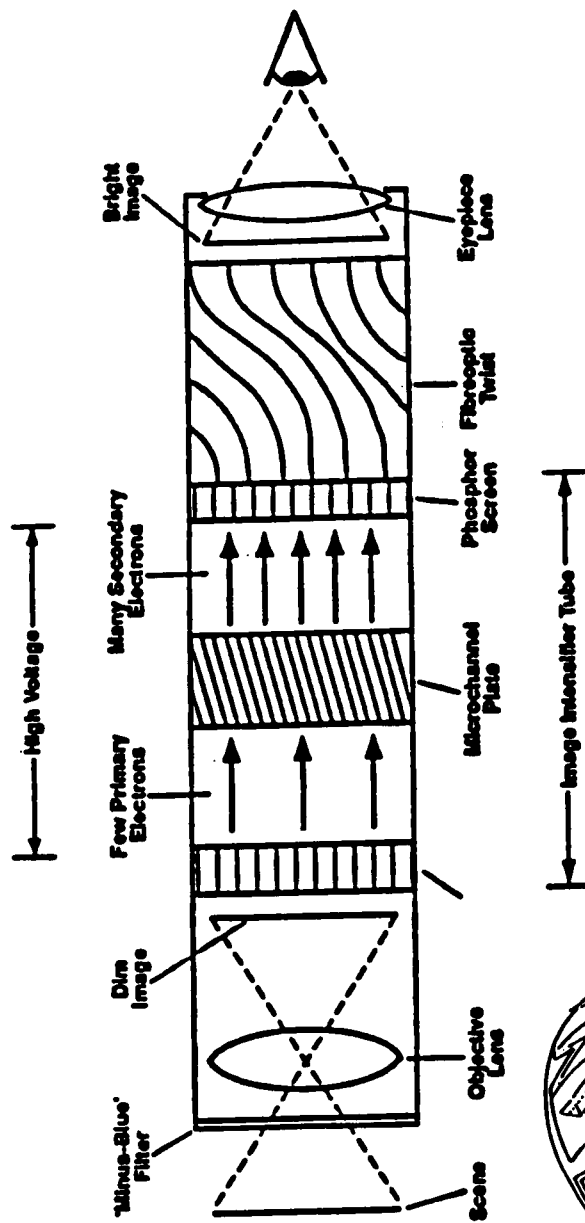
FEATURES:

- RESULTED FROM 70s SEMICONDUCTOR TECHNOLOGY
- ELECTRONS IMMEDIATELY HIT MICROCHANNEL PLATE
- MICROCHANNEL PLATE ONLY 1MM THICK
- 1.5 MILLION TINY TUBES IN MICROCHANNEL PLATE
- USED MUCH LESS POWER
- COULD NOW BE FITTED ON HELMETS FOR USE IN AIRCRAFT

DRAWBACKS:

- LIMITED USEFUL OPERATING RANGE (1/4 MOONLIGHT MIN)
- LESS INTENSIFICATION THAN GEN I (15K vs 25K)
- POORER RESOLUTION THAN GEN I
- TUBE LIFE REDUCED TO 3,000 HOURS

NVG - GEN II SERIES INTENSIFIERS



NVG - GEN III SERIES INTENSIFIERS

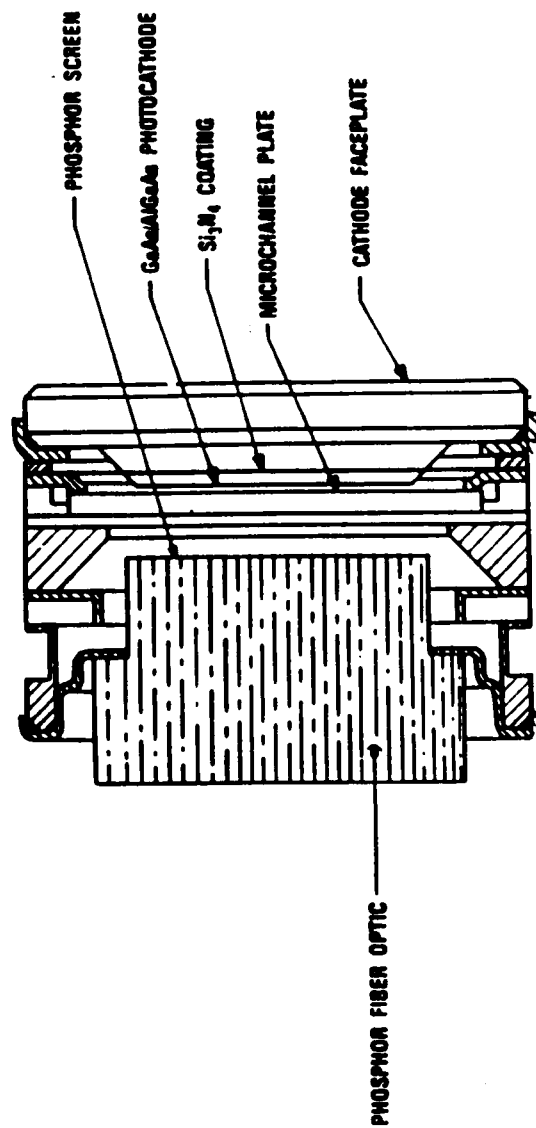
FEATURES:

- OPERATE UNDER STARLIGHT CONDITIONS
- PHOTOCATHODE 5X MORE SENSITIVE THAN GEN II DUE TO THE INCORPORATION OF GALLIUM ARSENIDE (GaAs) WHICH IS GROWN IN A HERMETICALLY SEALED ENVIRONMENT
- GAIN UP TO 30,000
- TUBE LIFE UP TO 10,000 HOURS

DRAWBACKS:

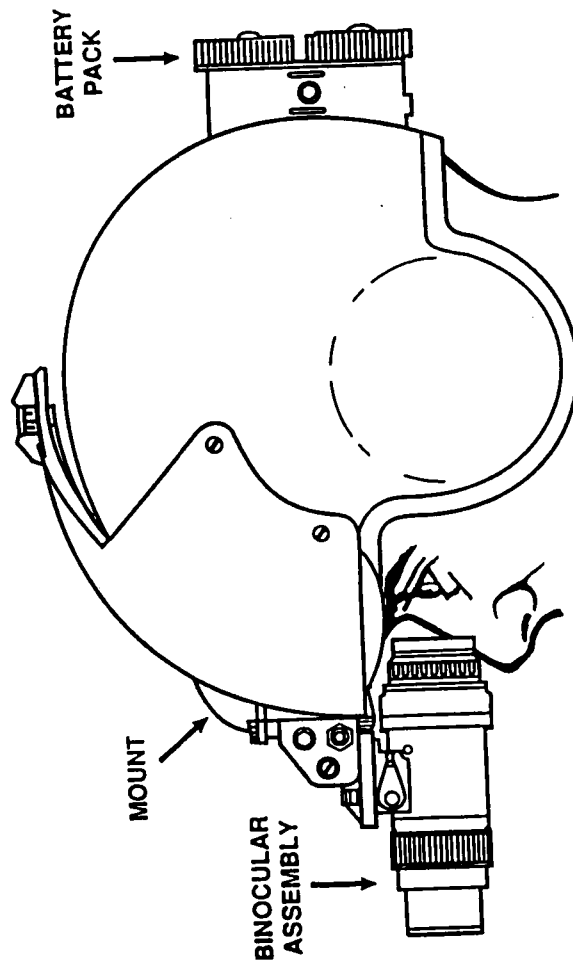
- REQUIRES 5 DAYS TO GROW GaAs PHOTOCATHODE
- 85% INDUSTRIAL PRODUCTION SUCCESS RATE FOR GaAs PHOTOCATHODE

NVG - GEN III SERIES INTENSIFIERS



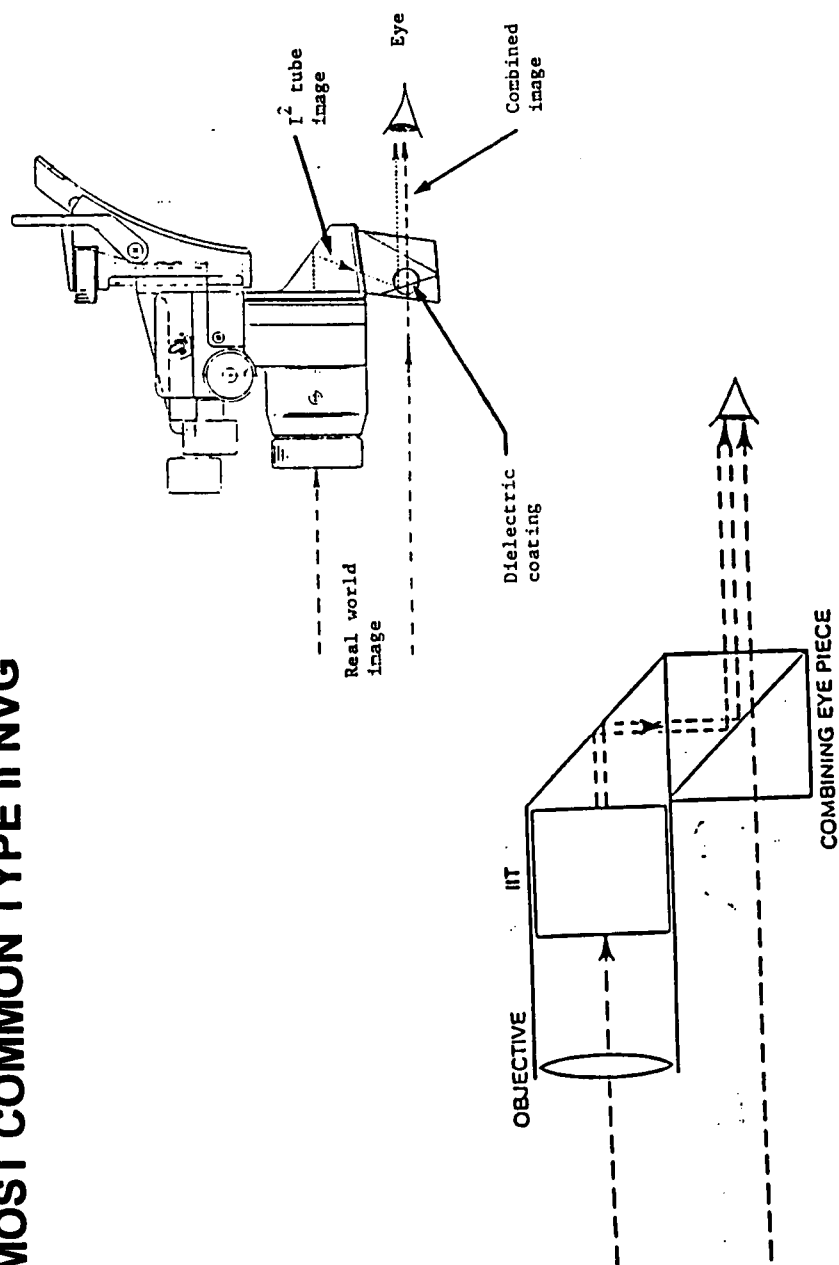
ANVIS (Aviator's Night Vision Imaging System) **NVGS**

- MOST COMMON TYPE I NVG - CONSIST OF THREE
MAJOR COMPONENTS

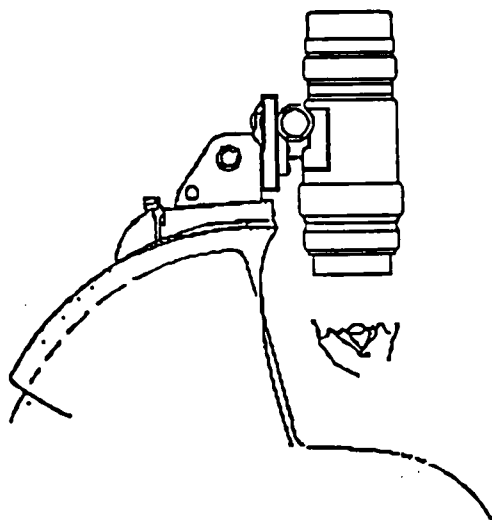


CATS EYES NVGS

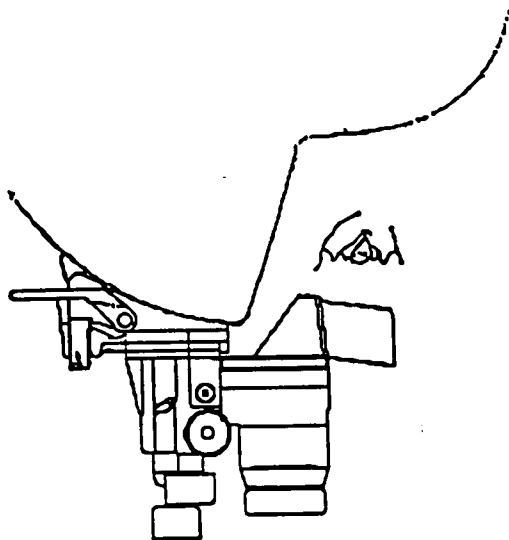
- MOST COMMON TYPE II NVG



NVG TYPE I AND TYPE II COMPARISON



ANVIS



CATS EYE

FIELD OF VIEW

40 DEG CIRCULAR

ACUITY (OPTIMAL CONDITIONS) 20/40

WEIGHT

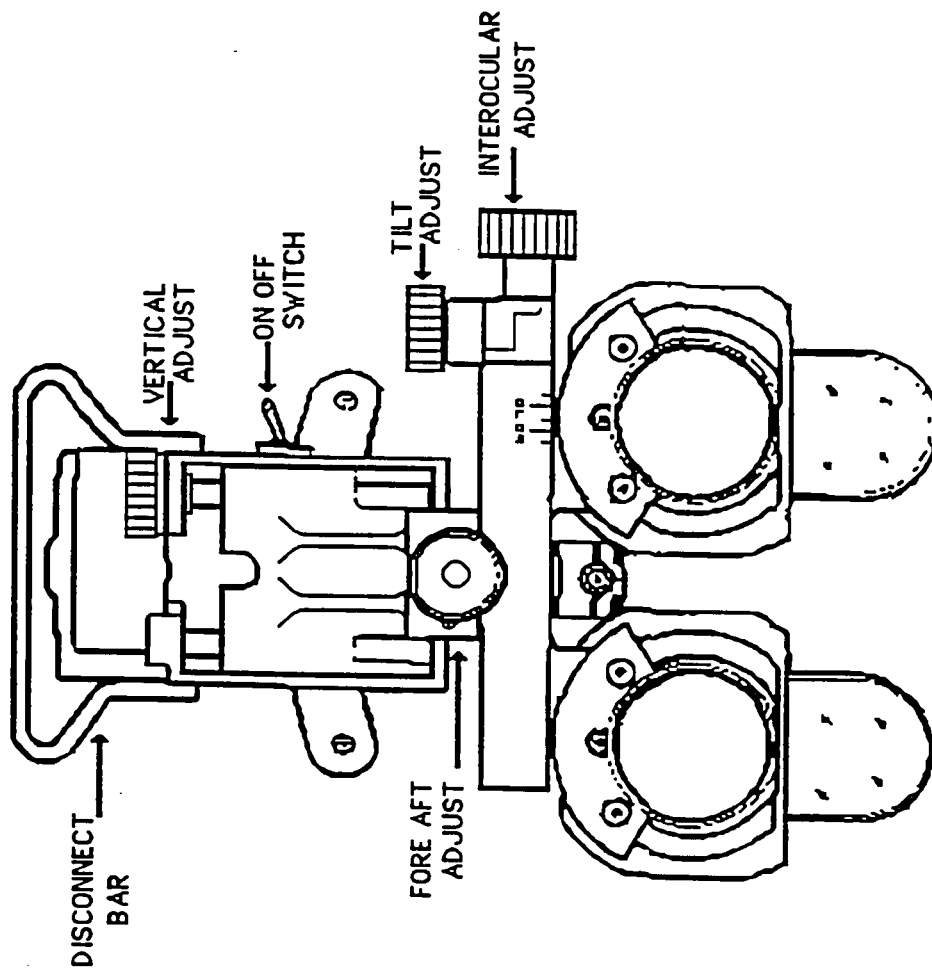
600 GRAMS

30 DEG SEMI-CIRCULAR

20/40

820 GRAMS

CATS EYE ADJUSTMENTS



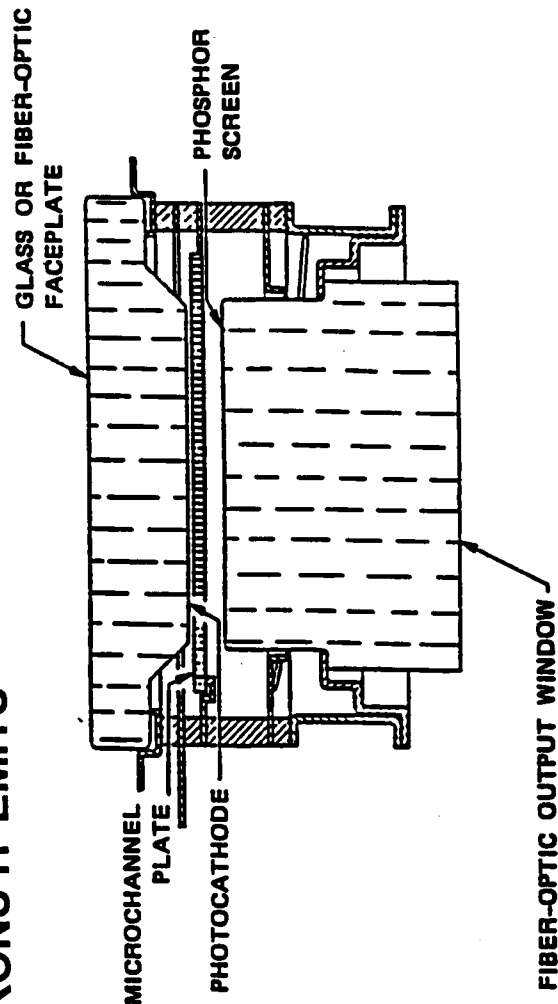
NVG IMAGE INTENSIFIER DETAILS

- IMAGE INTENSIFIER TUBE (IIT) HOUSING
- FIELD LENS:
 - FOCUSES LIGHT INTO IIT
- PHOTOCATHODE
 - TURNS LIGHT INTO ELECTRONS
- MICROCHANNEL PLATE (MCP)
 - AMPLIFIES ELECTRONS
- PHOSPHOR SCREEN
 - RECREATES IMAGE WITH AMPLIFIED ELECTRONS
- COLLIMATING LENS/COMBINER
 - DISPLAYS IMAGE TO OPERATOR

PHOTOCATHODE FUNCTION

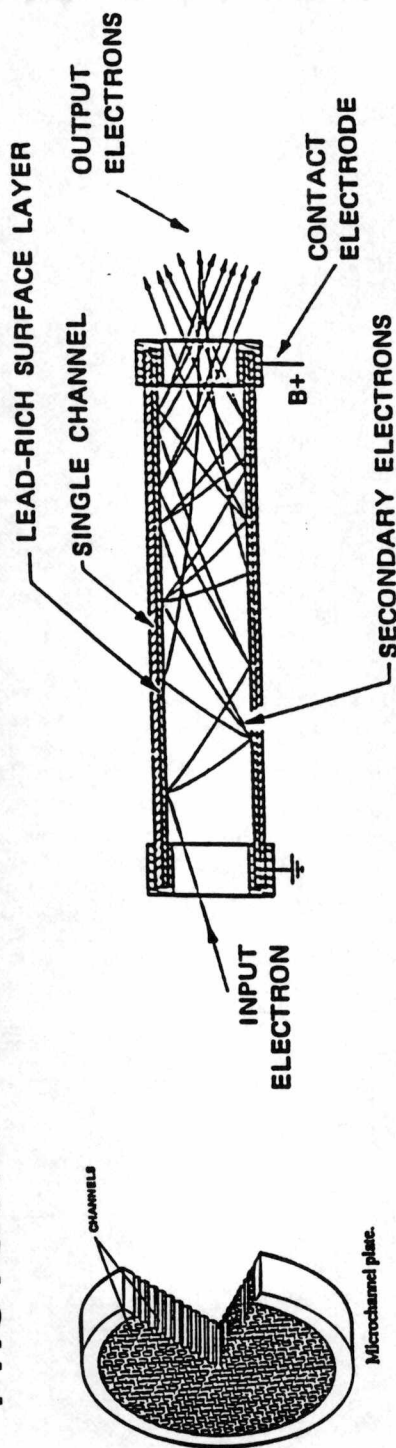
“CHANGE PHOTONS INTO ELECTRONS”

- IN GEN III TUBES THEY ARE MADE OF GALLIUM ARSENIDE (GaAs)
- IN USE, A HIGH NEGATIVE ELECTRICAL POTENTIAL IS APPLIED TO THE PHOTOCATHODE TO CAUSE IT TO ACTIVELY REPEL THE ELECTRONS IT EMITS



MICROCHANNEL PLATE FUNCTION

“COLLECT ELECTRONS EMITTED FROM
PHOTOCATHODE AND BOOST THEIR QUANTITY”



- ELECTRONS RELEASED FROM THE PHOTOCATHODE ENTER THE MICROCHANNELS AND BOUNCE OFF THE WALLS NEAR THE ENTRANCE (MCP IS COVERED WITH A LEAD COATING)
- ELECTRONS COLLIDING WITH THE CHANNEL WALLS KNOCK 2 OR 3 MORE ELECTRONS FREE AS THEY REBOUND (SECONDARY EMISSION)
- ELECTRONS REPEATEDLY COLLIDE WITH THE WALLS OF THE BORES AS THEY TRAVEL THROUGH MULTIPLYING IN NUMBER WITH EACH COLLISION. THOUSANDS OF ELECTRONS LEAVE EACH BORE FOR EACH ONE ENTERING.

MICROCHANNEL PLATE DESIGN

- A MCP IS BUILT UP OF GLASS FIBERS (GOOD FOR 10,000 HOURS)
- CONSTRUCTION STARTS WITH A COAXIAL ROD. THE OUTSIDE IS A HARD LEAD-RICH GLASS. THE INNER CORE IS A SOFT GLASS
- THE COAXIAL ROD IS HEATED AND STRETCHED THIN. THEN IT IS CUT INTO EQUAL LENGTHS AND THE PIECES ARE PACKED TOGETHER IN PARALLEL TO MAKE A BUNDLE
- THE BUNDLE IS FUSED TOGETHER AND STRETCHED AGAIN. THE PROCESS IS REPEATED UNTIL A BLANK CONTAINING ABOUT 2 MILLION FIBERS IS BUILT UP
- THE BLANK IS SLICED INTO THIN WAFERS, WHICH ARE PLACED INTO AN ACID BATH TO ETCH OUT THE SOFT GLASS CORES, LEAVING BEHIND A LEAD GLASS HONEYCOMB LIKE MATRIX
- THE ETCHED WAFERS ARE PLACED IN A HOT HYDROGEN FURNACE TO DERIVE A LEAD RICH LAYER IN THE LINING OF THE MICROSCOPIC BORE WALLS.

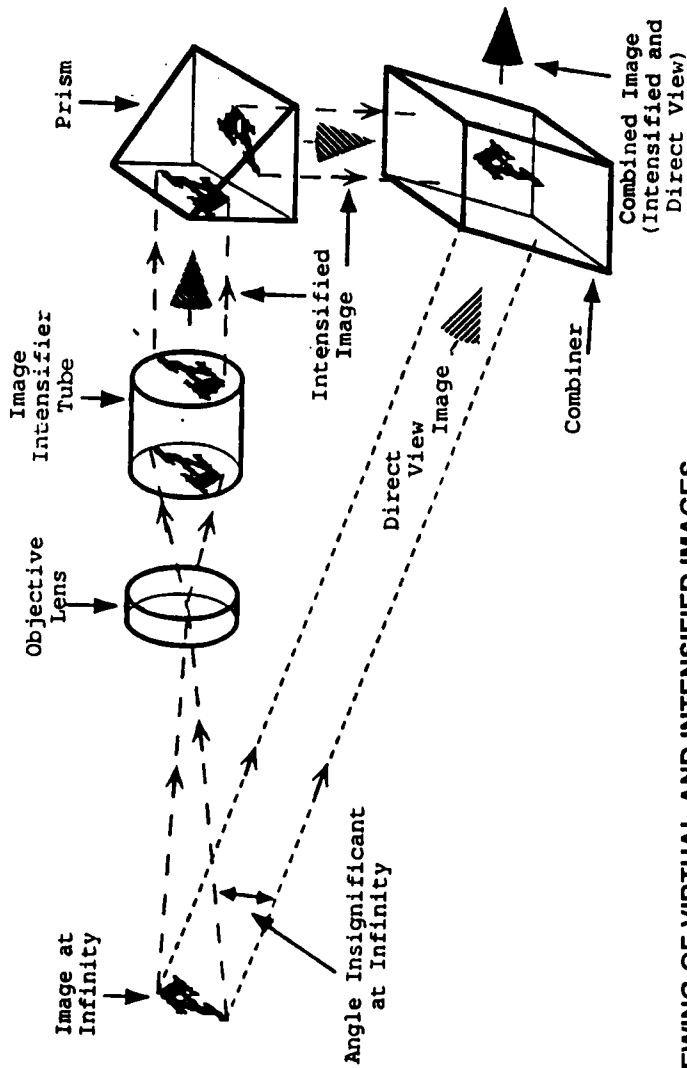
PHOSPHOR SCREEN

“RECREATES IMAGE WITH AMPLIFIED ELECTRONS”

- YELLOW-GREEN TO EXPLOIT PHOTOPIC VISION ABILITY
- RCA-1052 IN EARLY GEN III TUBES:
 - 0.530 MICRON WAVELENGTH (WARM GREEN)
- PRODUCES “SMOOTH” IMAGE
- P-20 USED IN PRODUCTION GEN II TUBES:
 - 0.560 MICRON WAVELENGTH (YELLOW-GREEN)
- CLOSELY MATCHES HUD PHOSPHER
- GREATER SCINTILLATION IN LOW LIGHT CONDITIONS
- GREATER RESOLUTION

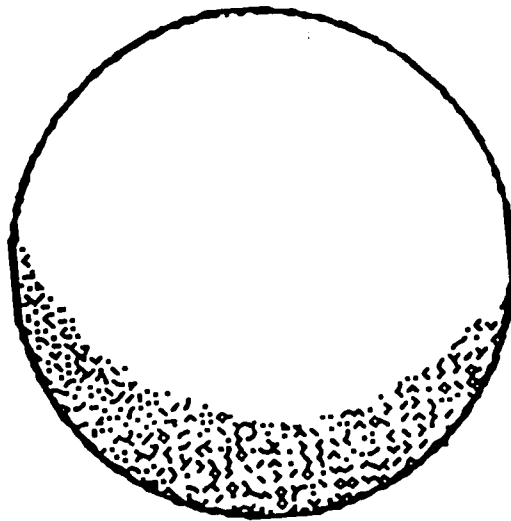
COLLIMATING LENS / COMBINING OPTICS

"PROJECTS THE IMAGE TO OPTICAL INFINITY AND POSITIONS THE IMAGE IN FRONT OF THE USERS EYES"



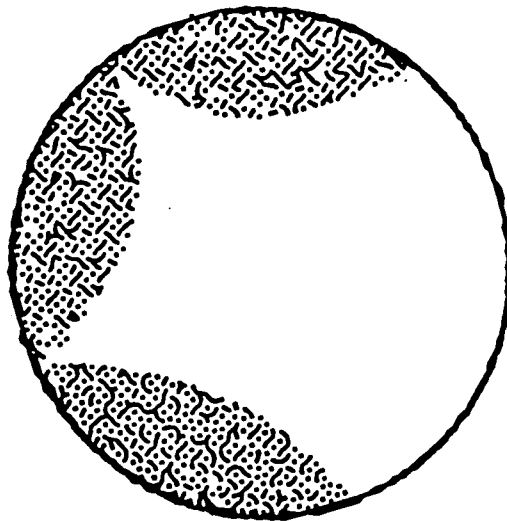
- PERMITS VIEWING OF VIRTUAL AND INTENSIFIED IMAGES
- NO PARTIALLY REFLECTIVE COATING NEEDED TO DISPLAY INTENSIFIED IMAGE
- DISPLAYS INTENSIFIED IMAGE BY EXPLOITING DIFFERENCES IN REFRACTIVE PROPERTIES OF GLASS AND AIR
- PERMITS DIRECT VIEW OF VIRTUAL IMAGERY IN THE EVENT OF NVG POWER FAILURE

SHADING



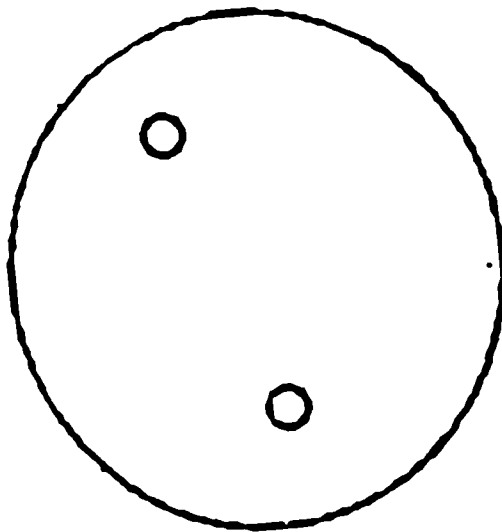
SHADING - BOTH TUBES SHOULD BE A PERFECT CIRCLE
(OR BASEBALL DIAMOND FOR CATS EYES). SHADING STARTS
ON THE EDGES AND MOVES INWARD.

EDGE GLOW



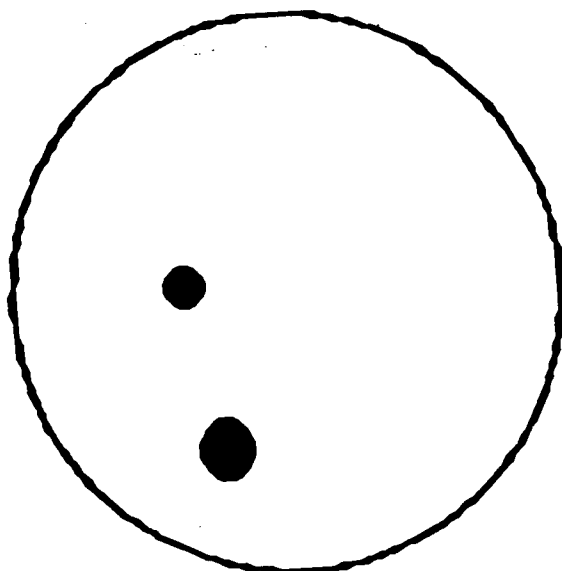
EDGE GLOW - CHECK BY BLOCKING LIGHT IN EACH LENS INDIVIDUALLY. THIS WILL BE A BRIGHT AREA IN OUTER PORTION.

BRIGHT SPOTS



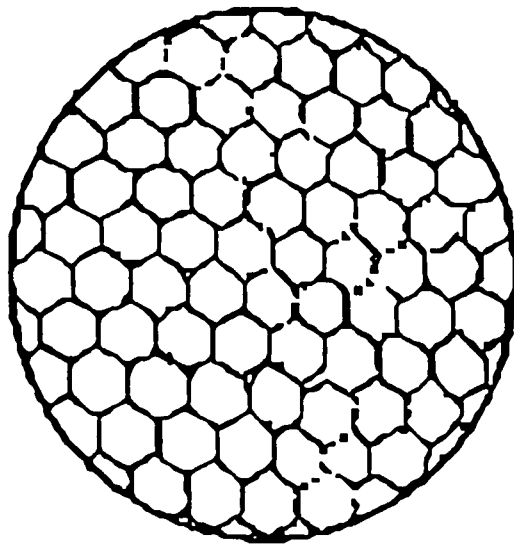
BRIGHT SPOTS - CAUSED BY PINHOLES IN PHOSPHOR.
CHECK BY COVERING EACH LENS INDIVIDUALLY.

DARK SPOTS



DARK SPOTS - BLACK MARKS CAUSED BY DEFICIENT CHANNELS
IN THE MCP. OK IF IT DOESN'T IMPAIR VISION.

HONEYCOMB

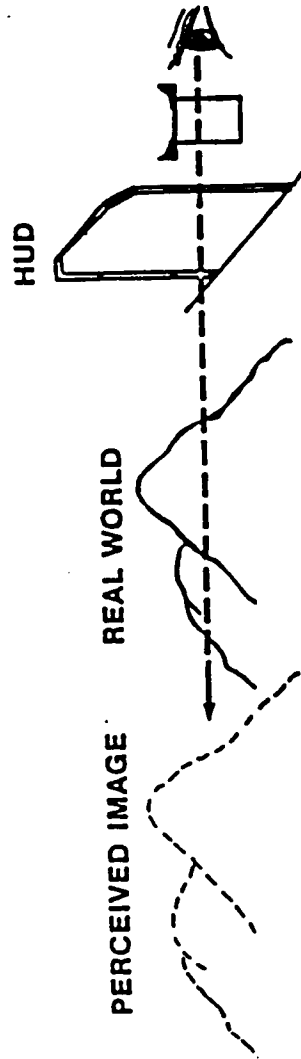


HONEYCOMB - RESULTING FROM FIXED PATTERN NOISE IN THE
MCP CAUSED BY HIGH LIGHT CONDITIONS.

WINDSCREEN/CANOPY TRANSMISSIVITY

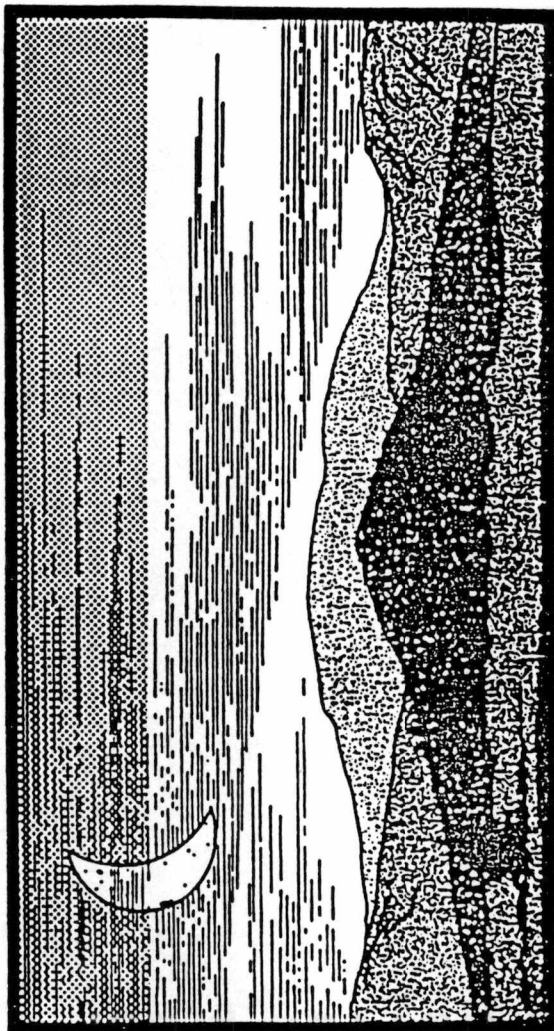
- The transmission of IR energy by windscreens and cockpit windows can be a significant problem.
- Designed to transmit visible light, many cockpit transparencies do not perform as well in the near infrared spectrum, and the transmissivity of some is very poor.
- Since NVGs (particularly GEN III) are primarily sensitive to the near IR portion of the spectrum, this can result in a serious reduction in goggle performance.
- Like the decreased visual performance resulting from incompatible cockpit lighting, the effect of decreased windscreen transmissivity may not be apparent to the aircrew.

INSTRUMENT MYOPIA



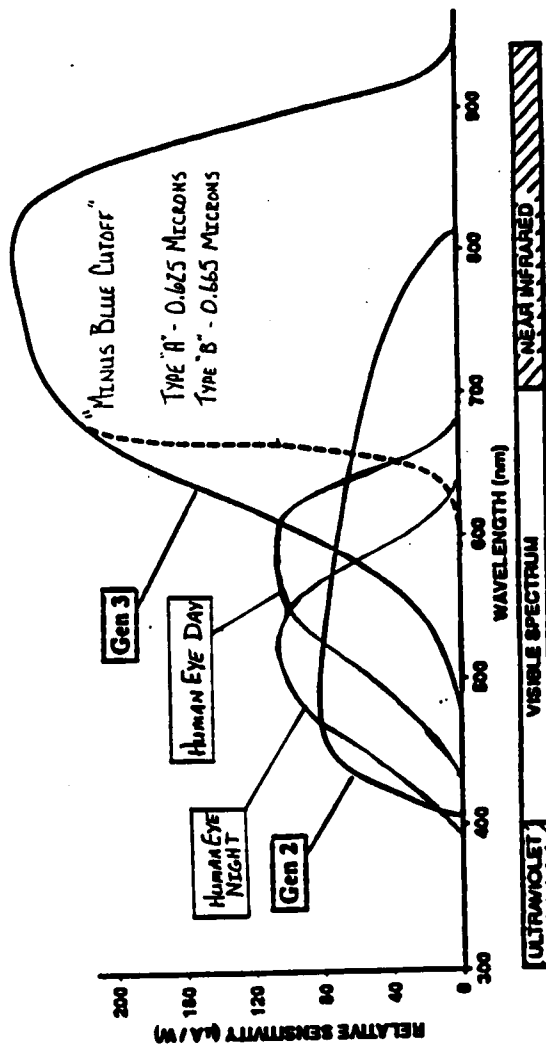
INSTRUMENT MYOPIA - In order to accommodate the image on the FLIR and NVGs, the eye perceives the displayed image as being further away than it actually is

SHADOWING

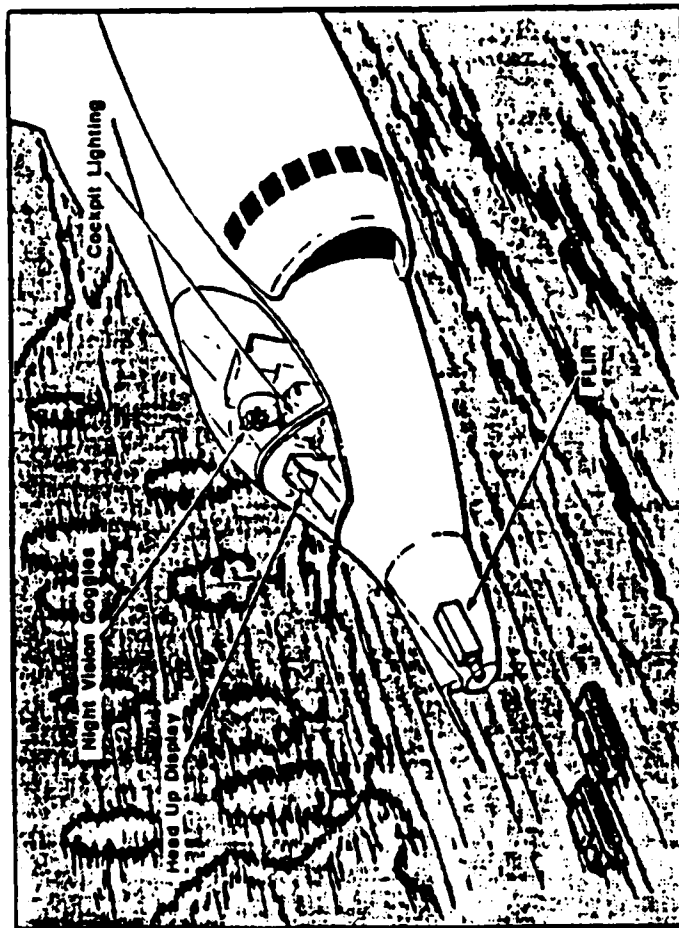


Shadowing - High terrain in the distance can completely obscure lower hills closer to the aircraft, particularly if the high terrain is between the aircraft and a light source. Rough or mountainous terrain can cast long shadows that completely obscure targets, checkpoints, and deadly flight hazards. One should plan to fly on the lighted side of valleys and not risk flying into an unseen ridgeline in an attempt to avoid a threat.

HUMAN EYE, SECOND, AND THIRD GENERATION IIT RESPONSE



EXPLOITATION OF THE ELECTROMAGNETIC SPECTRUM BASED ON CURRENT TECHNOLOGY

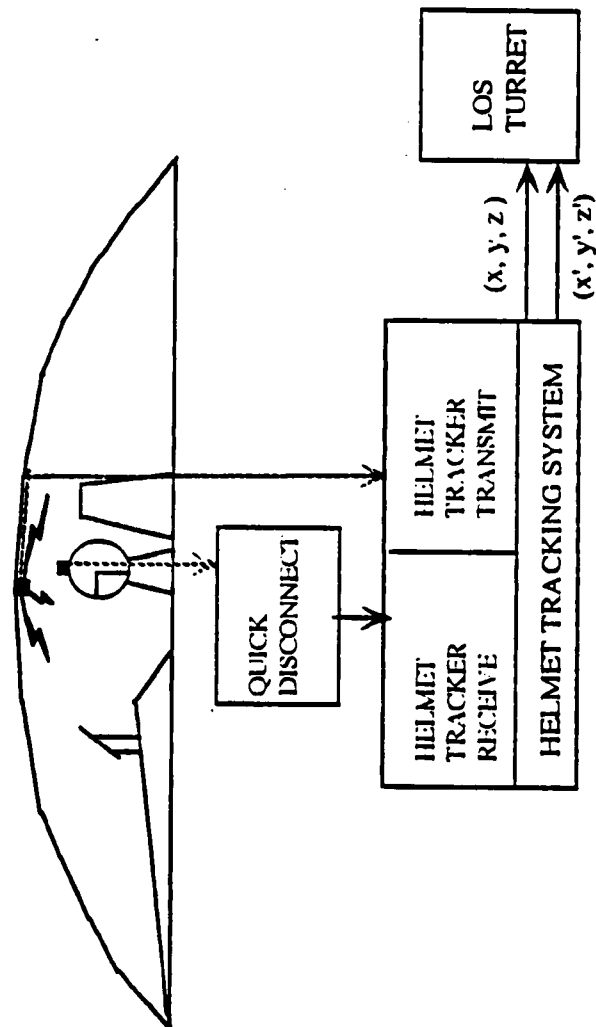


- USE THE RADAR TO NAVIGATE AND IDENTIFY TARGETS AND THE
FLIR / NVG COMBINATION TO VISUALLY PROSECUTE TARGETS...

...AT NIGHT !!

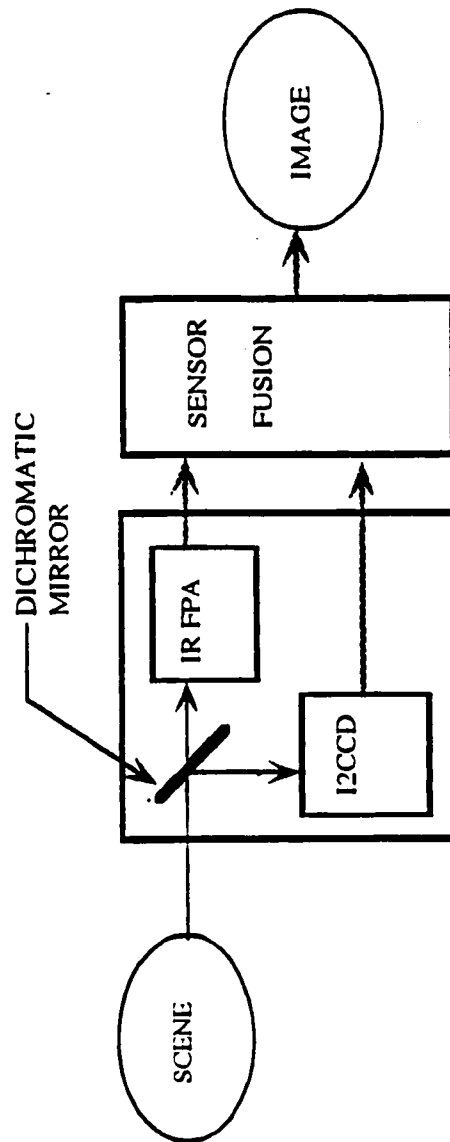
FUTURE SYSTEM POSSIBILITIES

SIMPLE HELMET TRACKING SYSTEM



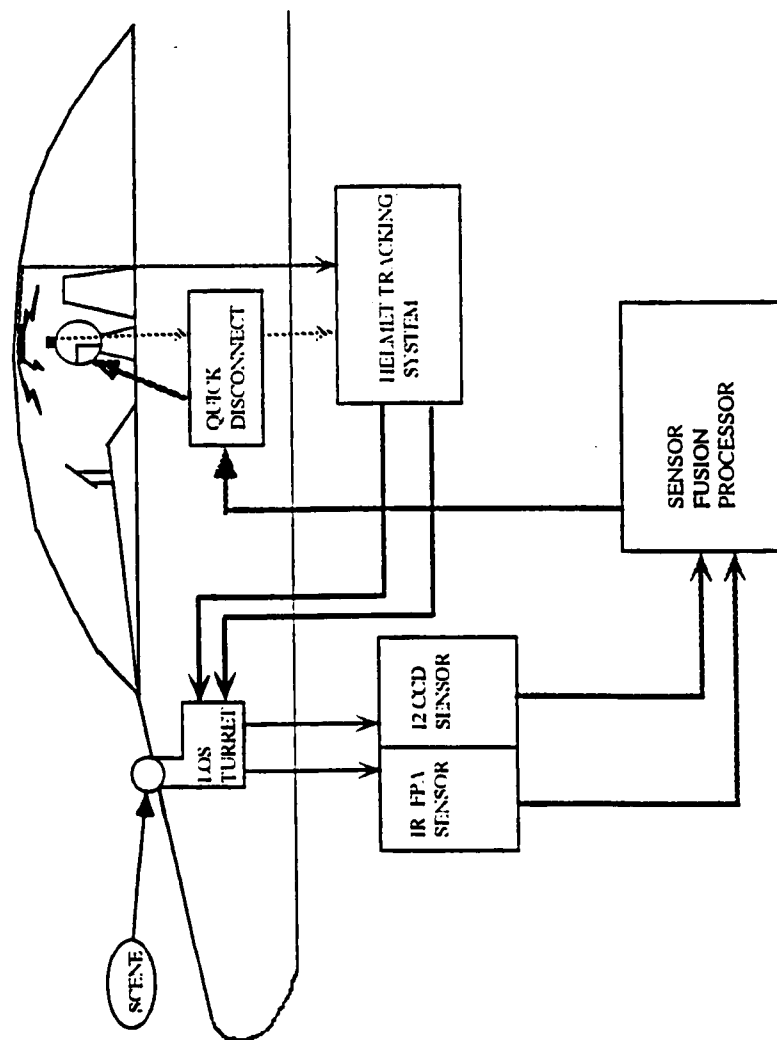
FUTURE SYSTEM POSSIBILITIES

DUAL SENSOR



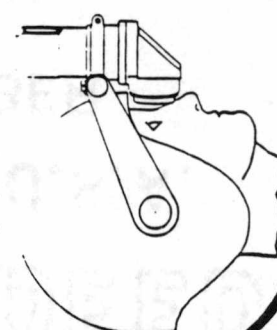
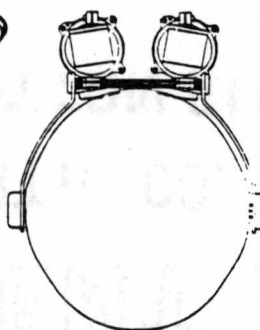
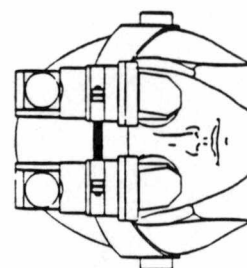
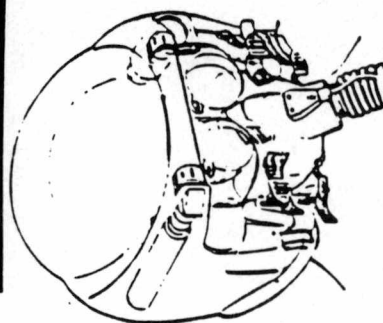
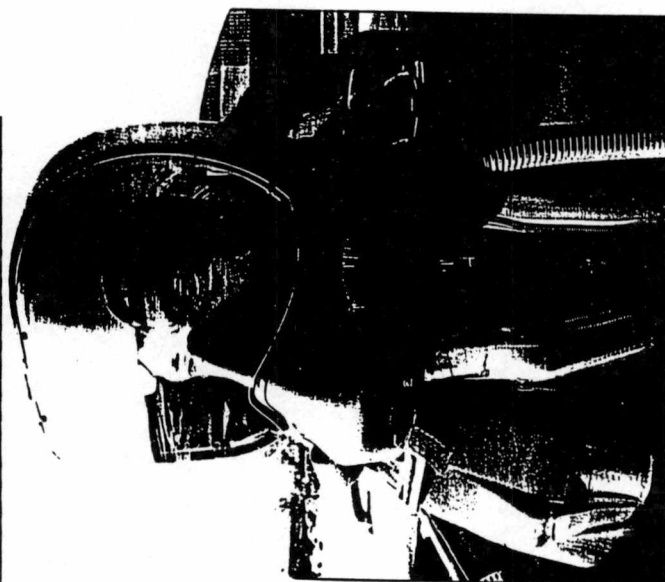
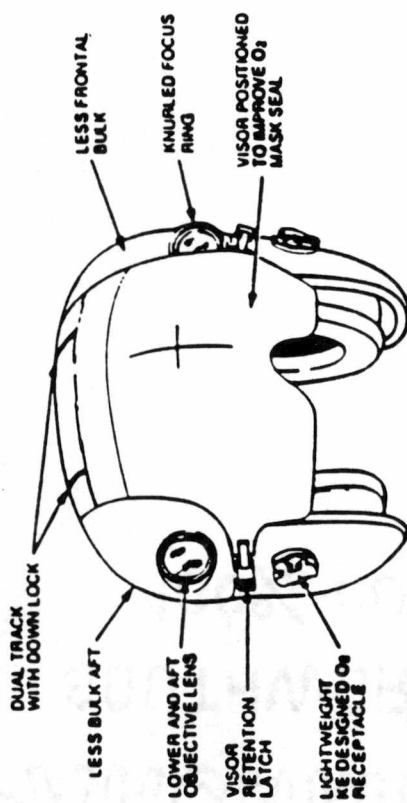
FUTURE SYSTEM POSSIBILITIES

CONCEPTUAL NIGHT VISION DESIGN



FUTURE SYSTEM POSSIBILITIES

INTEGRATED HELMET TECHNOLOGY



FUTURE SYSTEM POSSIBILITIES

EXAMPLE OF A FUSED IMAGE



VITA

Barry E. Wilmore was born in Murfreesboro, Tennessee on Dec 29, 1962. Following graduation from Mt. Juliet High School in the summer of 1981, Barry attended Tennessee Technological University (TTU) where he majored in Electrical Engineering and played varsity football. He graduated in August 1985 with a BSEE degree and since he still had another year of football eligibility (was "redshirted" his sophomore year due to reconstructive knee surgery) he decided to remain at TTU to play out his final year of eligibility and begin work on his MSEE degree. Barry received an appointment to the Aviation Officer Candidate School (AOCS) in the summer of 1986 and in November of that year was commissioned an "Ensign" in the United States Navy. Following flight school Barry flew the A-7E "Corsair II" initially aboard the USS Forestall CV-59 and then aboard the USS John F. Kennedy CV-67 during Operation Desert Storm where he flew 21 combat missions deep in to Iraq and Kuwait. Following Desert Storm Barry reported to VFA-106 for transition training to fly the F/A-18 "Hornet." It was during this training that LT Barry Wilmore was selected for duties as a test pilot and subsequently reported for duties in January 1992 as a test pilot under instruction at the U.S. Naval Test Pilot School (USNTPS). LT Wilmore is currently an instructor at USNTPS and has accumulated 2400 flight hours in greater than 40 different aircraft including the U-2B, Mirage 2000B, and MiG-29 just to name a few. He finally completed his MSEE degree in May 1994 and upon completion of this thesis will have met the requirements for the Master of Science degree in Aviation Systems from the University of Tennessee.