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NIGHT VISION DEVICES AND CHARACTERISTICS

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INTRODUCTION

Night vision goggles (NVGs) are widely used to enhance visual capability during night operations. NVGs are basically composed of an objective lens which focuses an image onto the photo-cathode of an image intensifier tube which in turn produces an amplified image that is viewed through an eyepiece lens. There are several versions of NVGs in use and in development. These include the AN/PVS-5,AN/AVS-6, PVS-7, Cat's Eyes, Nite-Op, Eagle Eyes, Merlin, and others. The first section of this paper provides a brief description and characterization of each of these NVGs.

There are several parameters that are used to characterize the image quality and capability of the NVGs. These parameters include field-of-view (FOV), resolution, spectral sensitivity, brightness gain, distortion, magnification, optical axes alignment, image rotation, overlap, beamsplitter ratio, exit pupil diameter, eye relief, and others. Each of these is discussed in the second section of this paper.

CURRENT NIGHT VISION GOGGLES

In general, all NVGs are similar in that they all have three basic components: an objective lens system, an image intensifier, and an eye lens system. However, there are several ways in which these different components can be designed and configured which vary the trade-off between some of the design parameters.

The heart of any NVG is the image intensifier tube. Both second and third generation tubes are in wide use in fielded systems today. The second generation image intensifier tubes (typically referred to as "gen II") are sensitive to light from about 400 nm to about 900 nm whereas the more sensitive third generation tubes are sensitive from about 600 nm to a little over 900 nm (see figure 1). This compares to a human visual spectral sensitivity that ranges from about 400 nm to 700 nm. The "gen III" tubes are about 4 to 5 times more sensitive to night sky illumination than the "gen II" tubes but they also cost significantly more.

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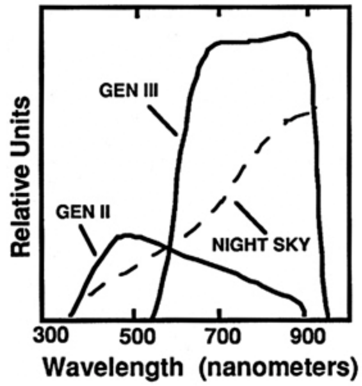

Figure 1. Spectral sensitivity of second and third generation image intensifier tubes.

The following sections provide a brief description of several fielded and developmental NVGs with an abbreviated table of some of their key characteristics.

PVS-5

The US Army developed the PVS-5 NVGs for use by vehicle drivers and ground troops. When these NVGs were initially fielded they all used a second-generation image intensifier tube. Although in later years some have been produced with a so-called "second gen plus" tube which provided about twice the gain as the original gen II tube. There are currently three versions of the PVS-5 (a,b, and c) which vary in their mounting mechanism, objective lens and image intensifier tube characteristics; but they all have the same basic construction. The PVS-5 is composed of two in-line oculars. Each ocular has an objective lens located directly in front of the image intensifier tube. The objective lens produces an image of the outside scene directly on the photo-cathode of the image intensifier tube. Since the objective lens inverts the image of the outside scene it is necessary to employ a fiber optics "twister" to rotate the amplified image back to an upright orientation. An eyepiece lens is located directly behind the output of the image intensifier and acts as a simple magnifier lens for viewing the output image. The objective lens and eyepiece lens have the same focal length to produce a system with approximately unity magnification. The eyepiece lens is adjustable to accommodate -6 to +2 diopters of correction to compensate for wearers who require eyeglasses.

The housing for the PVS-5 is somewhat bulky with a padded back surface that rests against the face. When originally fielded the PVS-5 was mounted to the head by a series of straps that went around and over the head. Later versions were modified to attach to a flyers helmet and had much of the housing cut out to permit the wearer to view under the NVGs at flight instruments (McLean, 1982). This led to the PVS-5c version. Table 1 is a brief summary of the key characteristics of the PVS-5 NVG.

Table 1. PVS-5 Characteristics

Field-of-view (FOV):	40 degrees circular
Resolution:	20/50 - 20/70 Snellen
Exit pupil:	None
Beamsplitter:	No
Eyelens Adjustment:	-6 to +2 diopters
Weight:	880 gm (31 oz)

The PVS-5 NVG does not have a real exit pupil since it does not use a relay lens. The resolution ranges shown in Table 1. reflects the range of values that have been published by different authors over the past 10-12 years. Since the image intensifier tube is a key component in limiting resolution it is most probable that the 20/50 Snellen acuity (published in more recent documents) is a result of improved image intensifier manufacturing and design.

AN/AVS-6 (ANVIS)

The AN/AVS-6, or aviator's night vision imaging system (ANVIS), NVG was developed by the US Army specifically for use in helicopter flying. These were also designed using third generation image intensifier tubes which has led to some confusion in terminology. The ANVIS NVGs have also been referred to as third gen NVGs and the PVS-5s as second gen NVGs primarily because those tubes came with the original systems. However, second generation plus tubes have been installed in ANVIS type housings so the correct designation should include both the NVG type (e.g. ANVIS or PVS-5) and the image intensifier tube (e.g. second gen, second gen plus, or third gen) to prevent confusion.

The ANVIS NVGs look very much like a pair of binoculars. The fundamental optical design is very similar to the PVS-5 in that an objective lens focuses an image onto the photo-cathode of the image intensifier tube, a fiber optics twister re-inverts the output image that is viewed by a simple magnifier eyepiece lens. The mounting system is substantially different in that the ANVIS was originally designed to attach to a helmet. The mounting system provides adjustments for inter-pupillary distance, tilt, vertical, and fore/aft position. The objective lens was also of a lower F/number (ratio of focal length to diameter of lens) to improve its light gathering capability and thereby increase the overall gain of the NVG. Table 2 is a summary of the key characteristics of the AN/AVS-6 NVG.

Table 2. AN/AVS-6 Characteristics

Field-of-view:	40 degrees circular
Resolution:	20/40 - 20/50 Snellen
Exit pupil:	None
Beamsplitter:	No
Eyelens Adjustment:	-6 to +2 diopters
Weight:	775 gm

AN/PVS-7

In an effort to reduce costs for providing NVGs to ground forces the US Army developed the PVS-7 NVGs. This NVG is unique in that it is biocular: it has one objective lens, one image intensifier but two eyepieces. The objective lens and image intensifier tube configuration is similar to the PVS-5 and ANVIS; however, since the optical system used to split the image for the two eyes re-inverts the image it was not necessary to twist the fiber optics to do the re-inversion. However, a fiber optics conduit was still used (without twist) since it was integral to the manufacture of the tube.

Another significant difference between this NVG and the ones previously discussed is that it uses a relay lens to transfer the image from the output of the image intensifier tube to the eyepiece lenses. This causes the creation of a real exit pupil (see later section on NVG characteristics). Table 3 is a summary of the key characteristics of the PVS-7 NVGs.

Table 3. PVS-7 Characteristics

Field-of-view:	40 degrees circular
Resolution:	20/40 - 20/50 Snellen
Exit pupil:	10 mm dia
Beamsplitter:	No
Eyelens Adjustment:	-6 to +2 diopters
Weight:	580 gm (w/mount)

It should be noted that the PVS-7 NVGs are not considered suitable for piloting aircraft for safety reasons: if the image intensifier tube fails then the image is lost to both eyes whereas with the PVS-5 or ANVIS if one channel fails the other is still available.

NITE-OP NVGS

The Nite-Op NVG was developed by Ferranti International for the British military as an improvement over the ANVIS NVGs. The basic design is very similar to the ANVIS NVGs but the mounting system is much more ruggedized and the field-of-view is larger. In addition, the eyepiece lenses are much larger in diameter, which permits larger eye relief and/or larger mounting/positioning tolerance with respect to the wearer's eyes. Table 4 is a summary of key characteristics of the Nite-Op NVGs.

Table 4. Nite-Op NVGs

Field-of-view:	45 degrees circular
Resolution:	20/40 - 20/50 Snellen
Exit pupil:	None
Beamsplitter:	No
Eyelens Adjustment:	-3.5 to +0.5 diopters
Weight:	750 gm

Cat's Eyes NVGs

The Cat's Eyes were developed and are produced by GEC Avionics in UK. The front-end optical system is similar in basic design to the ANVIS but the eyepiece optics are significantly different. These NVGs were designed to provide a see-through combiner (beamsplitter) in front of each eye which allows the wearer to see his instrument panel or head-up display (HUD)directly without going through the image intensifier. This concept was developed to allow a pilot to view his aircraft HUD without the loss of image quality that might occur if he/she viewed the HUD through the image intensifier system.

However, this design concept requires that the optical path after the image intensifier tube be folded which leads to a smaller obtainable field-of-view. In addition, the beamsplitter reduces the luminance from the image intensifier tube thus reducing the gain of the system. Table 5 is a summary of the Cat's Eyes NVGs.

Table 5. Cat's Eyes NVGs

Field-of-view:	30 degrees w/clipping
Resolution:	20/40 - 20/50 Snellen
Exit pupil:	None
Beamsplitter:	Yes
Eyelens Adjustment:	None
Weight:	750-800 gm

The folding of the optical system results in a circular 30 degrees field-of-view with some clipping of the image in the lower right and lower left. This makes the actual FOV appear something like a baseball diamond viewed from above.

EAGLE EYES NVGs

All of the previously discussed NVGs have been fielded and are in use in military applications somewhere in the world for either ground or aviator use. The Eagle Eyes NVG designed by Night Vision Corporation is still under development. The unique feature of the Eagle Eyes NVGs is that the optical system for both the objective lens and eyepiece lens are folded to produce a low profile NVG that fits fairly close to the face. In order to do this, the objective lens apertures are spaced further apart than the distance between the two eyes producing some stereopsis exaggeration at close distances. The Eagle Eyes are also designed with a beamsplitter eyepiece lens system to permit direct viewing of the HUD and/or instrument panel. Table 6 is a brief summary of the key characteristics of the Eagle Eyes.

Table 6. Eagle Eyes NVGs

Field-of-view:	40 degrees circular
Resolution:	20/40 - 20/50 Snellen
Exit pupil:	None
Beamsplitter:	Yes
Eyelens Adjustment:	None
Weight:	580 gm

Due to the nature of the folding in the Eagle Eyes optical system there is very little eye relief and the peripheral vision is reduced. These were the trade-offs to obtain the extremely low profile of these NVGs.

MERLIN NVGS

MERLIN (Modular, Ejection-Rated, Low-profile, Imaging for Night) is under development by ITT corporation. It uses two separate, independently adjustable oculars and a unique image intensifier tube design. The image intensifier tube and power supply have been repackaged. The tube does not use a fiber optics faceplate or twister, which allows for improved resolution. The optical system does employ a relay lens that produces a real exit pupil. The system is designed to fit onto existing HGU-53 and HGU-55 aviator helmets. Table 7 is a summary of the MERLIN characteristics.

Table 7. MERLIN NVGs

Field-of-view:	35 degrees circular
Resolution:	20/35 - 20/40 Snellen
Exit pupil:	10 mm dia
Beamsplitter:	Yes or No (optional)
Eyelens Adjustment:	None
Weight:	800 gm

OTHER NVG SYSTEMS

There are several other NVG systems that have been developed but due to their proprietary status they are not discussed here. The systems that have been presented provide a fairly complete coverage of the different approaches (beamsplitter vs. no beamsplitter; pupil forming vs. non-pupil forming; folded vs. non-folded optics; biocular vs. binocular; fiber optics twister vs. no twister; etc) that have been tried.

Another device that is closely related to the NVGs and has been retrofit to some NVGs is the NVG-HUD. The NVG-HUD was designed to provide critical flight information symbology overlaid on the NVG FOV. Several different designs have been developed to retrofit to existing NVGs and there is a desire by some organizations to include the symbology generation capability as an integral part of the NVG for airborne use.

NIGHT VISION GOGGLES CHARACTERISTICS

There are many parameters that are used to characterize night vision goggles. This section of the paper discusses a large number of these parameters and how they relate to vision. Table 8 is a list of these parameters.

Table 8. NVG Design Parameters

Field-of-view	Signal-to-noise ratio
Image quality	Luminance uniformity
Exit pupil size	Luminance level
Eye relief	Luminance gain
Image location	Beamsplitter ratio
Magnification	Fixed pattern noise
Image rotation	Binocular parameters
Distortion	Optical axes alignment

Field-of-View

Probably the first parameter that most people are concerned with in an NVG is the field-of-view (FOV). The FOV is the angular subtense of the virtual image displayed to the wearer. This is typically expressed in degrees for both the vertical and horizontal dimensions, or for the diameter of the FOV if it is circular. Another practical problem is the trade-off with resolution (image quality). The image intensifier has a finite number of picture elements (pixels). As the FOV is increased these pixels are spread over a larger angular expanse resulting in a larger angular subtense per pixel which corresponds to a lower angular resolution to the observer. (Note: this is an oversimplification of this trade-off since image quality is more complex than the concept of pixels implies but the general direction of the trade-off is the same: larger FOV means lower visual resolution).

The total NVG FOV can be made larger by making the FOV of each ocular of a binocular NVG partially overlap the other. The visual effects of partial overlap may outweigh the value of the extended horizontal FOV if the overlap is too little. At least one study suggests that there is little performance difference between 100% overlap and 80% overlap for visual recognition performance (Landau, 1990) implying that an 80% overlap binocular NVG may be a good compromise between the need for larger FOV without impacting visual performance.

Image Quality

Image quality is a complex subject that involves several other parameters (Task, 1979). Probably the key indicator of image quality is the modulation transfer function (MTF) of the display, which describes how much contrast is available as a function of spatial frequency (detail). Two parameters related to the MTF are gray-shades (contrast) and resolution (maximum spatial frequency that can be seen or "resolved"). For simplicity, the resolution of a display relates to the number of pixels. As noted earlier, the resolution tends to decrease as FOV increases which implies that image quality also decreases with increasing FOV; another trade-off of two desirable attributes.

There are some practical problems in measuring the resolution of the NVGs. The simplest approach to measuring resolution is to have a trained observer look through the NVGs at a calibrated test pattern under controlled lighting conditions. However, the results obtained still depend on the visual capability of the observer and on the type of test pattern used. Probably the most popular test pattern for determining resolution is the USAF 1951 Tri-Bar resolution pattern. Others that have been used include a Landolt "C," a tumbling "E," a standard Snellen chart, sine-wave gratings and more recently a test pattern made up of patches of square-wave gratings of different spatial frequencies (US Pat No. 4,607,923). These different approaches yield somewhat different results.

It should also be noted that the resolutions listed in the previous tables were all for ideal lighting conditions. As the light level is significantly reduced the resolution of the NVGs drops considerably (20/200 Snellen acuity or lower).

Exit Pupil

Most NVGs do not have a real exit pupil since they do not use relay optics. The exit pupil is the image of the stop of the optical system. An exit pupil is formed as a result of using relay optics to produce an intermediate image plane, which is then viewed by an eyepiece lens. This is in contrast to a simple magnifier optical system that uses a single lens system (no intermediate image) and therefore does not produce a real exit pupil. In a darkened room with the NVG activated the exit pupil can be observed by placing a piece of white paper near the designed eye position. If the NVG forms a real exit pupil then a circular spot of light will be observed imaged on the paper. As the paper is moved closer to and further away from the optical system there is a point at which the disc of light has a minimum diameter with sharply defined edges. The diameter of this disk of light is the diameter of the exit pupil of the system (Self, 1973).

When the eye pupil is fully within the exit pupil of the NVG then the entire FOV is observed; if the eye pupil is only partially in the exit pupil (and the exit pupil is unvignetted) then the observer will still see the entire FOV but it will be reduced in brightness. This can be particularly disconcerting for NVGs used in high performance aircraft because the pilot may not know whether he is starting to lose the exit pupil or if he is starting to lose consciousness from high acceleration maneuvers. Once the eye pupil is outside the exit pupil then none of the NVG FOV can be seen. It should also be noted that the NVG FOV may become vignetted (lose part of the image) if the eye pupil is too close to or too far away from the exit pupil.

From a visual capability standpoint it is important for the exit pupil to be as large as possible to ensure the eye pupil will remain within it to permit viewing of the NVG. However, large exit pupils typically come only at the expense of greater size of optics and weight on the head. In addition, if the FOV is very large then the eye must rotate to view the edge of the display. Since the eye rotates about a point within the eye, the eye pupil moves within the NVG exit pupil. If the NVG exit pupil is not large enough then it is possible for the entire display to disappear every time the observer tries to move his eyes to view the edge of the display. Exit-pupil-forming optical systems also increase the difficulty of making accurate adjustments for binocular or biocular NVGs in that each eye pupil should be centered in each exit pupil of the NVGs.

Eye Relief

The eye relief is the distance from the exit pupil to the nearest part of the NVG optical system. If the NVG is non-pupil-forming then the eye relief is the distance from the NVG optical system to the furthest back position of the eye where the eye can still see the entire FOV of the NVG.

As with so many other NVG parameters, larger eye relief usually means larger and heavier optics. The reason for having a large eye relief is to allow the use of eyeglasses with the NVG (Self, 1973; Task et al, 1980).

Image Location (optical image distance)

All NVGs produce a virtual image, which is viewed by the observer. The virtual image is produced at an optical distance that depends on the adjustment of the eyepiece (if the NVG has an adjustable eyepiece). For NVGs that do not have an adjustable eyepiece the virtual image is typically adjusted for near infinity. The adjustable eyepiece was provided to allow the wearer to set his eyeglass prescription (spherical power) on the eyepiece so he would not require eyeglasses to see the NVG image clearly.

Luminance Level

The luminance of the NVG image depends both on the luminance of the image source and the transmission efficiency of the optical system (note: it does NOT depend on the amount of magnification since it produces a virtual image). For NVGs that use a combiner the NVG image luminance level also depends on the combiner (beamsplitter) reflectance and transmittance coefficients.

Binocular Parameters

There are several other parameters that become important if the NVG is binocular. These include inter-pupillary distance (IPD-the distance between the exit pupils of the two oculars), image alignment between the two oculars, luminance balance, magnification balance, and image rotation balance.

There are several undesirable visual effects that may occur in binocular NVGs. These include binocular disparity (retinal rivalry) due to luminance imbalance, image misalignment, accommodation differences, and/or differential distortion. When binocular disparity is sufficiently severe the observer may see double images or may suppress one of the two disparate images. A more insidious problem is when the binocular disparity is not large enough to cause a loss of image fusion but is enough to result in "eye strain" or visual fatigue. This can lead to headache or nausea during extended use but may not show any effects for short-term use.

There have been some efforts to define the limits for these types of parameters (Self, 1973 and 1986; Landau, 1990).

Luminance and luminance gain

In most of the literature relating to NVGs these parameters are usually referred to as brightness and brightness gain. However, since luminance is what one measures and brightness is the visual sensation that one sees it is more appropriate to use the terms luminance and luminance gain for these parameters.

Night vision goggles are essentially light amplifiers, they cannot work in complete darkness. However, they do have a different spectral sensitivity than the human eye, which makes the concept of luminance gain a little more difficult to define. For example, the eye cannot see light at 900 nanometers but the NVGs are very sensitive to light in this wavelength range. Since luminance gain is the ratio of output luminance to input luminance and since luminance is only defined for the spectral sensitivity of the eye, it is possible to obtain an infinite luminance gain for a 900 nanometer input source (i.e. the luminance of any amount of light at 900 nanometers is zero since the eye is not sensitive to this wavelength but this will produce a non-zero output luminance; dividing output by the input results in dividing by zero producing an infinite gain). To overcome this problem it is necessary to define a specific spectral distribution for the input light source that does have a non-zero luminance. A blackbody radiator at 2856K was selected since it is a standard lamp source and has a spectrum that closely approximates night sky illumination. This is the same standard source that was selected by the US Army for measurement of the image intensifier tubes that are contained within the NVGs.

The luminance gain is usually measured for a specific input luminance since the gain can change with input level. The luminance output is measured on axis at the highest input luminance.

Luminance uniformity

Due to the fiber optics and light fall-off with angle typical of lens systems the central part of the field-of-view of the NVG image is usually of higher luminance than the edge of the FOV. This is measured by scanning with a photometer across the entire FOV to obtain a luminance profile of the NVG image. Uniformity can be specified by comparing the luminance at the center of the FOV with the luminance at a specified off-axis angle (e.g. 18 degrees off axis for the 40 degree FOV NVG). The uniformity is then expressed as a ratio of center luminance to edge luminance (e.g. 3:1).

Distortion, image rotation, magnification, and input/output optical axes alignment

These four parameters are grouped together because they can be measured using the same basic set-up and data. The different quantities are obtained by performing different analyses on the data.

Distortion is probably the most difficult parameter because there are several types of distortion that the NVGs may incur. The optical system may cause barrel or pincushion distortion and the fiber optics twister (which is in many but not all NVG designs) may produce shear effects or "S" distortion. Of all of these, the procedure herein described is primarily directed at the "S" distortion although evidence of shear and barrel distortion may also be detected. "S" distortion originates in the fiber optics plug, which is used to invert the image on the image intensifier. The fused fiber optics plug is heated and twisted approximately 180 degrees. The "S" distortion is so named because there is usually a small amount of residual effect due to the twist that produces an "S" shaped curve for a straight-line input. The more the line departs from a straight line the worse the distortion.

As noted above, the fiber optics plug is twisted through approximately 180 degrees but may be somewhat more or less than a true 180-degree twist. Any departure from a perfect 180 twist will result in the output image rotated compared to the input image. This effect may also be enhanced by inaccurate alignment of folding mirrors in a folded optical system. The measurement procedure herein described allows one to measure the amount of image rotation.

Most NVGs are designed to have unity magnification. However, if there is a mismatch between the objective lens of the NVG and the eyepiece lens it is possible to have a small amount of magnification (or minification).

Since the combination of objective lenses, folding optics, image intensifier and eyepiece lenses is relatively complex, it is possible to have a mismatch between the input optical axis and the output optical axis. Thus objects that are at a particular field angle in reality may appear at a different field angle through the NVGs.

Many of these effects discussed are typically not a significant problem by themselves or for a single ocular. But the combination of a small amount of distortion, rotation, magnification and/or misalignment in one ocular with a different amount (and direction) of these effects in the other ocular may result in a significant binocular rivalry problem.

A complete description of the procedures for measuring these parameters is beyond the scope of this paper but can be found in Task et al (1989).

Signal-to-Noise Ratio

Typically the signal-to-noise ratio (SNR) is not specified or measured for the NVG as a whole but rather is specified as a parameter of the image intensifier tube by itself. The SNR is a measure of how much scintillation appears in the NVG. The lower the SNR the noisier the image looks and the poorer the image appears. The details of measuring SNR are beyond the scope of this paper; suffice to state that in general, observed resolution is poorer for lower SNR tubes (Riegler, et. al.; 1991).

BIBLIOGRAPHY

Brickner, Michael S., "Helicopter flights with night-vision goggles -- human factors aspects," NASA Technical Memorandum 101039, March 1989.

Levine, Richard R. and Rash, Clarence E., "Visual acuity with AN/PVS-5A night vision goggles and simulated flashblindness protective lenses under varying levels of brightness and contrast," US Army Aerospace Medical Research Laboratory (USAARL), Fort Rucker, Alabama, report No. 89-16, July 1989.

Landau, Francine, "The effect on visual recognition performance of misregistration and overlap for a biocular helmet mounted display," in Helmet-mounted displays II, Proceedings of SPIE 1290, April 1990.

Lewandowski, Ronald J., Ed., Helmet-Mounted Displays II, Proceedings of SPIE 1290, April 1990.

McLean, William E., "Modified faceplate for AN/PVS-5 night vision goggles," US Army Aeromedical Research Laboratory (USAARL), Fort Rucker, Alabama, report No. 83-1, October 1982.

National Bureau of Standards, "Criteria for evaluating image quality of night vision devices," Report No. PB-257 171, August, 1974.

Riegler, J. T., Whiteley, J. D., Task, H. L. and Schueren, J, "The effects of signal-to-noise ratio on visual acuity through night vision goggles," March 1991, AL-TR-1991-0011

Self, H. C., "The construction and optics problems of helmet-mounted displays," in A symposium on visually coupled systems: development and application, AMD TR-73-1, September 1973.

Self, H. C., "Optical tolerances for alignment and image differences for binocular helmet-mounted displays," AAMRL-TR-86-019, May 1986.

Task, H. Lee, "Optical and Visual Considerations in the design and specification of Helmet-Mounted Displays," Society for Information Display International Symposium Digest of Technical Papers, Vol XXII, pp297-300, Anaheim, California, May 6-10, 1991.

Task, H. L., Hartman, R., and Zobel, A., "New methods for night vision goggle test and evaluation," paper published in proceedings of Test Technology Symposium III held at Johns Hopkins University Kossiakoff Conference and Education Center, Laurel, Maryland, 19-21 March 1990.

Task, H. Lee, "An evaluation and comparison of several measures of image quality of television displays," AAMRL-TR-79-7.

Task, H. Lee, Kocian, Dean F., and Brindle, James H., "Helmet mounted displays: design considerations," in Advancement on visualization techniques, Hollister, W. M. (Ed.), AGARDograph No. 255, Hartford House, London, October 1980.

Wiley, R. W., Glick, D. D., Bucha, C. T., Park, C. K., "Depth Perception with the AN/PVS-5 night vision goggle," USAARL report No. 76-25, July 1976.