



**A Performance History of AN/PVS-5
and ANVIS Image Intensification
Systems in U.S. Army Aviation
(Reprint)**

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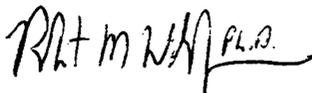
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A Performance History of AN/PVS-5 and ANVIS Image Intensification Systems in U.S. Army Aviation

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ABSTRACT

In 1973, the Department of the Army adopted night vision devices for use in aviation. Known as the AN/PVS-5 night vision goggle (NVG), these devices, which are based on the principle of image intensification (I^2), have become the mainstay for the aviator's capability to operate during periods of low illumination, i.e., at night. In the 26 years that have followed, a number of engineering advancements have improved greatly the performance of these devices. The current version, using 3rd generation I^2 technology, is known as the Aviator's Night Vision Imaging System (ANVIS). The performances histories of NVGs and ANVIS are presented with an emphasis on visual and biodynamic issues which have, and do, affect aviator mission effectiveness and safety.

1. INTRODUCTION

In the early history of warfare, battles generally were confined to periods of daylight. While an occasional mission requiring surprise and stealth may have been conducted under the cover of darkness, major confrontations were confined for the most part to those periods of time when the ability to see was greatest. Not content with this constraint, many efforts have been undertaken to expand soldier effectiveness during times of darkness and to turn "night into day." One of the first techniques used to enhance night vision beginning in WWI was the search light. This device was simple and effective. But, searchlights were unwieldy to transport and set up, required huge amounts of power to operate, and had a certain vulnerability since they could so easily be detected by the opposing force. This last disadvantage is inherent in all night vision enhancement techniques of an active nature. To achieve some level of covertness in WWII, search lights were modified with infrared filters which blocked visible and passed only near-infrared (IR) radiation [700-1200 nanometers (nm)]. A simple image converter tube was used to view the illuminated scene. While effectiveness was improved, this approach still was an active technique, providing the viewing capability to both friend and foe. What was needed was a passive technique, one which allowed night viewing using only available light. A device which met this requirement was the image intensifier (I^2).¹

Image intensifiers are totally passive in operation and are based on the principle of light (actually electron) amplification. These devices intensify (amplify) reflected or emitted light in order for the human eye to more easily see a poorly illuminated (low light) scene. The usability of the resulting intensified image depends on the "intensification (amplification) factor" of the I^2 device and the level of available light. It is important to note that I^2 devices can not see in total darkness; there must be some minimum level of light present.

The basic principle of image intensification (as applied in first generation I^2 devices) is that the scene being viewed is focused on a photosensitive material, known as the photocathode. The photocathode surface emits electrons proportional to the amount of light striking it from each point in the scene. The emitted electrons are accelerated from the photocathode toward a phosphor screen by an electric field. The light emerging from the phosphor screen is proportional to the number and velocity of the electrons striking it at each point. The observer views the intensified image formed on the phosphor screen through an eyepiece.¹ See Figure 1.

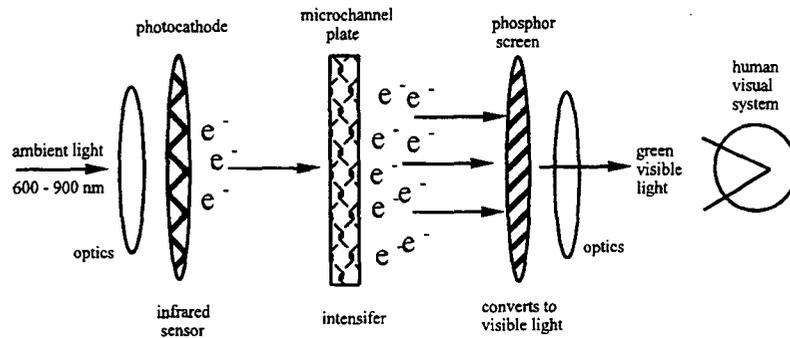


Figure 1. Diagram of the basic principle of image intensification.

The first generation I^2 devices were introduced into military use in the mid-1960s during the Vietnam campaign and were used by infantry for night observation/reconnaissance missions. Examples of these 1st generation devices include the 6-lb Starlight Scope (AN/PVS-2) and the 34-lb Night Observation Device (AN/TVS-4). The first helmet mounted I^2 night vision device was classified as the SU-50. Built around an improved 3-stage 1st generation I^2 tube or the newer 2nd generation tube. It used a fixed focused objective lens, and the fiberoptic faceplate of the intensifier tube had three focal planes to provide distant, near, and intermediate vision. It had a circular field-of-view (FOV) of 60 degrees and had a resolution which provided the user with best visual acuity of approximately 20/80 (0.43 cy/mr). This resolution was not acceptable for many tasks and resulted in a redesign to improve resolution to 20/50 (0.69 cycles/milliradian [cy/mr]), by reducing FOV to 40 degrees. Also, the multifocal intensifier tube and fixed focus objective lens were replaced with an intensifier tube with a single imaging plane and an adjustable objective lens.²

2. AN/PVS-5 NIGHT VISION GOGGLE

Upgrading to improved 2nd generation I^2 tubes and performing minor physical modifications, the SU-50 design transitioned into what became known as the AN/PVS-5* series night vision goggle (NVG). The 2nd generation of I^2 tubes were smaller and lighter, allowing for the mounting of two tubes to provide binocular viewing. The 2nd generation used a microchannel plate which amplified the number of electrons, producing a greatly amplified image of the outside scene. The resulting NVG design was a binocular, head-mounted, full-face, 40-degree, 2nd generation I^2 night vision system. It provided unity magnification and was equipped with an IR illuminator which provided supplemental lighting for near distance NVG viewing tasks as needed in total darkness. In the late 1960s and early 1970s, the Army was looking for a way to extend the effectiveness of aviation resources at night and during foul weather. A decision was made to test a modified version of the AN/PVS-5 for possible aviation use. The major modification consisted of remounting the goggle tubes into a more helmet compatible facemask which had been developed for NVG tests previously conducted by the U.S. Air Force.³ Other modifications were made to the head strap, foam cushions, and switches.⁴

Since 1973, several models of the basic AN/PVS-5 NVG have been fielded: the basic AN/PVS-5 and three modified versions, the AN/PVS-5A (Figure 2), AN/PVS-5B, and AN/PVS-5C. While all of the models differ in one or more ways, they all use the 2nd generation tubes.

The AN/PVS-5A differed from the basic AN/PVS-5 design in two ways. The mounting threads for the eyepiece and intensifier tube assembly were finer, which meant the PVS-5 and PVS-5A components were not interchangeable. The rotary switch which operated the IR illuminator was converted to a "pull and rotate" design to prevent inadvertent activation. The AN/PVS-5B had a f/1.2 objective lens, as compared to the f/1.4 for the AN/PVS-5A; this allowed 50 percent more light to enter the I^2 tubes. The AN/PVS-5C had an added battery compartment for two AA batteries. This

*This nomenclature derives from the following: the "AN" stood for Army or Navy application, "P" meant portable, "V" signified visual, and "S" indicated detecting or range bearing.⁵

provided a power option over the standard 2.7-volt mercury battery. Also, the AN/PVS-5C had a high-light cut off feature that shut down the I² tubes when exposed to bright lights. The purpose was to protect the tubes which could be damaged by such exposure. The AN/PVS-5C was not authorized for use in aviation.

In general, the various models of the AN/PVS-5 weighed approximately 1.9 pounds and were mounted on the then current Army aviation helmet, the Special Protective Headgear, Model 4, (SPH-4.). The attachment was made using Velcro straps and quick release straps for the side straps. From 1972 to as late as 1990, the AN/PVS-5 series with 2nd generation I² tubes were the mainstay of U.S. Army aviation night vision.

Since the AN/PVS-5 were I² devices, the amount of available light was extremely important. For the sensitivity of 2nd generation tubes, the moon is the major natural source of this light. (However, aircraft were fitted with a visual attenuating, IR transmissive filtered searchlight, called a "pink light" or invisible headlights, which allowed flight capability in the absence of lunar illumination.) For training purposes, the "pink light" was mandatory for US Army AN/PVS-5 flight with the moon less than an altitude of 30 degrees above the horizon and a fraction of illumination of less than 23 percent. To assist units in predicting the flight period envelope meeting these conditions, a procedure for generating a lunar light level calendar was provided in Army Field Manual No. 1-51 (FM-1-51), Rotary Wing Flight.⁶ The generation of these calendars was a very time consuming task. In 1983, a computer program was developed at the U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama.⁷ This program used the procedure and associated calculations provided in FM-1-51 and lunar data provided by the Nautical Almanac Office, U.S. Naval Observatory, Washington, DC, to print a calendar which covered a 6-month period. The predicted lunar light level for a specific night and time was presented in 15-minute increments for the local latitude and longitude (Figure 3). Light levels were classified as low, medium, or high, based on definitions in FM-1-51. The U.S. Army Aeromedical Research Laboratory (USAARL) published these charts for Fort Rucker, Alabama, and provided the program source code to Army units throughout the world from 1983-1991. In the following years a number of more sophisticated programs became available and adopted by individual units.

For the purpose of completeness, two additional head mounted infantry versions of NVG will be mentioned. The first is the AN/PVS-7 series NVG which has replaced the AN/PVS-5 for ground use. The AN/PVS-7 is a biocular (a single 3rd generation I² tube providing the same view to each eye), 40-degree FOV design (Figure 4). The second to be fielded in the near future is the AN/PVS-14(MNVD), which uses a single advanced 3rd generation tube to provide aided monocular vision for the preferred eye, leaving the remaining eye dark adapted. The AN/PVS-14 has improved resolution to 1.3 cy/mr and adjustable gain from 25 to greater than 3000.

The original full-face AN/PVS-5 design posed several performance and safety issues for aviators. These included poor light level performance, narrow FOV (40 degrees), excessive head supported weight, shifted center of mass (CM), and inability to read maps while wearing goggles.⁸ Most important was that of restricted FOV. With only the aided 40 degrees FOV the increased probability of collision with proximal aircraft had occurred by December 1981 during an Army training mission. Between the time that a decision was made to develop an I² device which would be designed to meet aviation requirements, and the actual fielding, several individuals proposed modifications to the AN/PVS-5 face plate known as the "cut-a-ways" (Figure 5) to provide increased look-to-the-side and look-under capability. The detailed procedure for performing the modification was developed and made available as early as 1982.⁹⁻¹⁰ The modified version was accepted by the Army and became the standard configuration in 1983.¹¹

3. AN/AVS-6 ANVIS

Although the first operational tests were in 1982, it was not until 1989 that 3rd generation tubes began to make their appearance. They were the foundation of a new night vision I² system which was designed specially for aviation. This system is the AN/AVS-6 Aviator's Night Vision Imaging System (ANVIS).

ANVIS (Figure 6) are described as binocular, 3rd generation, I² night imaging systems. They operate over a spectral range of approximately 625-950 nanometers (nm). This spectral range is a result of the inherent spectral sensitivity of the I² tube's photocathode and a dielectric coating (minus blue filter) incorporated in the objective lens.

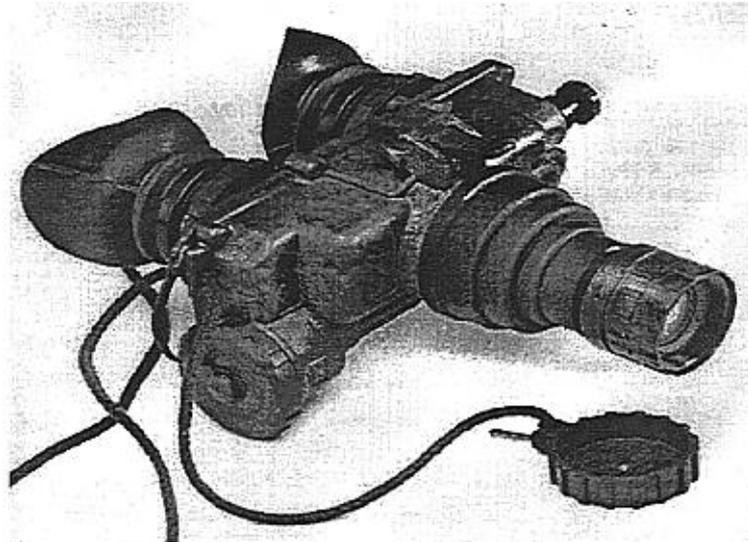


Figure 4. The AN/PVS-7 single tube biocular NVG for ground use.

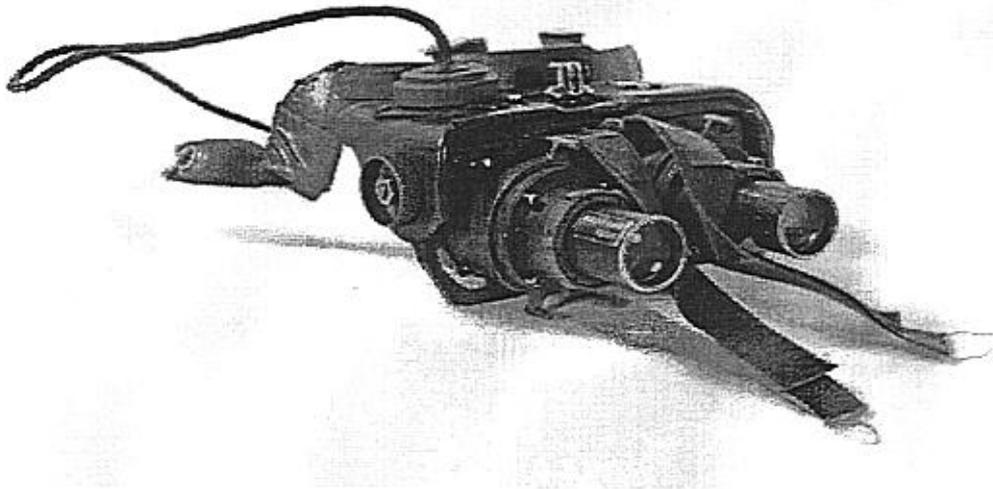


Figure 5. The prototype cut-a-way version of the AN/PVS-5.

This coating rejects energy below 625 nm and is designed to provide compatibility with blue-green cockpit lighting. Spectral sensitivities of 2nd and 3rd generation (with minus blue filters) 18-mm tubes are compared in Figure 7. ANVIS provides a circular 40-degree FOV and provides an average display luminance from a uniform background at the eye of between 0.7 and 2.2 footlamberts (fL). In comparison to AN/PVS-5, ANVIS has increased sensitivity, improved resolution, and a greater sensitivity in the near infrared.¹²

ANVIS optical characteristics¹³ (Omnibus I and II, which are purchasing contracts) include: a focus range of 28 cm (11 inches) to infinity, unity (1x) magnification, 27-mm effective focal length objective (f/1.2), 27-mm effective focal length eyepiece lens, >0.82 cy/mr (20/42), 2000x brightness gain (minimum), -6 to +2 diopter adjustment, and 52-72 mm interpupillary distance adjustment. The ANVIS housing can be flipped up or down, and has a 10 G breakaway feature. A tilt adjustment of approximately 8 degrees is provided. There is a minimum vertical and fore/aft adjustment range of 16 mm. ANVIS are designed to operate over a temperature range of -32°C to +52°C. They operate off of one

BA-5567/U lithium or two alkaline “AA” batteries. A dual battery pack is mounted on the rear of the helmet to provide redundancy and improve the location of the head supported center of mass (CM). The Omnibus III procurement provided a minimum of 3000 x brightness gain, scene illumination from 10^{-6} to 1 fc, 25-mm eyepieces, increased fore-aft range to 27 mm, and individual interpupillary distance (IPD) adjustments.

ANVIS are designed to provide the aviator the capability to “recognize terrain obstacles at an altitude of 200 feet or less, at a maximum speed of 150 knots, and at light levels down to overcast starlight.”¹⁴ The original system was designed to mount on the SPH- series aviator’s helmet using a mount assembly that replaces the normal visor. Different mounting configurations have evolved for different helmets.

The first major contract for ANVIS, awarded in 1982 (Omnibus I), called for a delivery of 1366 units. By the end of 1990 with Omnibus II, over 16,000 ANVIS had been delivered or were under contract. As of December 1996 after Omnibus III, approximately 17,500 ANVIS have been fielded.

ANVIS was designed to enhance look-around and look-under capability. The look-around capability improved peripheral vision and enhanced situational awareness. The look-under capability allowed aviators to view cockpit displays without refocusing the goggles. However, as early as 1990, there was a desire to modify ANVIS to allow continuous heads-up flight. This desire is based on concerns associated with aviators having to look down into the cockpit to obtain flight status information during critical phases of flight such as nap-of-the earth (NOE) and low level flight. As a result, the ANVIS/Heads Up Display (HUD), AN/AVS-7¹⁵, was developed with initial fielding in 1995. The display unit of the ANVIS HUD attaches to either the right or left tube housing and optically couples selectable flight information with the intensified image through the objective lens of the ANVIS. The pilot and co/pilot can individually select 8 different symbology modes with a four way switch on the engine power control (collective/thrust stick/throttle). This switch also controls display brightness. Four of the modes are user programmable from approximately 12 different types of information such as attitude (barometric and radar), velocity (ground and airspeed), heading, attitude indicator, way point direction and distance, etc. The master caution and warning information are displayed with all 8 modes.

4. PERFORMANCE

When I² devices are added to the aviator’s head to allow night and low illumination operation, night is “not turned into day.” The visual input provided by these systems does not approach that experienced using the unaided eye during periods of daylight illumination. When compared to unaided daylight flight, many visual parameters, e.g., acuity, FOV, depth perception, etc., are understandably compromised.^{12, 16-19} In addition, the mounting of these systems on the helmet increases the hazards associated with such physical parameters as weight and center-of-mass (CM).



Figure 6. Aviator’s Night Vision Imaging System (ANVIS) under OMNIBUS I & II.

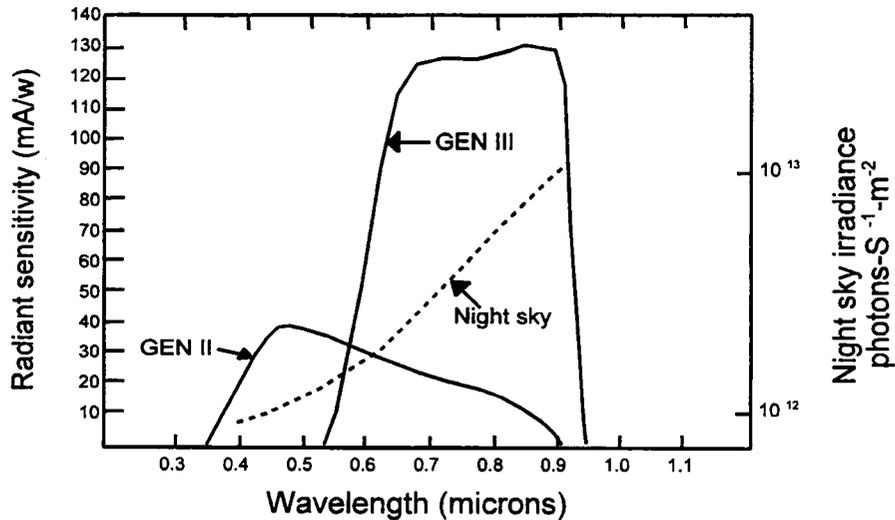


Figure 7. Comparison of 2nd and 3rd generation tube sensitivities in 1982.

4.1 Resolution and visual acuity

Resolution, referred to in optics as resolving power, is defined as the ability of an optical system to reproduce the points, lines and surfaces in an object as separate entities in the image.²⁰ The resolution usually is expressed in either linear or angular units as the separation between two object points which can be viewed as separate images. The system resolutions of I² devices usually are expressed in angular units “cycles per milliradian (cy/mr).” For I² tubes, a linear unit of “line pairs per millimeter (lp/mm)” is used to separate the optical characteristics of the objective and eyepiece lenses from the resolution of the intensifier tube. At moonlight illumination levels, AN/PVS-5 resolution is specified at 0.72 cy/mr (20/48); ANVIS (Omnibus I and II) resolution is 0.86 cy/mr (20/40). At starlight levels, AN/PVS-5 resolution decreases to 0.40 cy/mr, and ANVIS resolution decreases to 0.55 cy/mr.

Visual acuity is a measure of the ability of the human eye to resolve spatial detail. Snellen visual acuity commonly is used and is expressed as a comparison of the distance at which a given set of letters are read correctly to the distance at which the letters would be read by someone with clinically normal eyesight. A value of 20/80 indicates that an individual reads at 20 feet the letters normally read at 80 feet. Normal visual acuity is expressed as 20/20 and represents 1-arcminute separation between the dark or light periodic components of the resolution target whether the targets are letters or bars such as the tri-bar Air Force 1951 resolution chart. Snellen visual acuity with the AN/PVS-5 typically is cited at 20/50 under optimal conditions (high contrast and scene luminance). Snellen visual acuity with the ANVIS (Omnibus I & II) is cited at 20/40 under optimal conditions of ambient illumination and contrast. However, such optimal conditions rarely are met in actual field use.¹²

Optimal I² resolution is obtained under high light level conditions with high contrast targets. The resolving power of an I² device decreases with light level because of the proportional decrease in luminance output below the automatic brightness control level and the noise in the intensified image increases. Visual performance for these optimal conditions was previously cited as 20/40 and 20/50 for ANVIS and AN/PVS-5, respectively. The low light level resolution is not limited, but continues to decrease with decreasing light levels. Although there may be a measurable resolution at very low light levels, the AN/PVS-5 loses its effectiveness at about starlight, as visual acuity approaches 20/100, and the original ANVIS loses its operational effectiveness at overcast starlight.

In order for aviators to take full advantage of the I² devices’ resolution capability, the goggle should be focused for both the objective and eyepiece lenses. With the very fast ANVIS objective lens, the depth of focus is very small where one diopter of blur equates to approximately 20/700 visual resolution. Therefore, the minimum recommended distance for adjusting the ANVIS objective lenses for infinity is 50 meters.²¹ Each eyepieces for ANVIS are independently adjustable over a range of +2 to -6 diopters. This extensive diopter adjustment range was based on the

older AN/PVS-5 NVGs, which were not compatible with prescription spectacles. The adjustable eyepiece focus provides the potential for optimum resolution for the variability of the refractive states of the users under low light through electro-optical devices.²²

A number of studies have been conducted to investigate factors which can degrade visual acuity with I² systems.²³ These factors include FOV,²⁴ night sky condition and target contrast²⁵⁻²⁹, flashblindness protection,²⁵ chemical protective masks,³⁰⁻³¹ signal to noise ratio,³² instrument myopia,³³⁻³⁴ and decreased unaided visual acuity.²³

A 1976 limited (3 subjects) study²⁴ investigated visual acuity versus FOV and ambient light level for a single I² tube. Snellen visual acuity was measured for three FOVs (40, 47, and 52 degrees circular) and five different light levels (output luminances). The results of the study are reproduced in Figure 8. In general, visual acuity decreases as ambient illumination decreases below about approximately 1/4 moon and with an optical increase in FOV. A more global study,²⁸ conducted by Kotulak and Rash (1992), investigated effects of night sky condition, target contrast, and generation of I² device on visual acuity. It was found that the difference in visual acuity between the 2nd and 3rd generation I² devices widens under two conditions: 1) when target contrast is constant, but night sky irradiance decreases, and 2) when night sky irradiance is constant, but target contrast decreases. Furthermore, it was found that for a given I² generation, visual acuity falls off more rapidly for a low contrast target than for a high contrast target as night sky irradiance decreases.

The modern battlefield with its high tech weaponry is forcing the aviator to don additional protective devices. One such device which has been considered is flashblindness protection. Use of such add-on devices will compromise visual performance with I² devices if they attenuate the device's output luminance. Levine and Rash (1989) investigated the effects of such attenuation on visual acuity.²⁶ The study looked at visual acuity across three ambient light levels (twilight, moonlight, and starlight), three contrast levels (low, medium, and high), and six attenuation levels. The effect of reducing output luminance to the eye varied as a function of both ambient light level and target/background contrast. Under the two higher lighting conditions (twilight and moonlight), visual acuities for the medium and high contrast targets remained nearly unchanged for attenuation levels as high as 90 percent. At 97 percent attenuation, a loss of two lines of Snellen acuity was found. At attenuation levels of 3 down to 1 percent, visual acuity dropped to as low as 20/200. Under starlight conditions, acuities for both high and medium contrast targets remained unchanged up to an attenuation level of 70 percent. Above 70 percent, acuities were severely degraded to as poor as 20/400.

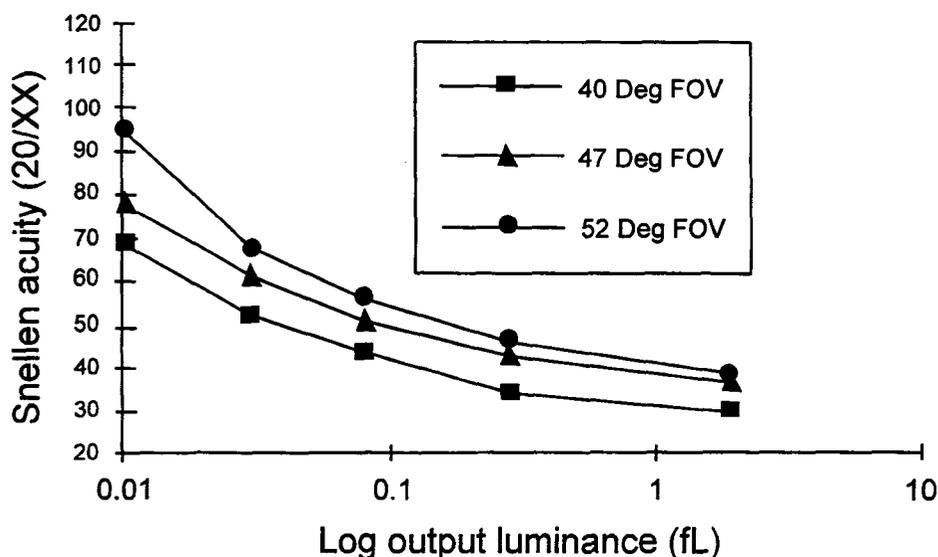


Figure 8. Visual acuity as a function of I² output luminance and FOV.²⁴

A recent (1996) study²⁹ looking at visual acuity in I² devices found that contrast attenuation associated with viewing through I² devices is a major factor in the limiting visual acuity of such devices. This contrast attenuation is determined by the modulation transfer functions of the optical and electrical components of the I² devices and the presence of noise. In addition, output luminance is very likely a factor, since several studies have documented acuity loss at low levels of sky illumination.

4.2 Field of view

For the purpose of this paper, FOV refers to the instantaneous field of vision through the I² device.

The human eye, as a single sensor, has an instantaneous FOV which is oval in shape and measures approximately 120 degrees vertically and 150 degrees horizontally. When both eyes are used, the overall FOV measures approximately 120 degrees vertically and 200 degrees horizontally. Both AN/PVS-5 and ANVIS use I² tubes which provide a circular 40-degree FOV. The parallel alignment of the tubes produce a 100 percent overlap of the right and left images for distant viewing, resulting in a total FOV of still only 40 degrees. A comparison of the I² FOV to that of the unaided FOV shows why flying with these devices often is referred to as “tunnel vision” (Figure 9). However, when compared to the aviator’s unobstructed FOV of the outside world from the cockpit of any aircraft,³⁵ the I² FOV loss is less dramatic (see Figure 10). Still, the aviator must use continuous head movements in a scanning pattern to compensate for this FOV reduction. The use of scanning during I² flight is an important safety issue. A 1992 study³⁶ described several scanning methods for night vision goggle flight in Army helicopters. The proposed scanning methods recommend free search techniques over formalized scan patterns.

While the ANVIS FOV is cited as 40 degrees, the actual design FOV specification is 40 degrees, +1 or -2 degrees, i.e., 38-41 degrees. These values can be verified by techniques presented in MIL-A-49425 (CR)³⁷ or by specialized equipment built for FOV measurement.³⁸⁻³⁹ And there is no guarantee that provided FOV actually will be achieved. Eye clearance distance and helmet fit are two factors which can influence actual FOV.

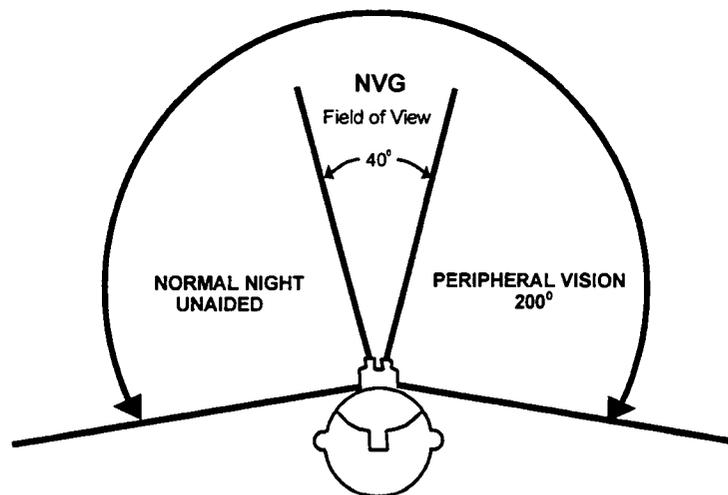


Figure 9. Instantaneous FOV for the human visual system and I² night vision devices.¹²

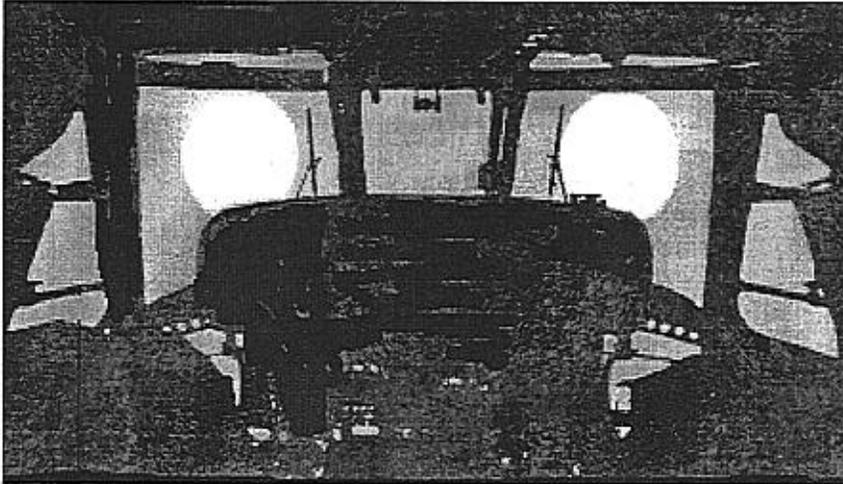


Figure 10. UH-60 cockpit view. Circles show limited FOV for aviators wearing ANVIS.

A 1992 study⁴⁰ measured the vertex distances from the center of the ANVIS eyepieces to the cornea of the eye of 105 aviators to calculate the resultant in-flight FOV using ANVIS. Also, it attempted to determine the degree to which improper user fore-aft adjustments degraded FOV and to evaluate options for optimizing in-flight ANVIS FOV. It was found that only 15 percent of the aviators actually could achieve a 40-degree FOV with ANVIS during flight. The FOVs were reduced due to system limitations (e.g., lack of fore/aft adjustment range and excessive eye relief for the standard eyepieces), rather than to user misadjustments, except in a small percent of the sample .

An obvious question is why not use NVGs with a greater FOV. The answer for previous I² technology is that FOV and resolution are tradeoffs against one another for unity magnifying viewing systems. Increasing FOV results in a loss of resolution above eye limiting values. A model for predicting this tradeoff was developed and validated by Donohue-Perry et al.,¹⁹ in 1994. When a 1975 study⁴¹ asked 7 aviators to compare two AN/PVS-5 night vision goggles, one with a 40-degree and another with a 60-degree FOV, 5 of the 7 rated the 40-degree goggle as providing the “sharper” imagery. The conclusion was that the aviators in this study preferred higher resolution over increased FOV at this stage of image intensifier development.

4.3 Stereopsis and depth perception

Stereopsis, also called stereoscopic vision, is the perception of relative differences in the distances of objects from the viewer resulting from the simultaneous viewing with both eyes and the separation distance between the eyes or viewing perspective. Normal stereopsis is most functional within distances of 10 meters. Depth perception is the ability to judge one object’s position with respect to another object based on both monocular and binocular cues. Stereo vision with AN/PVS-5 and ANVIS is theoretically possible since the two I² tubes provide two images viewed at the normal eye separation distance.⁴² Distance estimation and rate of closure are important cues in reducing aircraft accidents involving I² devices.⁴³

The phenomena of stereopsis and depth perception were explored first for the AN/PVS-5 in a 1976 study.⁴⁴ Both laboratory (using a modified Howard-Dolman apparatus) and field experiments were conducted. Four viewing conditions were used: unaided monocular, unaided binocular, monocular (single) I² tube, and binocular NVG. This study concluded that “stereopsis through night vision goggles, regardless of the model or viewing conditions, is essentially eliminated and equivalent to the threshold obtained with unaided monocular viewing.” However, a more recent study in 1990⁴⁵ using ANVIS produced conflicting results. Assessing stereopsis with ANVIS and unaided vision under varying light levels, this study concluded that stereo vision is present with I² devices and that they provide depth perception which is better than with unaided vision when the ambient levels are lower than twilight. In another

report ⁴⁶, after using NVGs, some pilots had decreased stereopsis. Using the original day filters with ANVIS and the Armed Forces Vision Tester (AFVT), it has been found that pilots have no difficulty passing the same stereopsis test used for flight physicals, when the goggles are properly focused.

A 1991 field study on distance estimation ⁴² asked 4 helicopter pilots to make distance judgements under several viewing conditions which included normal day and night unaided vision, day and night unaided vision restricted to 40 degrees, and AN/PVS-5 and ANVIS. The study found that distance estimation performance for the day and night unaided conditions did not differ significantly from the day and night unaided restricted (40 degrees) conditions. It also was found that estimation errors were higher for the AN/PVS-5 and ANVIS over daytime viewing. However, these errors were not consistent, there being errors of both over- and underestimation.

4.4 Distortion

Distortion in I² tubes is of two types: gross distortion and shear distortion. Gross distortion causes the image of a straight line to appear curved. Shear distortion, defined as the displacement or rotation of a small line segment with respect to a perfect straight line, appears as discrete lateral displacements. These distortions are primarily caused by deviations in the inverting fiber optic bundle. Gross distortion is caused by a long-range deformation or flow of the fibers during fabrication, while shear distortion is due to localized misalignment errors in the assembly of the fiber bundle. The overall result of having distortion present is that straight lines in the viewed scene will be curved or broken. In severe cases, the visual effect will be similar to the waviness seen in old window panes. Distortion typically is measured in percent.⁴⁷ The ANVIS has a one percent, or less, distortion value.

In 1988 a problem arose with distortion in the AN/PVS-5B and -5C (ground use). Testing of suspect I² devices from the field showed that the level of distortion present was unacceptable. An investigation concluded that the problem was a result from poor definitions of acceptable levels of distortion and testing procedures. The investigation recommended a more stringent set of test specifications, to include a third test parameter, "shear rate," defined as the rate of distortion expressed in units of microns per milliradians.

4.5 Contrast sensitivity

While visual acuity can define the limiting spatial resolution available through the various I² devices, it primarily gives information relating to the limit for detecting a separation between two high contrasting objects. Contrast sensitivity provides a functional description of visual capabilities to detect the minimum contrast for a given target size.

A 1976 study used sinusoidal gratings generated on a CRT to measure contrast sensitivity through 2nd generation AN/PVS-5.⁴⁸ Data from this study showed that for light levels of quarter moon, and less, contrast sensitivity was superior at all spatial frequencies for viewing with the AN/PVS-5 as compared to unaided viewing. Sensitivity peaked at moderate spatial frequencies. However, under full moon condition, contrast sensitivity with AN/PVS-5 was slightly better than unaided viewing for low frequencies, but better for unaided viewing at higher frequencies. Unfortunately, this study measured and determined the light levels and contrasts on the CRT with a photometer corrected for visual sensitivity without consideration of the NVG spectral sensitivity. Therefore, the light levels and contrast values for the NVG response may not correspond to natural moon and starlight absolute illuminations, which would have more near infrared components than the CRT used in this study.

An investigation ⁴⁹ of contrast sensitivity with 3rd generation ANVIS under several simulated night sky conditions (i.e., full moon, quarter moon, starlight, and overcast starlight) produced the curves presented in Figure 11. In this study, the night simulating light source was spectrally adjusted for the range of night sky ambient illuminations. As with the data for the AN/PVS-5, contrast sensitivity peaks at the moderate frequencies and then decreases for the higher spatial frequencies. The absence of data at low frequencies is due to the fact that the test stimuli were letter characters rather than simple sinusoidal gratings.

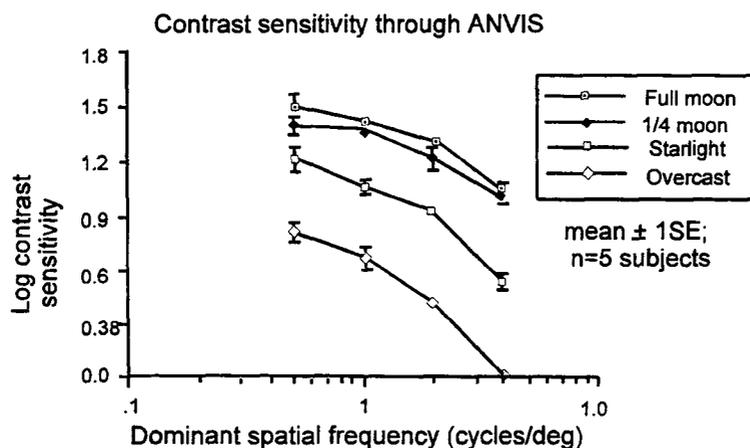


Figure 11. Contrast sensitivity through ANVIS.⁴⁹

4.6 Flicker detection

Most performance measures with AN/PVS-5 and ANVIS address spatial characteristics of these devices. However, the temporal characteristics of imaging systems intended for flight are equally important.⁵⁰ A 1994 study⁵¹ investigated flicker detection through ANVIS for two different phosphors (P22 and P43). The minimum contrast needed to detect flickering targets was measured for a range of night sky luminance conditions. It was found that flicker detection was limited by the contrast and luminance of the ANVIS. Under optimal light levels (full moon), the maximum rate of flicker detected with ANVIS was only slightly less than that with unaided vision. However, with decreasing light levels, flicker detection also decreased. It should be noted that the primary difference in temporal response and flicker detection for image intensifiers for a given ambient illumination is a function of the rise and decay characteristics of the phosphors and not the electronics. Figure 12 shows flicker sensitivity with and without ANVIS over four night sky conditions.

5. COCKPIT LIGHTING COMPATIBILITY

I² systems amplify light. Incoming photons are converted into electrons. These electrons are multiplied and strike a phosphor display screen and then converted back into photons. Light is amplified up to several thousand times. For each photon in, a greatly increased number are put out. The presence of bright light sources within the viewing area can overpower the I² devices, producing high levels of veiling glare and damaging the phosphor screen. In the AN/PVS-5, an automatic brightness control (ABC) monitors the average screen luminance and adjusts the microchannel plate -to-phosphor screen voltage to maintain a prescribed current and display luminance.¹ ANVIS are equipped with a bright source protection (BSP) circuit, which operates as an automatic gain control.⁵²⁻⁵³ The BSP circuit decreases the "gain" of the I² tubes when they are exposed to bright lights. However, one inherent problem is that I² devices can not differentiate between photons originating from outside the cockpit and ones originating from inside the cockpit, i.e., from flight instruments, floodlights, console lighting, warning, caution, and advisory signals, jump lights, and electronic and electro-optical (EO) displays. Therefore, the presence of cockpit light sources to which the I² devices are sensitive can erroneously degrade performance. If the outside ambient light level is sufficiently high, the effects are minimal. However, under very low ambient light levels, when greater gain is required, cockpit light sources can adversely lower the gain, degrading the system performance. User performance also is degraded since the aviator often is unaware of the reduced gain and related lost of system performance.

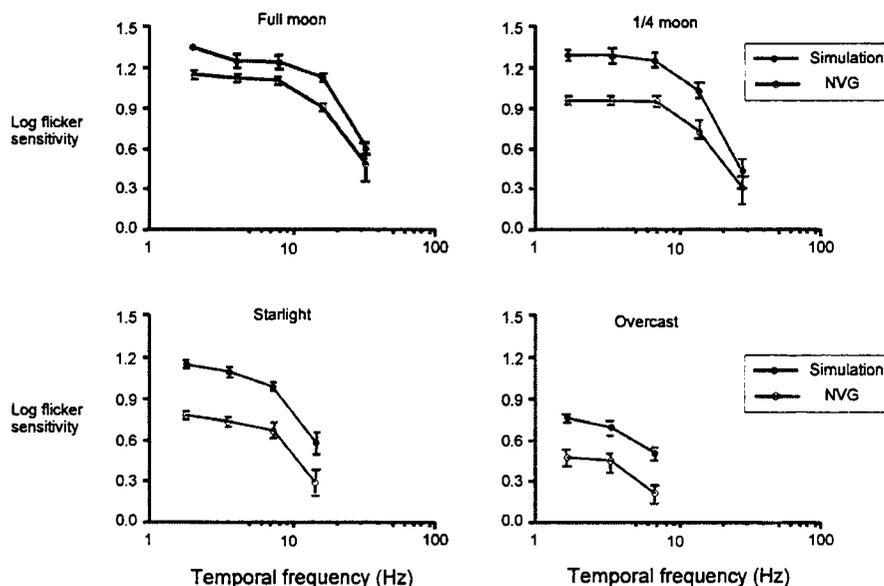


Figure 12. Flicker sensitivity for unaided and ANVIS viewing.⁵¹

When AN/PVS-5s were introduced, it was necessary to severely reduce the level of internal cockpit lighting. This was attempted through the use of numerous techniques including low-reflectance black paint, light louvers, filters, low intensity lamps, opaque tape, and turning off displays.⁵⁴ The instruments were primarily illuminated with a map light modified with an infrared filter to block visible light. The instruments were viewed momentarily by rapidly focusing one objective lens of the NVG for the instrument panel distance, and then returning the focus back to infinity. Other areas in the cockpit that were not illuminated by the IR lights such as the overhead and side panels required that the switch and control positions had to be memorized and/or marked with tape. To prevent the red and yellow caution lights from shutting down the goggles and severely reducing outside vision, the master caution and fire warning lights were taped leaving either two small vertical or diagonal slits to minimize their effects on the goggles. Only limited success was achieved using any of these methods.

While designing the ANVIS, particular attention was given to this problem. One solution was to coat the inside surface of the objective lenses in the ANVIS with a dielectric film (the “minus blue filter”) that would reject light of wavelength less than 625 nm. The theory was that displays could be illuminated by and/or emit light between 400 and 625 nm (blue-green in color) that was visible to the human eye (which responds to wavelengths between 400-700 nm) but detected by the ANVIS. As early as 1988, the Communications and Electronics Command (CECOM) and the U.S. Army Aviation and Troop Command (ATCOM), St. Louis, Missouri, initiated the first programs for making Army aircraft cockpits “ANVIS compatible.” From 1988 to 1995, the cockpits of all Army rotary-wing aircraft were upgraded through various re-designs and retrofits. Army “compatibility testing” was performed primarily at the U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama. Items tested included instrument panels, dedicated displays, indicator lamps, lighted bezels, and filter kits.⁵⁵⁻⁶⁰ Field testing for ANVIS compatibility included an assessment of a patient litter kit designed for use in the UH-60 air ambulance⁶¹ and an evaluation of a blackout curtain set designed for the UH-60Q MEDEVAC concept helicopter.⁶²

Testing for ANVIS “compatibility” is performed in accordance with MIL-L-85762, “Military specification: lighting, aircraft, interior, night vision imaging system (ANVIS) compatible.”⁶³ MIL-L-85762 (revised to MIL-L-85762A in 1987) is a tri-service specification adopted to establish performance, general configuration, and test and acceptance requirements for ANVIS/ANVIS compatible aircraft interior lighting. It is applicable to all systems, subsystems, component equipment and hardware which provide the lighting environment in aircraft crewstations and compartments where ANVIS is employee. Compliance with MIL-L-85762A requires the light source under test to meet specific criteria for ANVIS weighted radiance and chromaticity.

Until recently, the light sources used in the cockpit have been primarily incandescent bulbs, light emitting diodes, or cathode ray tube (CRT) displays. The last few years has seen the emergence of a new class of EO displays, flat panel displays (FPDs). This new class of displays are based on a number of different technologies, i.e., liquid crystal (LC), electro luminescent (EL), light emitting diode (LED), plasma, field emission, etc. The class of FPDs derives its name from the physical characteristics of the viewing surface and the reduced depth (thin form) as compared to CRTs.⁶⁴ These characteristics, along with the reduced weight and power requirements, makes these displays ideal candidates for military use, including aviation, where space, weight, and power constraints are important factors.⁶⁵⁻⁶⁷

These FPDs, operating using various technologies, may present new challenges to maintaining a MIL-L-85762A compliant cockpit and provide sufficient brightness and resolution over large viewing angles. This issue is important as FPDs currently are planned for use in the Army's RAH-66 Comanche and most certainly will be retrofitted into fielded aircraft. An investigation of this problem is currently underway at USAARL, Fort Rucker, AL.⁶⁸

Another major ANVIS compatibility program was initiated in 1988. Referred to as the Auxiliary Lighting Program, it was directed by the U.S. Army Natick Research, Development and Engineering Center, Natick, Massachusetts. Its goal was the development of ANVIS compatible finger lights, lip lights, and flashlight filters (Figure 13). These devices are used by aircrew to perform a number of ground and in-flight procedures such as preflighting, map reading, and adjusting radio frequencies. Under this program a number of candidate devices were tested.⁶⁹⁻⁷² Because MIL-L-85762 did not address these devices, a Statement of Need, Clothing and Individual Equipment (SN-CIE) was developed by the U.S. Army Aviation Center, Fort Rucker, Alabama.⁷⁰ It was based on input provided by the Naval Development Center (NADC), Warminster, Pennsylvania, and the U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama. A limited field evaluation also was conducted. As a result, a list of approved devices has been distributed to field units. Currently, purchase of these devices must be made out of unit or personal funds.

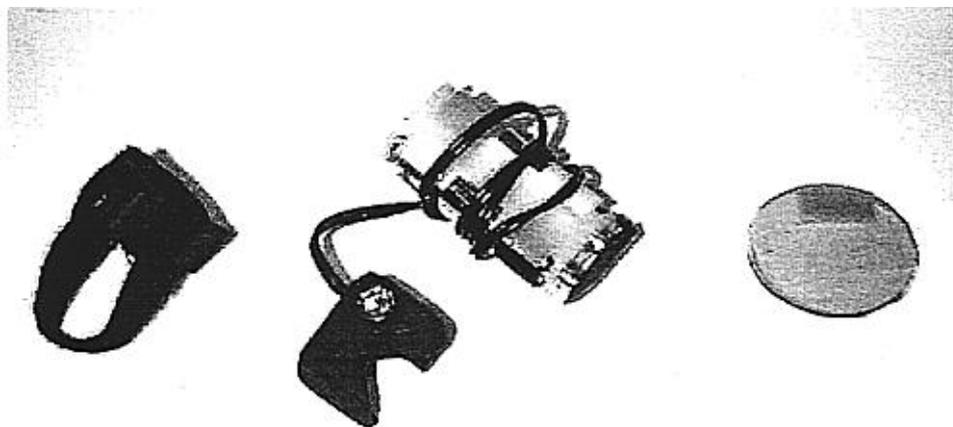


Figure 13. Auxiliary lighting devices: finger light, lip light, and flashlight filter.

It should be noted that the concept of a "compatible" cockpit for ANVIS using a 625-nm "minus blue" filter precludes the use of full color displays or any color display using red. While the use of color in information presentation is well known, the position of the Army aviation community is that in low level and nap-of-the-earth (NOE) flight, the loss of sensitivity which would result from changing the 625-nm filter is not acceptable. However, the issue of ANVIS compatibility with color displays in the helicopter cockpit is not closed.⁷³

6. HUMAN FACTORS

6.1. Visual illusions

Almost since their introduction into aviation, I² devices have produced a number of visual phenomena which at the least have annoyed aviators and, at the worst, have been responsible for visual effects contributing to accidents.

In the early 1970s, a visual phenomenon referred to as “brown eye syndrome.” A misnomer, this phenomenon was later referred to for what it was, an afterimage. The problem was that aviators were reporting experiencing brown or pinkish for a few minutes after flights with AN/PVS-5s. This problem was investigated and determined to be a result of viewing the green imagery of the AN/PVS-5s.⁷⁴ The effect was most pronounced after extended flights. It was determined that the effect was a transitory normal physiological reaction or after-image which disappeared after several minutes following doffing of the goggles.

In 1989, a comprehensive study of visual illusions associated with I² and forward looking infrared sensors was conducted.⁷⁵ It consisted of a questionnaire survey of 150 attendees of an international triservice night vision goggle conference and 90 responses to an insert to the U.S. Army aviation safety publication, *Flightfax*. Based on the data collected, classifications were developed to organize the various subjective responses of visual effects and illusions. The responses were classified as “Degraded Visual Cues” or “Disturbed Orientation.” The latter classification was divided further into “Static Illusions” and “Dynamic Illusions,” depending on whether motion (real or perceived) was a factor. The most frequently reported degraded visual cue was impaired acuity, often to the point of causing loss of visual contact with the horizon and occasionally requiring transition to instrument flight. Other reported degraded visual cues were FOV and lack of depth cues. For the disturbed orientation category, the most common static illusion reported was difficulty in judging height above the terrain, especially over water. Closely related were problems with estimation of aircraft clearance. Unawareness of actual aircraft drift was the most frequently reported dynamic visual effect, followed by the illusion of drift when the aircraft was actually stationary.

6.2 Spatial disorientation

Spatial disorientation (SD) continues to be a significant hazard associated with the use of I² systems. Analyzes⁷⁶⁻⁷⁷ of helicopter accidents performed by the spatial disorientation team at USAARL over the last few years have revealed the following statistics. Between 1987 and 1995, 107 (37 percent) of the 291 accidents in which SD was considered a significant factor occurred during flight with I² systems. These accidents cost \$186M and 62 lives. The comparative SD accident rates for class A-C per 100,000 flying hours for all types of Army helicopter for FY 1990-95 as a whole are: 1.66 for day flight, 3.87 for night unaided flight, and 9.27 for NVG flight. The majority of mishaps occurred during hover and hover-taxi flight, or in recirculation conditions. Despite the advantages of an enhanced visual image through I² devices, depth perception estimations are degraded, and the FOV is limited, thus reducing the orientation cues normally present in daytime flight. This much higher rate of SD accidents when flying with I² devices clearly is a considerable concern for operational effectiveness. A study is in progress to examine further the factors associated with these accidents.

Recommendations to control the SD hazard include enhancement of aircrew awareness of SD during night aided flight, a review of the SD content of I² systems training, and more stringent currency requirements for I² flying. The introduction of the ANVIS HUD for certain type aircraft are providing the aviators with some reference of spatial orientation and within the I² device’s FOV.

7. MECHANICAL CONSIDERATIONS

There are a number of mechanical features and considerations of the AN/PVS-5 and ANVIS which have changed over the period of their use. These include mass properties, the development of the dual battery pack, the evolution of battery type, range of adjustments, the mount for the I² on the helmet, and compatibility with the various aviators’ helmets.

7.1 Mass properties

7.1.1 AN/PVS-5

The AN/PVS-5 goggles in their original full-face configuration has a mass of approximately 0.86 kilogram (kg) and the AN/PVS-5 with the cut-a-way faceplate for aviation use had a mass of approximately 0.77 kg. (1 kg = 2.2 lbs.) The additional original dual battery pack with mercury batteries had a mass of approximately 0.18 kg for a total mass of the aviator head supported devices (regular size helmet, AN/PVS-5, and battery pack) of 2.63 and 2.54 kg, respectively. Poor helmet stability and neck fatigue with AN/PVS-5 attached prompted aviators to add a counter weight

or counter balance system, such as suspenders and attached surgical tubing to the roof of the aircraft, to reduce the helmet's tendency to rotate over the eyebrows. After the counterweights were approved and the method standardized, the amount and type of counterweight used by aviators were self determined and observed to range between 0.18 and 0.68 kg in mass.⁷⁸ The cumulative total of these components placed the amount of weight supported by the head in excess of 6 pounds.

The coordinate system used by the USAARL to define helmet assembly center of mass (CM, commonly called center of gravity) is based on the head anatomical coordinate system illustrated in Figure 14.⁷⁹ The x-axis is defined by the intersection of the mid-sagittal and Frankfort planes with the positive direction anterior of the tragion notch. The y-axis is defined by the intersection of the Frankfort and frontal planes with the positive y-axis exiting through the left tragion notch. The z-axis is oriented perpendicular to both, the x- and y-axes following the right hand rule. The mass properties for five configurations of the SPH-4, size regular, and AN/PVS-5 NVG, with the original version of the dual battery pack are provided in Table 1. Due to the helmet and goggle symmetry about the mid-sagittal plane, the y-axis center of mass location is not reported.

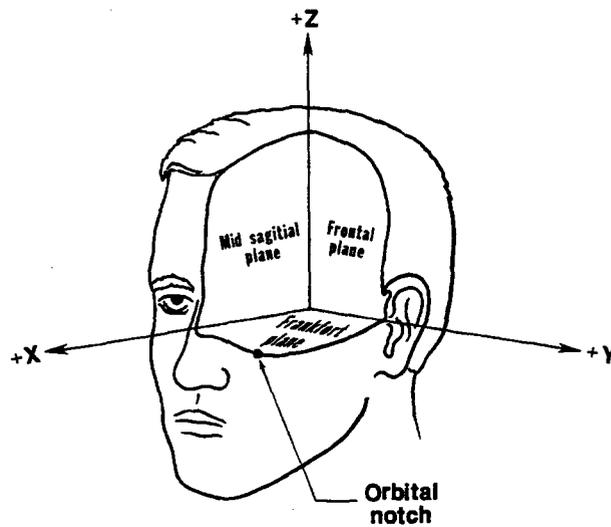


Figure 14. Head anatomical coordinate system.⁷⁹

Table 1. SPH-4 and AN/PVS mass properties.

| Configuration | Mass (kg) | CM location | |
|--|--------------|-------------|----------------|
| | | x-axis | (mm) z-axis |
| SPH-4 modified to receive AN/PVS-5 | 1.59 | -6.6 | 38.1 |
| SPH-4 w/ std. AN/PVS-5 & battery pack | 2.63 | 30.0 | 26.9 |
| SPH-4 w/ std. AN/PVS-5, battery pack & 0.63 kg counterweight | 3.26 | -2.8 | 26.9 |
| SPH-4 w/ mod. AN/PVS-5 & battery pack | 2.54 | 30.5 | 36.3 |
| SPH-4 w/ mod. AN/PVS-5, battery pack & 0.63 kg counterweight | 3.17 | -4.1 | 22.9 |

7.1.2 ANVIS

The mass of ANVIS was reduced from that of AN/PVS-5, and its center of mass location was also different. The ANVIS property values are provided in Table 2.

Table 2. SPH-4/SPH-4B size regular and ANVIS mass properties.

| Configuration | Weight (kg) | CM location (mm) | |
|--------------------------------|----------------|------------------|--------|
| | | x axis | z axis |
| SPH-4 | 1.54 | -3.3 | 42.7 |
| SPH-4 w/ ANVIS & battery pack | 2.54 | 25.4 | 38.3 |
| SPH-4B | 1.31 | 10.2 | 52.0 |
| SPH-4B w/ ANVIS & battery pack | 2.22 | 31.7 | 39.4 |

The mass properties of standard ANVIS, independent of the helmet, also were determined by USAARL.⁸⁰ For this determination, an ANVIS unique coordinated system was established. This coordinate system is illustrated in Figure 15 and aligns the x-axis coincident along the length of the fore/aft adjustment screw. The origin is placed at the back plate which supports the end of this screw with positive x directed forward, toward the adjustment knob. The y-axis is normal to the x-axis and is parallel to the shelf assembly with positive y directed to the left side. The z-axis is normal to both x- and y-axis and its direction, following the right hand rule, is directed upward.

Two configurations of ANVIS are defined by MIL-A-49425(CR). Both versions utilize a ball and socket mount for attachment to a helmet. Version 1 (V1) has this mount located at the midpoint of the support shelf assembly and was designed for use with the SPH-4 flight helmet. Version 2 (V2) has the mount positioned to the left of midpoint of the support shelf assembly. The V2 version was designed for use on the SPH-4 flight helmet modified with a helmet mounted sight (AH-1 cobra helicopter) for weapon firing. Center of mass determinations were made for both ANVIS versions.

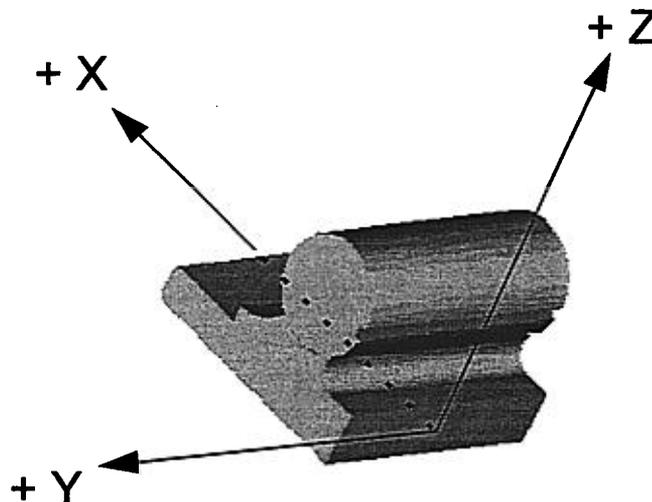


Figure 15. ANVIS coordinate system.

Three sets of ANVIS (V1) and two sets of ANVIS (V2) were measured and their averaged values presented. Because the ANVIS goggle has four independent mechanical adjustments (interpupillary distance, fore/aft, tilt, and diopter) which affect its center of mass location, multiple measurements were taken to assess each at their maximum, minimum, and middle adjustment range. The vertical height adjustment was not evaluated since it is not a part of the goggle, but an adjustment on the visor mount. The results of these evaluations are provided in Table 3.

Table 3. ANVIS (V1) and (V2) center of mass locations.

| Item | Mass (kg) | Value | X axis (fore-aft) (mm) | Y axis (IPD) (mm) | Z axis (Vert.) (mm) |
|------------|-----------|----------------|------------------------|-------------------|---------------------|
| ANVIS (V1) | 0.52 | maximum | 25.9 | 0.8 | -30.7 |
| | | mid adjustment | 16.3 | -0.3 | -31.2 |
| | | minimum | 5.6 | -1.0 | -31.5 |
| ANVIS (V2) | 0.53 | maximum | 25.9 | -24.1 | -32.8 |
| | | mid adjustment | 16.8 | -24.1 | -33.0 |
| | | minimum | 6.1 | -24.4 | -33.5 |

The minimal variation in the z-axis values is due to the lack of vertical height adjustment. Additionally, the lateral center of mass value possessed a small range within each ANVIS type. This is because neither goggle type had independent interpupillary distance adjustments, which is now available since the Omnibus III ANVIS procurement. The greatest variation range existed along the x-axis due to the fore/aft adjustment capability.

7.2 Head supported weight effects

The introduction of the AN/PVS-5 NVG into the aviation community increased the head worn mass beyond 2.54 kg. Increased mass of head supported devices have detrimental effects on pilot performance due to neck muscle strain and fatigue and, also, to increase the risk of severe neck injury in crashes. The disadvantages of increased helmet mass, however, are offset by the enhanced visual capability for night flying and increased weapons aiming capability offered by helmet-mounted image intensification devices and other helmet-mounted devices. In order to permit the use of higher mass helmet assemblies without overloading the neck in severe crashes, the ANVIS-6 was developed with a spring-loaded, ball-socket mount which permits the goggles to break free during a crash. The 0.52 kg night vision goggle (NVG) device was designed to break free of the helmet at a goggle deceleration of 10 to 15 times the acceleration of gravity (G) (Military specification, MIL-A-49425(CR)). Although this approach offers one solution to the problem of increased head-supported mass in Army aviation, little is known about the dynamic behavior of this device in a crash or of the physical limitations of the human neck to support these masses.

In an initial attempt to define a safe limit on flight helmet mass for the Army, USAARL in 1982 proposed a limit of 1.8 kg during the development of the AH-64 Apache flight helmet⁸¹. The helmet system subsequently developed met this mass limitation while providing the desired visionics and required protection levels. Nonetheless, the SPH-4 helmet with NVG attached used for night operations in all other Army helicopters continued to exceed the proposed 1.8 kg limit by more than a full kilogram. Although there have been anecdotal reports from aviators complaining of considerable discomfort with this system, particularly after long missions, the effects on pilot performance of bearing this much mass has never been systematically studied. Furthermore, the dynamic consequences of crashing with head-borne masses approximating 3 kg remain largely speculative.

Shanahan and Shanahan, in a study of U.S. Army helicopter crash injuries from 1979-1985, found 82 reported spinal fractures⁸². Figure 16, taken from the Shanahan report illustrates the spinal fracture distribution by vertebral level. The cervical and upper thoracic vertebra with the highest frequency of fracture was the 7th cervical. The lower thoracic and the lumbar region experienced a higher frequency rate, but these injuries are believed due to compression loadings resulting from high vertical impact loads in precrashworthy seat designs. Cervical spine fractures comprise only 1.6 percent of the 1484 injuries sustained in survivable crashes. The cervical injuries were caused by either acceleration loadings or contact injury. No differentiation between these two injury mechanisms was made.

This review of helicopter crash injuries indicates a lack of evidence supporting significant inertial neck injury for Army aviators wearing a 1.5-1.8 kg helmet. In some crashes, heavier helmets of 2.9 kg (including night vision components) have been worn, but the extra 1.1 to 1.4 kg mass of night vision goggles and counterbalance weights have broken free from the helmet and relieved the neck of this added loading. A survey of 37 NVG instructor pilots found an average head supported weight of 2.6 kg with a range from 2.1 to 3.1 kg with helmet, ANVIS, battery packs, counterweights, and auxiliary equipment. The average counterweight with ANVIS was 0.36 kg, with a range from 0.25 to 0.62 kg. An epidemiological survey of helicopter accidents from 1985 through 1994 showed no significant increase in neck injuries with the use of NVGs, but found an increase in head injuries with the older AN/PVS-5 NVGs, which were primarily mounted to the helmet with surgical tube and straps⁸³. The non-documentation of inertial neck injury does not mean none occurred, but that the accident investigators may have failed to recognize this injury among the more obvious contact, crushing, and spinal column injuries in the older, non load-limiting seats.

Recent Army helicopter designs incorporate minimal levels of crashworthiness with specific performance levels for the crewseats. Helicopter crew seats are typically procured to military performance specifications with a 30 G longitudinal static load requirement and a vertical energy absorption capability (Military specification, MIL-S-58095(AV)).⁸⁴ The 30 G longitudinal requirement is a structural integrity check of the seat and its mounting hardware to provide assurance that the seat will not separate from the floor. The vertical energy absorber is a mechanical device which restricts the vertical crashloads experienced by the occupant. The desired vertical load is an average of 14.5 G over the range of seat stroke. Peak loads of 18.3 G have been measured in anthropomorphic test dummies during seat qualification trials⁸⁵. The worst case condition would be a seat experiencing 30 G longitudinally and stroking with a peak vertical load of 18.3 G. The resultant from these two loading vectors is 35 G directed 31.4 degrees downward from horizontal.

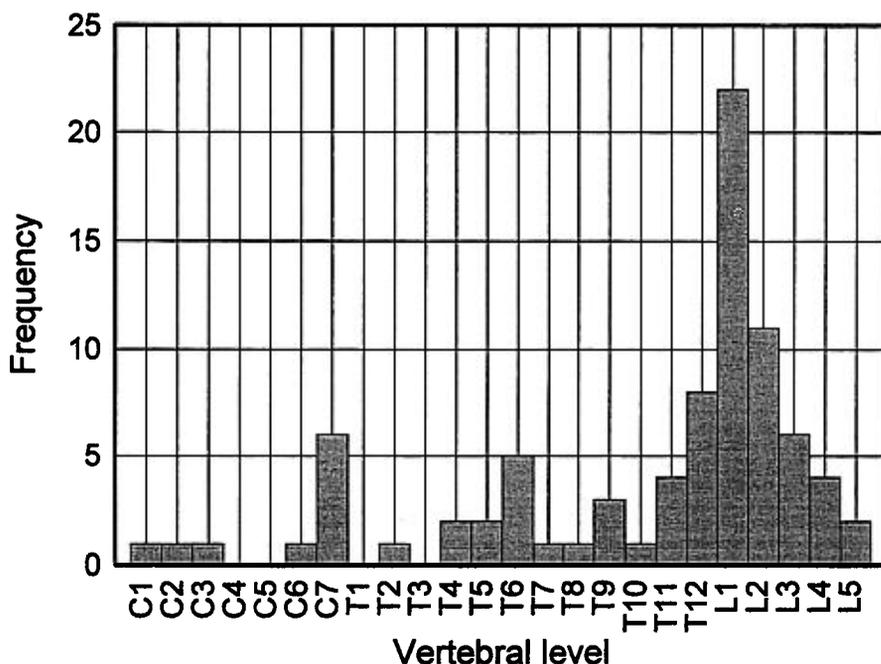


Figure 16. Frequency distribution of spinal fractures in class A and B survivable crashes as vertebral level.

The determination for maximum allowable helmet system mass is based on Newton's second law: $F = ma$. This equation is used by considering the neck tensile strength threshold of 4050 Newtons and the acceleration environment of 35 G with a restraint system induced dynamic overshoot ratio of 1.5. The effective mass acting on the C7/T1 juncture can then be calculated as follows:

$$F = ma$$

$$m = F / a = 4050 / [(35) * (1.5) * (9.81)] = 7.86 \text{ kg}$$

The mass acting on the C7/T1 juncture includes the helmet, head, and neck. The total mass of the neck is included in this calculation to be conservative. By subtracting the head mass (4.32 kg) and neck mass (1.04 kg) from the above value, we arrive at the allowable helmet mass for the given impact condition.

$$m = m_{\text{head}} + m_{\text{neck}} + m_{\text{helmet}}$$

$$m_{\text{helmet}} = m - m_{\text{head}} - m_{\text{neck}} = 7.86 - 4.32 - 1.04 = 2.5 \text{ kg}$$

The current USAARL recommendation for vertical center of mass limit is based on a constant mass moment concept acting about the C7/T1 juncture. This rationale allows for greater helmet mass as the vertical CM location moves downward. The C7/T1 juncture was selected as the pivot point because, as noted by Shanahan,⁸² it is more frequently injured in helicopter accidents than upper cervical vertebra. Application of this theory requires selection of a HSD mass and vertical CM position to use as a constant mass moment. Lack of empirical data necessitated the selection of the “worst case” fielded helmet system, the AH-1 cobra helmet configuration, to establish an acceptable constant mass moment. This helmet configuration has a mass of 1.74 kg and a vertical CM location of 5.2 cm above the tragon notch. The final variable needed to determine the constant mass moment is the vertical distance between the C7/T1 juncture to the tragon notch. A value of 11.94 cm was selected which represents the 95th percentile female and the 85th percentile male.⁸⁶

To determine the constant mass moment, the definition of a mass moment is used: $M = md$. The mass is the helmet mass of 1.74 kg and the distance is the total distance of the helmet vertical CM position above the C7/T1 juncture (11.94 cm + 5.2 cm). This is calculated as follows:

$$M = md = (1.74) * (11.94 + 5.2) = 29.8 \text{ kg-cm}$$

This moment value can be used to establish a relationship between the vertical CM position and mass by rearranging the above equation as follows:

$$29.8 = m_{\text{helmet}} * (11.94 + Z_{\text{helmet cm}})$$

$$Z_{\text{helmet cm}} = (29.8 / m_{\text{helmet}}) - 11.94$$

Plotting this relationship results in the curve shown in Figure 17. The allowable mass is limited to 2.5 kg as determined above. Additionally, the allowable vertical CM position is limited to 5.2 cm since biodynamic reactions to higher CM locations are unknown. Plotting item specific mass and vertical CM values on the graph allows acceptability assessment. The mass and vertical CM values for the SPH-4 and SPH-4B helmets configured with AN/PVS-5 and ANVIS goggles are also shown in Figure 17.

7.2.1 Fatigue

The longitudinal CM locations of helmet systems are believed to have greater effects on wearer fatigue and performance decrements than crash induced injury. Efforts have been conducted by Butler⁸⁷ to assess these effects by exposing volunteers to controlled helicopter ride environments with various helmet mass and CM configurations. During his study, Butler measured both physiological and biomechanical responses to the changes in helmet system mass properties. The property changes included three masses (2, 3, & 4 kg) and four longitudinal CM positions (-2, 0, 2, & 4 cm) measured relative to the head center of mass. A head supported weight moment of $82.8 \pm 22.8 \text{ N-cm}$, measured about the occipital condyles, was recommended based on changes in head pitch accelerations and posterior neck myoelectric responses. It was also recommended that negative moments be avoided. By using the recommended weight moment, including the tolerance (105.6 N-cm total), this value can be converted into a mass moment relative to the tragon notch and plotted. This relationship is shown in Figure 18. The rearward CM location was limited at -2 cm based on Butler’s recommendation⁸⁷ that negative moment be avoided. Mass was limited at 2.5 kg as determined earlier. The forward limit was arbitrarily set at 9.5 cm. The mass and longitudinal CM values for the SPH-4 and SPH-4B helmets configured with AN/PVS-5 and ANVIS goggles are also shown in Figure 18.

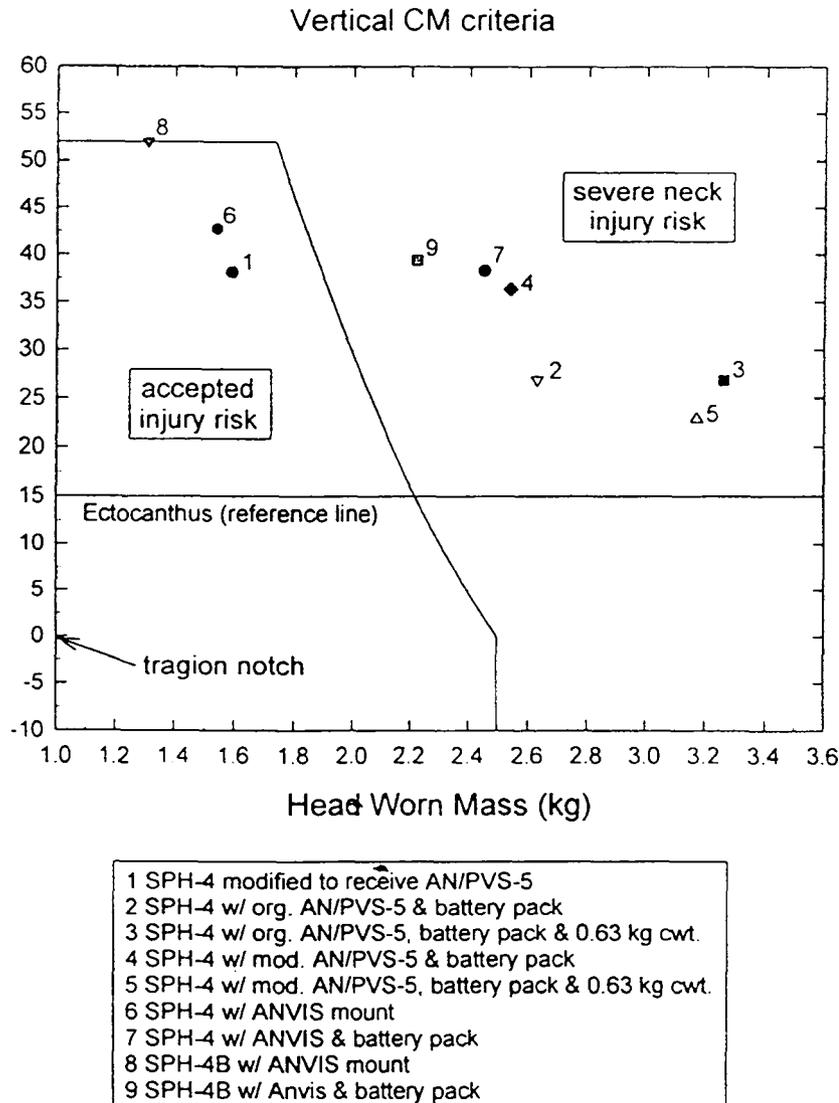


Figure 17. Vertical center of mass criteria.

7.3 Batteries

The AN/PVS-5 and ANVIS are equipped with a self-contained power supplies. This allows the aviator, or infantryman, a greater freedom of movement with these systems. The AN/PVS-5 was originally outfitted with a mercury battery (BA-1567/U) at 2.7 volts-direct current (vdc). Later one lithium battery (BA-5567/U) at 3.0 vdc was used. The AN/PVS-7, which replaced the AN/PVS-5 for ground use, uses either one lithium battery or two "AA" alkaline batteries. The mercury battery was replaced with the "AA" alkaline batteries due to its high cost and environmental hazards associated with disposal. The ANVIS also uses either one lithium battery or two "AA" alkaline batteries per channel. The average life for a lithium battery at 70 ° F is 13 to 16 hours and for "AA" alkaline batteries at 70° F is 10 to 22 hours.⁸⁸ During flight training Army aircrewmembers primarily use AA batteries, using one set of batteries until the low battery indicator is activated keeping new batteries in the dual battery pack as reserve.

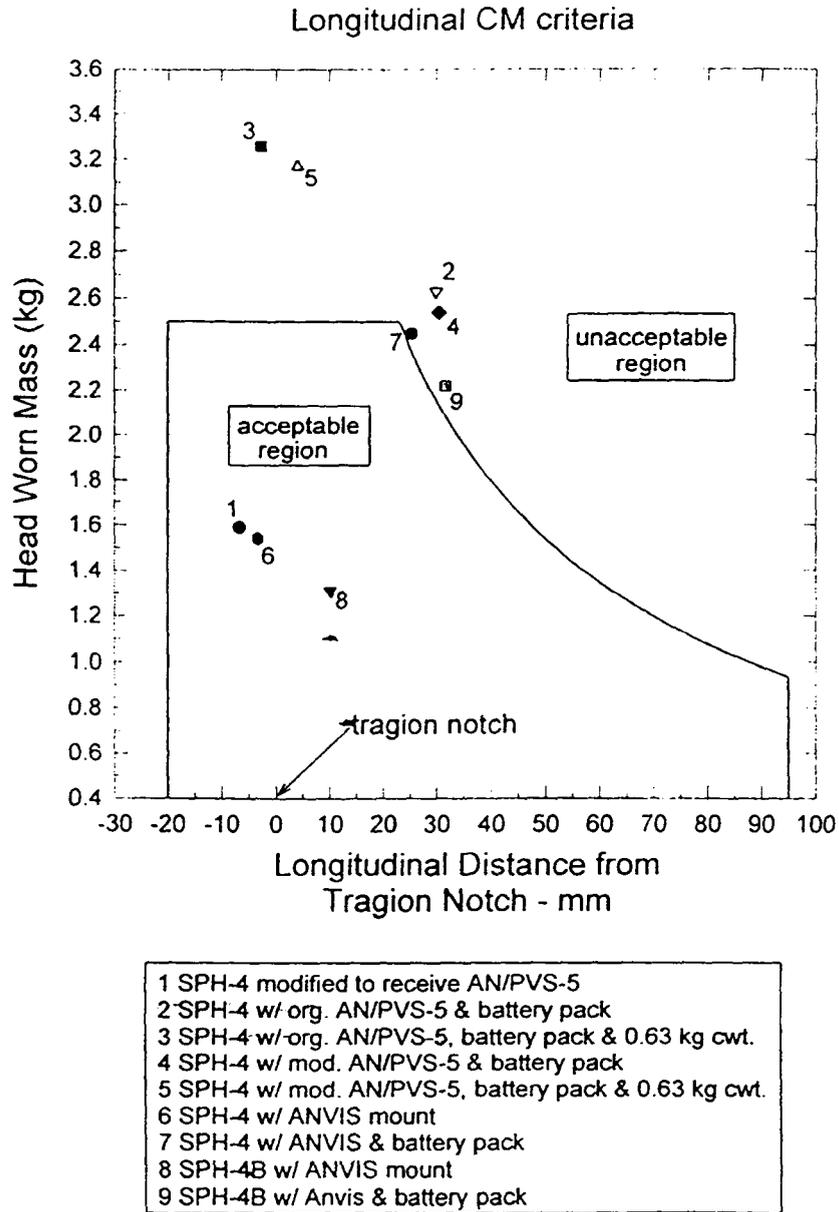


Figure 18. Longitudinal center of mass criteria.

The advantages to the "AA" alkaline batteries in I² devices over the lithium or mercury is their wide availability and low cost. Although "AA" alkaline batteries weigh more than lithium batteries, their extra weight can be turned into an advantage by using them as part of the counter-weight on the ANVIS. (The weight of I² devices place a forward shift on the CM which contributes to fatigue, discomfort, and helmet rotation. The battery pack is placed on the back of the helmet to shift the CM towards an acceptable position.) The lithium battery still is used, primarily due to its effectiveness in cold weather climates as compared to the "AA" alkaline battery. For example, the lithium battery can supply the required voltage for five to eight hours at -20° F, as compared to one to three hours at 20° F for two "AA" alkaline batteries.¹³ However, there are a number of safety issues involved with the use of lithium batteries.

The battery pack consists of two separate battery compartments, the primary and spare⁸⁹ (Figure 19). Only one of the battery compartments needs to be filled to allow the I² device to function properly. The spare battery compartment function is to provide a safe guard. With batteries placed in either compartment, a low voltage indicator is powered. If a voltage drop (below 2.4+/-0.2 volts) is detected, then a red LED indicator on the ANVIS visor will become lit.⁷³ Above 2.0 volts, the luminance output and gain of ANVIS remain constant. Below 2.0 volts, the luminance drops rapidly (Figure 20).⁷⁴ For lithium batteries, the useable time for ANVIS after the low battery indicator has been activated is approximately 30 minutes. A 1997 study of battery performance in ANVIS⁹⁰ found that several hours of use without a decrease in luminance output were typical after the low battery indicator light was activated for "AA" alkaline batteries. Another feature of the dual battery system is that when the primary battery has lost voltage, the operator can use the selector switch on the battery pack to switch over to the spare battery.⁹⁰ This allows the operator to finish the mission. The ANVIS battery pack also has the ability to be adapted to an auxiliary aircraft power supply. This is accomplished through an DC to DC transformer. If aircraft power is lost, then the power pack will switch automatically over to battery power.

7.4 NVG Adjustments

The principles of adjusting the various NVGs are the same. For the mechanical adjustments, the user aligns his line of sight with the optical axis of each eyepiece of the NVG at a vertex distance that provides the maximum display FOV and the maximum unaided FOV, if unaided look around vision capability is present as with the ANVIS. By observing the vignetting (shading) of the circular display FOV, the user can find the optimum sighting alignment point within a few millimeters for all three axis (fore-aft, vertical, and interpupillary distance (IPD)).¹³ Most NVGs also have a tilt or pitch capability where the line of sight relative to the head can be adjusted either upwards or downwards. An example of different desirable tilt positions would be for the standing soldier, the goggles (front lenses) would be tilted down to better see the ground; and in the prone position, the goggles would be tilted upwards to reduce backward neck thrust. Pilots would optimize the NVG tilt position in the aircraft according to the seat position relative to the line of sight and flight.

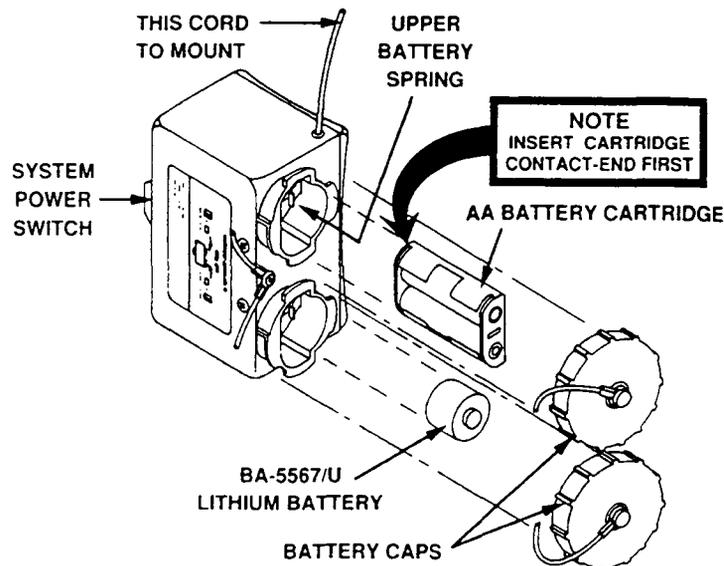


Figure 19. Dual battery pack.

Luminance Output vs Voltage Input ANVIS

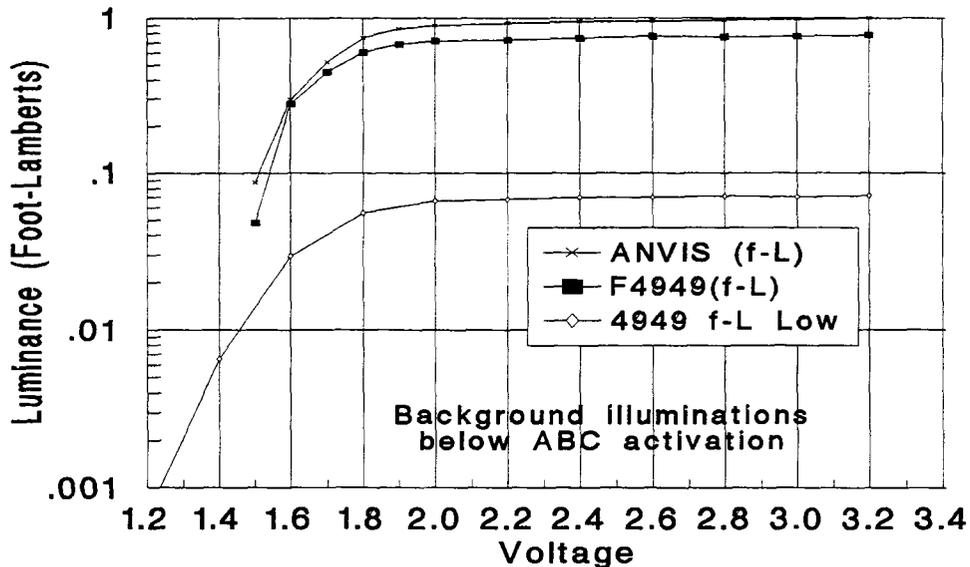


Figure 20. ANVIS luminous output versus voltage input.

To obtain the maximum comfortable resolution with the NVGs, the objective lenses would be focused for the viewing distance, and the eyepieces focused for the user's refractive status resulting in a clear image without overly stimulating accommodation.

The AN/PVS-5 NVG are aligned vertically, fore-aft, and tilt angle with right and left friction clamp knobs in elongated holes in the faceplate. The IPD adjustment also use a friction lock arrangement. The faceplate itself can be positioned on the face with a headstrap adjustment (usually slipping down on the face from the forward center of gravity). The ANVIS was designed like a fine instrument with screw threads for the fore-aft, vertical, and IPD adjustments. ANVIS versions after Omnibus II extended the fore-aft adjustment range from 16 to 27 mm and provided independent IPD adjustments for each eye.

Focusing the objective lenses for the older AN/PVS-5 was simple. The lens metal housing with the objective lens was rotated maximum counterclockwise for infinity focus, and clockwise rotation moved the focal distance closer to a minimum distance of 25 centimeters with one-half turn.

To reduce weight and prevent potential changes in alignment errors with changes in focus, the ANVIS house assembly was manufactured from a durable plastic, and the objective and eyepiece lenses did not rotate with focusing movements. The one-half turn of the focusing knob changed the objective lens focus from infinity to 10 inches as the previous AN/PVS-5. Unfortunately, the ANVIS objectively lens could not be accurately set at infinity with the plastic housing and coarse threads for the F# 1.2 lens. In the initial operational testing of ANVIS, the pilots frequently tried to over rotate the objective lens resulting in either breaking the housings or unscrewing the objective lenses. To prevent stress on the objective lens without a major redesign, it was decided to adjust the maximum counter clockwise position to go slightly pass infinity. For high contrast targets under high night illumination, the observer can detect image blur from the objective lens of the ANVIS with as little as 0.05 diopter change. The 0.05 diopter change equates to slightly more than 2 degrees rotation of the objective lens focusing knob. The latest versions of the ANVIS use the mounting threads for the objective lens focus, resulting in a 6 times increase in angle rotation per diopter change, but with a reduced near point focus.

7.4.1 Image effects on misadjustments

Although the NVG users become proficient in optimizing the adjustments after training and experience, the primary image effects of the misadjustments for the goggle or eyepiece type with the eyes located at the optimum sighting alignment point (OSAP) are shown in table 4 to follow. ⁹¹ The OSAP vertex distances are approximately 20 mm for the standard 18-mm eyepiece and 28 mm for the 25-mm ANVIS eyepiece

7.4.2 Optical Effects with Perpendicular Displacement from the Optical Axis

The eyepieces for the AN/PVS-5 had significant spherical aberrations such that approximately 4 mm of displacement induced about 1.00 diopter of plus lens power. For the production 18-mm and 25-mm eyepiece ANVIS, the spherical aberrations were less than 0.12 diopters with 10 mm of displacement.

Table 4. Image effects on misadjustments.

| Adjustment | 18-mm Eyepiece AN/PVS-5, and ANVIS for 20 mm OSAP |
|-------------------|---|
| Fore-aft | Increase vertex distance beyond OSAP decreases diameter of the FOV at the rate of 1.8 degrees per millimeter of excessive eye clearance. |
| IPD* and Vertical | Lateral and vertical displacements reduce FOV opposite the direction of displacement at the rate of 2.5 degrees per millimeter of displacement |
| Tilt | No effect, except possible vertical displacement FOV effect |
| Adjustment | 25-mm Eyepiece ANVIS for 28 mm OSAP |
| Fore-aft | Increase vertex distance beyond OSAP decreases diameter of the FOV at the rate of 1.3 degrees per millimeter of excessive eye clearance. |
| IPD* and Vertical | Lateral and vertical displacements reduce FOV opposite the direction of displacement at the rate of 3.7 degrees per millimeter of displacement. |
| Tilt | No effect at the OSAP. However, keystone distortion has been demonstrated when the eye is closer to the eyepiece and tilted. |

* Note: When the eye clearance is behind the OSAP, reducing the monocular FOV through the ANVIS, some of the pilots have slightly misadjusted the IPD either narrower or wider to achieve a horizontal full field of view, but with a reduced binocular overlapped and vertical FOV.

A misconception frequently expressed about misadjusting the IPD is that the displacement will induce significant convergence errors. On the contrary, when the eyepieces are adjusted for zero diopter power, the eyepieces theoretically can be adjusted from the minimum to the maximum IPD range (20 mm) without any change in the image convergence angles to the eyes. With lens power and eye displacement, the convergence changes, expressed in milliradians, are the product of the lens power in diopters times the displacement in millimeters.

7.4.3 Eyepiece focus

The early operator's manuals for the NVGs simply stated to rotate the eyepiece diopter adjustment ring for each ocular until the scene was clearest. For healthy young soldiers not requiring corrective lenses, the clearest vision setting could vary from infinity to the adjuster's near point of focus with maximum eye accommodation. This resulted in the convergence angle from the eyepieces being at infinity for distant objects and the eyepiece focus distance to the eye at much less than 1 meter. With both eyes open and the convergence and accommodation points being at different distances, the user would have eye strain, blurred, and/or double vision, with a definite reduction in stereovision.

Procedures to reduce the accommodation when focusing the eyepieces are described in the latest ANVIS operator's manual. For the monocular technique, the images are first blurred beyond infinity by rotating the eyepieces counter clockwise and inducing excess plus lens power before reversing the rotation to clear vision. With the binocular method, both eyes are opened and one channel is slightly blurred with the objective lens while the eyepiece of the other channel is refocused.

7.5 Faceplate and mounting housings

The faceplate, or the lack of a faceplate in the case of the ANVIS were results of the intended use. The AN/PVS-5 were designed for the ground forces and the faceplate held the intensifier system and prevented the detection of the light from the eyepieces. The faceplate was eliminated with the AN/PVS-7 design, but lens cups could be used to block the light from the intensifier tubes. For aviation use, the display lighting from the eyepieces is an insignificant signature when compared to the audio and visual signature of a helicopter.

Before the fielding of ANVIS, the AN/PVS-5 were mounted in several different modified faceplates for aviation. These included the "cut-a-ways"; the GX-5 which used a modified camera mount and a locally fabricated fiberglass housing that provided a flip-up capability; and the GM-6, which used the fiberglass housing of the GX-5 mount and an ANVIS visor and connector.

The standard mount for the ANVIS was the center located V-1 type. For the AH-1 Cobra, the visor on the SPH-4 helmet included a monocular sight over the right eye. For the ANVIS to be compatible with the Cobra sight, the mount was shifted away from the sight and was called the V-2. The bracket on the ANVIS which connected to the helmet mount also had to be shifted on this V-2 version.

7.6 Helmet compatibility

The ANVIS was designed for the SPH-4 Army aviator single visor helmet and other helmets required different mounting schemes. Although the Apache AH-64 primary night imaging system uses a thermal sensor coupled to a monocular helmet mounted display, under certain conditions the ANVIS could provide better definition for pilotage and some of the Apache helmets were modified to accept the ANVIS visor.

With the fielding of dual visors with the SPH-4B helmet and later the HGU-56/P helmet, it was thought that the eye clearance would be increased to the ANVIS eyepieces and possibly reduce the FOV for the standard eyepieces. However, the mount on the SPH-4B was tilted downward and the clearances between the two visors and the visor housing in the HGU-56/P were no greater than the single visor housing for the SPH-4⁹².

8. SAFETY ISSUES

In addition to the added head supported weight associated with the I² systems as discussed in the previous section, the presence of the two I² tubes located millimeters from the eyes poses a potential hazard of ocular injury during crash scenarios.⁹³ With the older AN/PVS-5 NVGs, head and facial injuries were statistical were significantly greater with NVG use compared to matched day mishaps. Even when wearing corrective lenses, injury could occur if the lenses do not provide some minimum level of impact resistance. In 1988 USAARL conducted an investigation into this problem. This investigation compared the impact resistance of glass, CR-39 (plastic), and polycarbonate lenses and established the approximate level of force necessary to cause lens breakage. It was concluded that polycarbonate lenses would reduce the number of severity of impact injuries and recommended their use.⁹⁴ With the break-away feature of the ANVIS, the head and facial injuries did not increase with the use of NVGs compared to matched day accidents. However, advanced aircraft designs are considering airbags, which may reverse some of the advantages achieved with the break-away feature for helmet mounted devices.

With the advent of laser rangefinders and target designators on the battlefield, there is potential for this energy (visible and near infrared) to seriously damage the retina of the eye. As a result there have been a number of studies to assess the potential hazard and recommend laser protection levels.⁹⁵⁻⁹⁷ When I² systems are in use, visors (including laser protective visors) can not be deployed. Therefore, the laser protection provided when wearing ANVIS is that provided by the physical structure of the ANVIS itself.⁹⁸ During Desert Storm, some laser protective spectacles were

worn with ANVIS, but noticeable decrease in low light performance was considered unsatisfactory. The I² devices also needs protection from laser damage. Multilayer coatings on windows in front of the objective lenses provide sharp wavelength cut-off filters, blocking known laser wavelengths with very minimal decrease in the I² sensitivity. The goals of current funded programs are to improve laser protection to the eyes and sensors with less visual or sensor degradation over a wider and variable spectrum.

9. MISCELLANEOUS ISSUES

A number of additional issues relating to I² devices are important enough to warrant mentioning. The first is the “bifocal” AN/PVS-5. This was an experimental version of the AN/PVS-5 to address the ability to focus inside the cockpit through the AN/PVS-5. This test version consisted of a standard 40-degree goggle modified such that the lower 30 percent of each eyepiece was set at a pre-focused distance of 26 inches. A 1975 test³⁶ of this configuration showed a preference of this design over the standard design during low altitude, enroute flight. However, it was found unacceptable for NOE and other close to the ground maneuvers. Accepting the basic premise of the bifocal concept, a second study⁹⁹ was performed to determine if a smaller bifocal cut would provide an advantage, but would be acceptable to aviator’s operating close to the ground. Two bifocal designs, 14 and 24 degrees, were tested. Both designs were found to be “statistically” better than the unmodified AN/PVS-5 when looking at the aviator’s ability to hold precise altitude at night. Data further suggest that a 24 percent bifocal was preferred over the 12 percent. However, bifocal designs never were pursued.

The interaction of I² devices with interior cockpit lighting has been discussed previously. However, during I² flight, the aviator encounters additional lights, mostly aircraft related, which are an issue.¹⁰⁰ The external aircraft lights also effect the I² performance. Previous methods to reduce this effect during NVG flight training with older aircraft have been dimming and masking of the standard position lights. However, the masking procedure may not be in compliance with FAA regulations in civilian airspace. Most of the primary helicopters now have infrared and electro-luminescent panel lights for position information when operating in approved military NVG training areas.

The display on the eye end of the AN/PVS-5 and ANVIS includes a phosphor screen. The AN/PVS-5 initially used the P20 phosphor. P20 is yellow-green, relatively narrow band (100 nm), and has a peak of 530 nm. Due to a noise problem (related to the low cathode sensitivity of the 2nd generation tubes), the P20 was replaced with a RCA F2126 - type 1052 phosphor. This replacement was similar to the P20 in that it was yellow-green and peaked close to 530 nm. This phosphor also had a slower persistence than the P20. ANVIS has used P20 and P22 phosphors (both yellow-green in color with peaks near 530 nm). However, ANVIS has recently been switched to the P43 phosphor. P43 also is yellow-green in color but is extremely narrow band (5 nm) and peaks at 543 nm. The persistence (10%) of P43 is 1.2 milliseconds, making it a medium-short persistence phosphor. P43 is the phosphor used in the miniature cathode ray tubes in AH-64 Apache’s Integrated Helmet and Display Sighting System (IHADSS). A 1996 study¹⁰¹ found little difference in performance of the P43 over the P20 and P22. In addition, the narrower band P43 produces less chromatic aberration.

Some configurations for the RAH-66 Comanche aircraft have display imagery originating from a nose-mounted forward looking infrared (FLIR) camera and from helmet-mounted I² devices. These two types of imagery are similar in color and size, but may differ perspective, contrast and luminance. The luminance of the I² display is not adjustable and will be in the mesopic or low-photopic range (0.3 to 2.0 fL). The FLIR display is adjustable up to 100 times that of the I² display. There has been concern that aviators switching from the one luminance value to another may experience some transitory effects on visual resolution. This question was investigated in 1994.¹⁰² The study found a “significant reduction in letter recognition occurring within the first second after switching from simulated FLIR to simulated I² imagery when the FLIR luminance was greater than 10 fL. For a 49.2 fL FLIR luminance, the reduction in visual acuity was determined to be two-fold and lasted up to 4 seconds.

10. THE FUTURE OF I² DEVICES

I² systems have come a long way since the 1st generation devices of the 1960s. A question often heard is, “Has the physics of I² devices reached a barrier, or will there be a 4th generation I² device?” At the moment, the only answer is that there is a continuing effort to improve I² systems. One method used to improve the maximum I² performance was the optimization of the various components and characteristics of the intensifier tubes and determining

the relationships between the combinations of these characteristics. Under the Improved Resolution Wafer Tubes Program, the various intensifier tube component parameters were varied in various combinations to maximize resolution and modulation transfer functions (MTF) without reducing the signal to noise ratio. Some of the variables were component spacing, phosphor size and types, and screen voltage ¹⁰³.

The first AN/PVS-5 NVGs used 18-mm 2nd generation intensifier tubes with a resolution specification of 25 line pairs/mm, a luminance gain from a standard 2856K light source of 400, and typical life expectancy of less than 1000 hours. Recent 18-mm 3rd generation tubes have demonstrated resolutions greater than 70 line pairs/mm and gains of 5000, with life expectancy of up to 10,000 hours. Other developments include reduced electron spread (halos) around bright lights, faster phosphors, and improved signal to noise ratios.

The primary Air Force priority in I² development is a wide field of view panoramic NVG for fighter aircraft that will fit under the visor and provide safe ejection without prior removal. Using a 30 horizontal (H) by 40 degrees vertical (V) central intensified image to both eyes and two 35 H by 40 V degree outside intensified panels, a FOV of approximately 40 by 100 degrees has been demonstrated in a prototype that weighed no more than the present ANVIS with resolution of .95 cy/mr (20/36) at 1/4 moon illumination.

The advanced image intensifier program (AI²) program has developed a 60 degree FOV NVGs with built in displays for overlaying symbology. The resolution is approximately 0.86 cy/mr (20/40) and the weight is slightly less than the present ANVIS. However, this development has strong competition from the previously mentioned panoramic NVG.

Why not incorporate a forward looking infrared (FLIR) sensor (1-3 or 8-12 micron) with the I² in the turret of the aircraft? The user could select either sensor, or the best of the two images could be fused into a composite. Such a program has been ongoing since 1991, and the initial results have been encouraging for an enhanced system. ¹⁰⁴ This image fusion program was part of the advanced technology demonstration program and used a common module FLIR with ≥ 0.5 cycles/milliradian and a 8-bit, 1024 x 480 pixel digital video coupled to a 25-mm 3rd gen intensifier tube. Besides the ongoing reduced budgets for development, some of the technical problems with this approach concern the resolution, the bandwidth requirement for the video format, and the gray levels for both the sensors and the display.

With the latest intensifier technology approaching 3000 (80 lp/mm) discernable pixels per 18-mm tube diameter, converting the intensifier image to a video format of lesser pixels is indeed "placing the telescope in front of the amblyopic eye" with the present and near term technology. Even with computer image enhancements, it is difficult if not impossible to regain resolution and gray levels that may be lost in the video conversion.

Another I² prototype development is the ANVIS camera system, where a small CCD camera is optically coupled to one of the intensifier tubes in the ANVIS at the eyepiece (Figure 21). What the pilot sees can be recorded or transmitted as a video image. The FOV of the video is reduced to approximately 20 degrees to provide resolution approximately half that of the actual intensified 40 degree image. The low light sensitivity of the small light weight CCDs used in this application are still below the human visual capabilities with the intensified image under starlight conditions.

The 1st and 2nd generation intensifiers amplified primarily the visible spectrum with less response in the near infrared using the S-20 multialkali photocathodes, whereas the 3rd generation spectral response began in the red and peaked in the near infrared with the gallium arsenide photocathode. With either photocathode, the single type sensor in a device will have low contrast under certain target, background, and illumination conditions. Contrast for certain objects and backgrounds are better with the 2nd generation intensifiers and others are better with the 3rd generation systems. If two or three different spectral sensitive photocathodes could be incorporated in a system, alternating the placement between adjacent photocathode types, and each photocathode type connected to a primary colored phosphor, then both luminance and color contrast would enhance the imagery. Using a black and white video CCD camera with spectral response from approximately 400 to 1000 nanometers, filters that transmitted only the visible or the red and near

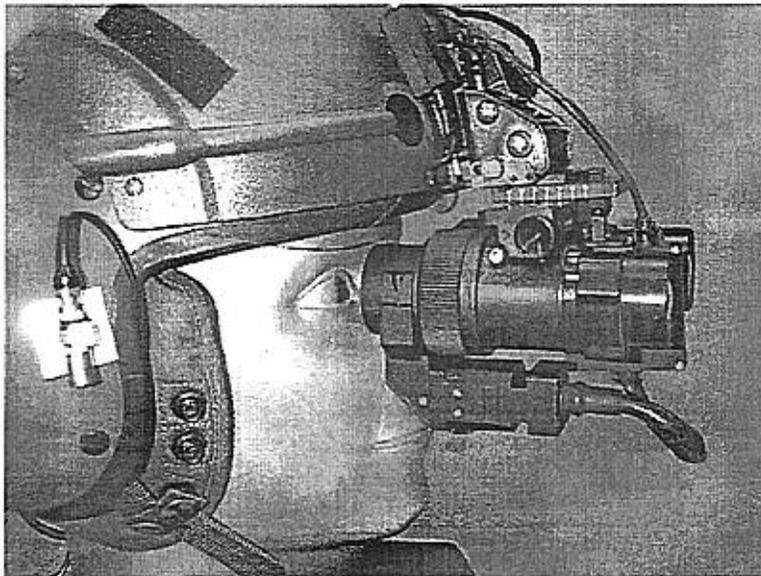


Figure 21. ANVIS CCD camera system

infrared spectrum were alternately placed in front of the camera. The visible and near infrared images were taken from a 10 meter tower overlooking the firing range and rural Alabama scenery. Using a computer graphics program, the visible, near infrared, and broad spectrum pictures of the same scene were combined using the primary colors. This technique demonstrated some of the potential advantages and disadvantages of a colored NVD before hardware funding.

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12. DISCLAIMER

The views, opinions, and or findings contained in this paper are those of the authors and should not be construed as an official Department of the Army position, policy, or decision unless so designated by other official documentation.

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