Night Vision Goggles (NVGs) and NVG Equipment with Market Potential

Terry Turpin, Turpin Technologies
Under Subcontract to PLRA

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PLRA
485 Summit Springs Road, Woodside, CA 94062

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1.0 INTRODUCTION

Background

Civil aviation operators have expressed an increased interest in conducting night operations more efficiently and arguably more safely by employing night vision imaging systems (NVIS), specifically night vision goggles (NVGs). While NVGs can reduce risk during night VFR operations, the also have known performance limitations. The additional night vision capabilities afforded by NVGs, together with their performance limitations, require the development of special operational concepts, hardware requirements, and training requirements, supported by regulatory agency oversight in order for crewmembers to safely train and operate with NVGs in the National Airspace System (NAS).

RTCA Special Committee 196 (SC-196) was formed to assist the Federal Aviation Administration (FAA) in transitioning the use of NVGs from the military and public sector, predominantly military and law enforcement, to the private aviation sector. RTCA, a non-profit corporation formed to advance the art and science of aviation for the benefit of the public, has worked side-by-side with the FAA for the past year to develop the documentation required to support this technology transfer. The cornerstone document produced was the Minimum Operational Performance Standards (MOPS). This document specifies, among other things, the minimum design specifications and performance parameters that NVGs must meet to be considered safe enough to operate in the NAS.

As with any new standard, this specification needs some sort of validation to ensure appropriateness for the intended application. The strengths and weakness of the specification must be determined when compared to fielded military and civil NVGs. Additionally, it must be determined through an evaluation of fielded systems, that the MOPS does not limit future innovation.

Purpose.

The purpose of this research is to develop a list of present and, where possible, near term marketable NVG devices that may be reasonably submitted for civil certification. Additionally, this study assessed each potentially marketable device for compliance with the minimum MOPS requirements, referred to herein as the "MOPS baseline". The information in this report will assist in building the database of information required for establishing both appropriate certification criteria, and effective certification procedures and measurements.

Use.

The information contained in this document is intended to provide the reader with a clear picture concerning the full spectrum of NVG appliances that are available on the domestic and foreign market that could potentially be used use by civil operators. This document may also be used to compare the technical specifications of various NVGs on the market, and understand the strengths and weaknesses of each product when compared to the MOPS baseline. A primary source for hardware performance requirements in the MOPS was the military contract for NVGs referred to as the OMNI IV contract. Requirements relevant to civil aviation operations were merged with requirements unique to civil aviation by SC-196 in developing the NVG MOPS. While these two documents could each be cited for many of the MOPS requirements, this study makes reference exclusively to the requirements as stated in the MOPS.

Research Task.

The goal of this task was to research and develop a list of marketable NVG devices that may be reasonably submitted for civil certification. The primary list was limited to devices that meet the minimum operational performance requirements or equivalent for AN/ANVIS-6 or the OMNI III contract. A secondary list is provided that shows products on the market that are marginal or unacceptable potential for civil use. Each device listed has been compared to the MOPS requirements. The following information is provided for each device:

- Manufacturer (or potential manufacturer)
- Anticipated date available
- Anticipated or actual price
- Technical data
- Brief analysis of technical aspects relative to human factors issues
- Limitations and advantages in comparison to the MOPS baseline
- Recommendations regarding suitability of equipment for the civil market and potential certification issues
- Recommendations for testing equipment based on potential suitability in cases where there is a lack of technical data relating to human performance.

Research Methodology.

This effort entailed data collection, data organization and categorization, data analysis, data summary, and conclusions with comments regarding the potential for future civil use of the subject NVGs. An information comparison matrix is provided that clearly indicates the design strengths and weaknesses of selected NVGs as compared to the MOPS baseline.

Data collection. Data collection was primarily be accomplished by Internet search for manufacturers and distributors of NVGs. The MOPS was used as a baseline against which each NVG device listed was compared. Known manufacturers (foreign and domestic) of NVGs were contacted for technical specifications concerning their products.

Data organization and categorization. Data is organized and categorized by its potential to meet the specifications outlined in the MOPS. The devices in the list are arranged from high probability to low probability of meeting performance standards.

Data analysis. The available specifications for each candidate NVG were compared against the MOPS baseline. A summary of the known or predicted performance is provided.

Data conclusions and comment. Conclusions were drawn and stated with respect to each NVGs performance capabilities compared to the MOPS requirements. Conclusions were also drawn with reference to human factors issues apparent with the equipment and comments have been provided concerning the potential for civil use of each NVG device in the NAS.

2.0 OVERVIEW OF NIGHT VISION GOGGLE DESIGN

Current designs for night vision goggles fall into certain general categories. From the user's perspective, there are two basic components, the physical goggles and the electro-optical system that is housed within the goggles. Due to the interchangeability of the electro-optics among different physical goggle designs, many of the goggles can accept a range of different electro-optical systems. Thus goggles which have the same exterior physical appearance and the same mechanical functions may differ greatly in electro-optical performance.

Definitions. The reader must understand the technical terms associated with goggle design and performance in order to get the most out of this document. The following is a presentation of the most common terms used to describe the performance characteristics and the physical and mechanical attributes of NVGs.

Generation. The term "generation" is often used to describe the age of the technology used to manufacture the image intensifier tubes. There are currently three generations of tubes described below:

Generation I. These intensifier tubes were developed in the 1960's using vacuum tube technology. They use simple grid shaped electrodes to accelerate the electrons through the tube. They required a full moon to achieve an acceptable level of performance. This tube was characterized by excessive blooming and distortion from light sources in the field of view. GEN I tubes have a light amplification of only 1,000 times in comparison with GEN III tubes at 40,000 times. Operating life was only 2,000 hrs.

Generation II (GEN II). These tubes were developed with 1970's technology and incorporated the first microchannel plate (MCP) application to achieve brightness gain. These tubes could operate satisfactorily with one-quarter moon illumination and exhibit low distortion. They amplified light 20,000 times and had an average operating life of 2,500 hrs.

Generation III (GEN III). Generation III tubes were developed in the 1990's and use Gallium Arsenate (with even deeper sensitivity to the infrared spectrum) for the photo-cathode and a micro-channel plate for gain. The micro-channel plate is also coated with an ion barrier film to increase tube life. The GEN III tube provides very good to excellent low light level performance and can be used in illumination levels down to starlight only. The image is clean and with excellent contrast, and has a long tube life. The expected life span for the GEN III tube is estimated to be 10,000 hours of operation.

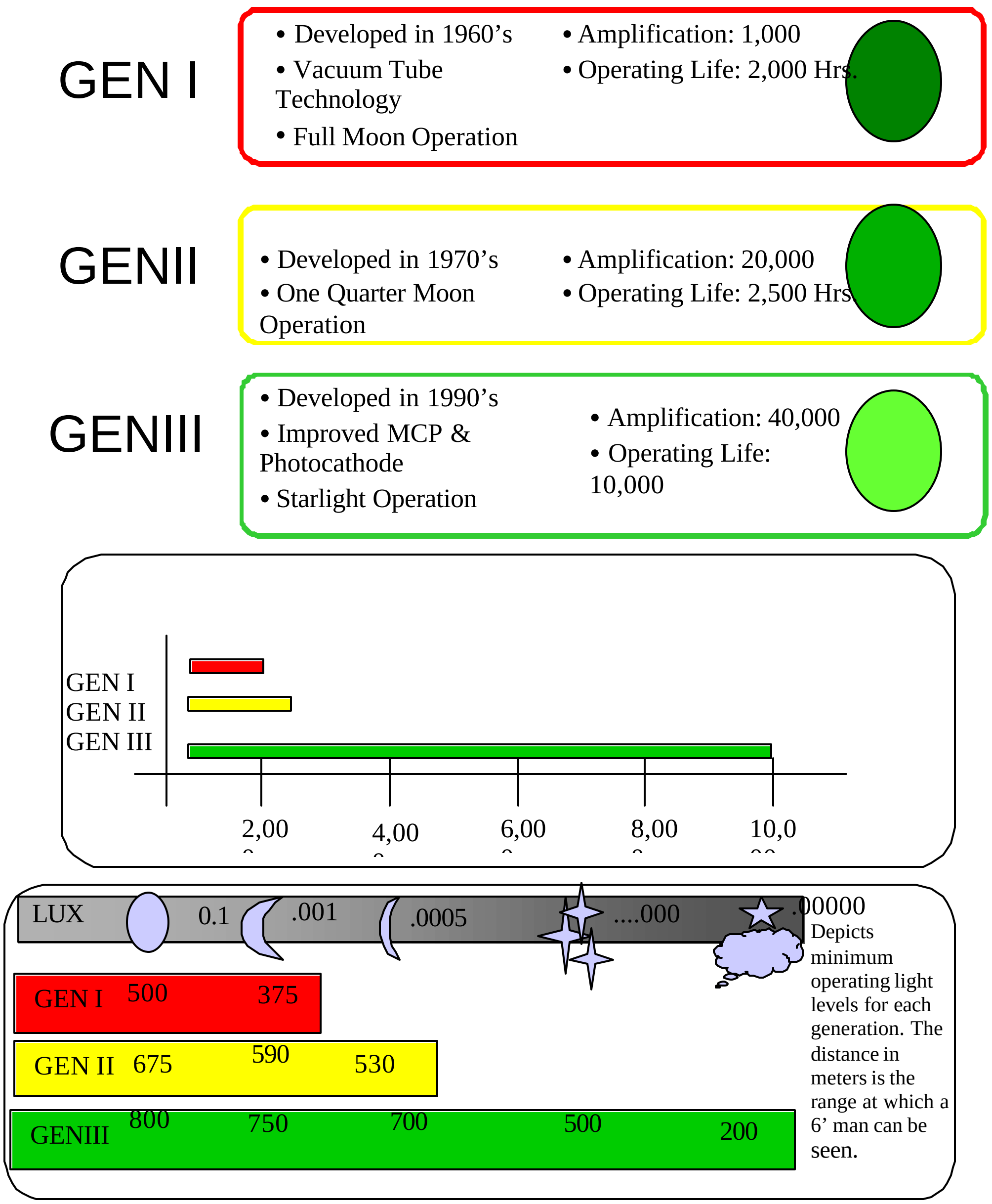


Figure 1. NVG Performance Characteristics

Goggle Form Factor. The term "goggle form factor" refers to the general physical and mechanical characteristics of the goggles. Traditionally there have been and still are two basic goggle form factors, full face goggles and displaced goggles.

Displaced Goggles. Displaced goggles have the eye pieces displaced from the user's eyes such that the user can look through the goggles for night vision aiding or can look under, above, or to the sides of the goggles with unaided vision. A pilot wearing this type of goggle will focus the goggles for far vision, which is required for out the cockpit viewing. The displaced design has the advantage of allowing pilots to look down under their goggles at the instrument panel or up at their overhead panel without having to first refocus the goggles for near distance. The side viewing allows pilots' peripheral vision to pick up some peripheral visual cues without having to turn the head.

Full Face Goggles. Full face goggles are an earlier goggle form factor. The goggle covers the entire upper face much like swimming goggles or masks. A pilot wearing this type of goggle cannot look under, over, or to the side of the goggles, but must instead move his head up, down, or sideways to see the overhead panel, instrument panel, or objects in peripheral vision, respectively. This creates certain human factors problems for pilots. It is too time-consuming to continually refocus the goggles between far and near viewing. So, pilots have to focus one lens to far distance and the other to near distance and then use only the appropriate eye for viewing outside the cockpit or inside the cockpit, respectively. Full face goggles are not acceptable for civil aviation use.

Acuity. The human eye has a nominal resolution of 1 minute of arc. The common measure of visual acuity is based on reading letters with 1 minute line width, Snellen letters, or patterns with similar detail, such as Landolt rings. Visual acuity is reported as a fraction. The denominator is the test distance (usually 20 feet). The numerator is the relative size of line that can be resolved. That is, 20/40 indicates that the resolution was 2 minutes of arc, twice the nominal value. In other words, that individual can resolve at 20 feet what a "normal" person can at 40 feet.

Automatic Brightness Control. An electronic feature that automatically reduces voltage to the microchannel plate to keep the image intensifier's brightness within optimal limits and protects the tube. The effect of this can be seen when rapidly changing from a low light to high light conditions. The image gets brighter and then, after a momentary delay, dims to a constant level.

Black Spots. These are either cosmetic blemishes in the image intensifier or dirt or debris between the lenses. Black spots that are in the image intensifier tube do not affect the performance or reliability of the night vision device and some number of varying size are inherent in the manufacturing process. Spots due to dirt or debris between the lenses should be removed by careful cleaning if the system is designed for interchangeable optics.

Brightness Gain. When referring to an image intensification tube, brightness gain is the ratio of the brightness of the output in units of foot-Lambert, compared to the illumination of the input in foot-candles. A typical value for a GEN III tube is 25,000 to 30,000 Fl/fc. A tube gain of 30,000 Fl/fc provides an approximate system gain of 3,000. This means that the intensified NVG image is 3,000 times brighter to the aided eye than to the unaided eye.

Bright Source Protection (BSP). An electronic function that reduces the voltage to the photocathode when the night vision device is exposed to bright light sources such as room lights or car lights. BSP protects the image tube from damage and enhances its life. However, BSP may have the effect of lowering resolution when it is functioning.

Bright Spots. These are signal-induced blemishes in the image area caused by a flaw in the film on the MCP. A bright spot is small, non-uniform, bright area that may flicker or appear constant. Bright spots usually go away when the light is blocked out. Not all bright spots make the ANVIS unserviceable. A test can be performed as follows: Place a cupped hand over the lens to block out all light. Make sure any bright spot is not simply a bright area in the viewed scene. If the bright spot remains, an emission point exists and needs to be checked.

Chicken Wire. An irregular pattern of dark lines in the Field-of-View (FOV) throughout the image area or in parts of the image area. Under the worse condition, these lines will form hexagonal or square-wave shaped lines.

Collimation. The act of making rays of light travel in parallel lines. Also the process of aligning the various internal optical axes of a system with each other.

Convergence. The shifting of an observer's eyes inward to view a nearby object i.e. crossing the eyes.

Counterweight system. Counterweight systems are used to adjust the center of gravity of the pilot's flight helmet with goggles installed. Without counterweights, there can be a fatiguing forward and downward force on the pilot's neck. The counterweight system may consist of a weight bag and counterweights. The Army's recommended initial weight is 12 ounces for one of its systems. Pilots are instructed to add or remove weight to achieve the best balance and comfort, not to exceed 22 ounces. Attachment of the weight bag is below the back of the helmet with the battery pack mounted vertically above it. The adjustment of the weight is to be made with the binoculars attached and flipped down.

Cycles per Milliradian (cy/mr). Units used to measure resolution. A milliradian is the angle created by one yard at a distance of 1,000 yards. This means that a device that can detect two 1/2 yard objects separated by 1/2 yard at 1,000 yards has a resolution of 1.0 cy/mr.

Diopter. The unit of measure used to define eye correction or the refractive power of a lens. Usually adjustment to an optical eyepiece accommodates for differences in individual eyesight. Many military systems provide +2 / -6 diopter range.

Dipvergence. The shifting of an observer's eyes vertically, one up and one down.

Distortion. In an optical system, alterations in the shape of the displayed image as compared to the actual image. Geometric distortion is inherent in all GEN 1 and some GEN II image intensifiers that use electrostatic rather than fiberoptic inversion for image inversion.

Divergence. The shifting of an observer's eyes outward.

Exit Pupil. In an optical system, the rays of light passing through the system will be limited by either the edges of one of the components such as the eyepiece lens, or by an internal aperture. The image passing through the entrance side of the optical system is the entrance pupil. The image passing out the exit side is the exit pupil. This image forms a small disk containing all of the light collected by the optics from the entire field-of-view.

Eyepiece Lens. The eyepiece lens focuses the image from the fiber optic inverter on to the eye by adjusting for individual eye acuity. There are two eyepiece lens assemblies in current systems; the 15 mm and the 25 mm eyepiece lens assembly. Tests show the larger eyepiece is more effective. This lens assembly is designed to provide some adjustment for the user to compensate for minor vision deficiencies (i.e. diopter adjustment). However, the assembly does not correct for all eye deficiencies and does not replace the need for wearing prescribed spectacles or contact lenses.

Eye Relief. The distance the eyes must be from the last element of an eyepiece in order to achieve the optimal image.

Fiber Optic Inverter. A bundle of microscopic light transmitting fibers twisted 180 degrees.

Field of View (FOV). The width or spatial angle of the outside scene that can be viewed through the intensifier tubes measured laterally and vertically. Typical NVGs have a 40° FOV. There are NVGs in development that attempt to increase this FOV significantly in an effort to enhance pilot performance. An example of a wide FOV NVG would be the Panoramic NVGs with a 100° FOV being developed and tested by the Air Force.

Fixed-Pattern Noise (Honeycomb). This is usually a cosmetic blemish characterized by a faint hexagonal pattern throughout the viewing area that most often occurs at high-light levels or when viewing very bright lights. The pattern can be seen in every image intensifier if the light level is high enough.

Honeycomb. See Fixed-Pattern Noise.

Image Disparity. This condition may exist when there is a difference in brightness between the two image intensifier assemblies within the same binocular.

Image Distortion. This problem is more easily detected in high-light conditions. Image distortion is evidenced by vertical objects, such as trees or poles appearing to wave or bend when the user moves his head vertically or horizontally when looking through the goggles. Ground surfaces in the direction of hover may appear to swell or sink. Distortion does not change during life of an image intensifier. Limits on allowable distortion are an important part of performance specifications since excess distortion can interfere with viewing the image and thus with the operator's ability to perform necessary flight maneuvers.

Image Intensifier (I2). The image intensifier is an electro-optical device (tube) that detects and amplifies light to produce a visual image. The GEN III components are: 1) photocathode, 2) microchannel plate, 3) phosphor screen, 4) power supply, 5) fiber optic inverter.

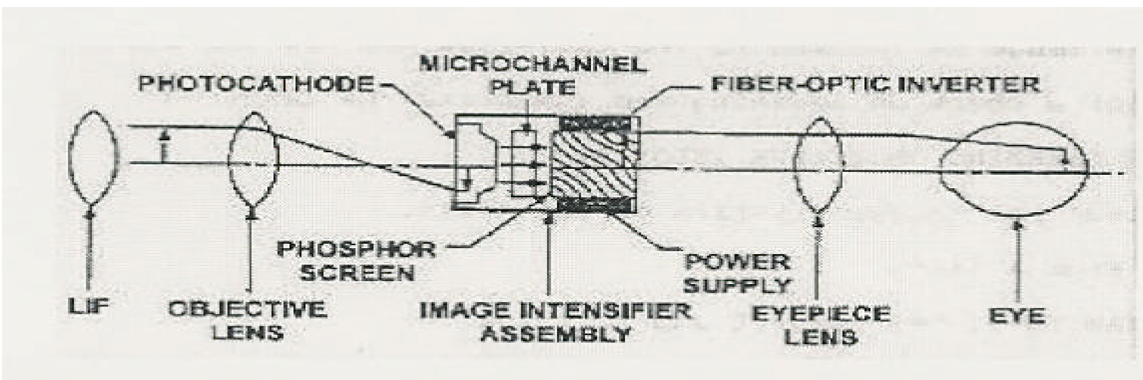


Figure 2. Image Intensifier Tube

Interpupillary Distance (IPD). Interpupillary distance is the distance between the centers of the pupils of the eyes when the eyes are parallel. Adjustment provisions for variable IPD should be a feature of the NVG to allow the full image to be seen by the NVG user. The recommended range of adjustment should be at least 57-70mm to accommodate an estimated 90% of the potential user population. If no adjustment is provided, then the exit pupil must be large enough for the user to get a full field of view.

Light Interface Filter (LIF). An optical filter that protects the NVG device and its user from some laser hazards by the LIF. The LIF's, if installed, are mounted on an adapter attached to the end of the objective lens.

Line Pairs per Millimeter (lp/mm). Units used to measure image intensifier resolution. Usually determined from a 1951 Air Force Resolving Power test target. The target is a series of different sized patterns composed of three horizontal and three vertical lines. The lines and spacing between lines in each of the different patterns differ in width; the narrower the width, the greater the resolution is needed to distinguish the lines in a given pattern. Human test subjects must be able to clearly distinguish all the horizontal and vertical lines of a particular pattern in order for an image intensifier to achieve the resolution represented by that pattern.

Lumen. The unit denoting the photons (light) perceivable by the human eye in one second.

Lux. A unit measurement of illumination. The illuminance produced on a surface that is on meter square, from a uniform point source of one-candela intensity, or one lumen per square meter.

Microamps per Lumen (A/lm). The measure of electrical current (A) produced by a photocathode when it is exposed to a measured amount of light (lumens).

Microchannel Plate (MCP). A metal coated glass disk that multiplies the electrons produced by the photocathode. An MCP is found only in GEN II and GEN III systems. These devices normally have anywhere from 2 to 6 million holes (or channels) in them. Electrons entering the channel strike a wall and knock off additional electrons which in turn knock off more electrons, producing a cascading effect. MCPs eliminate the distortion characteristic of GEN I systems. The number of holes in an MCP is a major factor in determining resolution.

Near-Infrared. The shortest wavelengths of the infrared region, normally 750 to 2,500 nanometers. GEN II operates from around 440 to 950 nanometers.

Objective Lens. The objective lens assembly collects the available light energy and focuses it on the photocathode (front end of the image intensifier tube). It is housed in an assembly that is used for distance focusing. A coating is placed on the inside portion of the lens that filters out specific wavelengths, thus allowing the use of properly modified interior lighting.

Operational Defects. These are defects that relate to the reliability of the image intensifier and are an indication of instability. If identified, they are an immediate cause for rejecting a particular NVG device. Some operational defects are listed below:

Shading. Each monocular should present a full circle. If shading is present, a full circular image will not be seen. Shading is indicative of a dying photo-cathode caused by a defective vacuum seal of the image intensifier. Shading is very dark and images cannot be seen through it. Shading always begins on the edge and migrates inward eventually across the entire image. Shading is a high contrast area with a distinct line of demarcation. Shading should not be confused with variations in output brightness.

Edge Glow. Edge glow is a bright area (sometimes sparkling) in the outer portion of the viewing area. Edge glow is sometimes caused by an emission point (or series of emission points) just outside the field of view, or by a defective phosphor screen that permits light feedback to the photo-cathode. To check for edge glow, block out all light by cupping a hand over the lens. If the image monocular assembly is displaying edge glow, the bright area will still show up.

Flashing, Flickering, or Intermittent Operation. The image may appear to flicker or flash. This can occur in either one or both monocular tubes. If there is more that one flicker, check for loose wires, loose battery cap, or weak batteries.

Output Brightness Variation. This condition is evidenced by areas of varying brightness in or across the image area. The lower contrasts do not exhibit distinct lines of demarcation nor do they degrade image quality. This condition should not be confused with shading.

Phosphor Screen. The phosphor screen converts electrons into photons. A very thin layer of phosphor is applied to the output fiber optic system, and emits light when struck by electrons. See also Photocathode.

Photocathode. The input surface of an image intensifier that absorbs light energy and in turn releases electrical energy in the form of an electron image. The type of material used is a distinguishing characteristic of the generations of image intensifiers.

Photoresponse (PR). See Photosensitivity.

Photosensitivity. Also called photocathode sensitivity or photoresponse. The ability of the photocathode material to produce an electrical response when subjected to light waves (photons). Usually measured in microamps of current per lumen (A/lm). The higher the value, the better the ability to produce a visible image under darker conditions.

Resolution. The ability of an image intensifier to distinguish between objects close together. Image intensifier resolution is measured in line pairs per millimeter (lp/mm) while system resolution is measured in cycles per milliradian (cy/mr). For any particular night vision system, the image intensifier resolution will remain constant while the system resolution can be affected by altering the objective or eyepiece optics by adding magnification or relay lenses. Often the resolution in the same night vision device is very different when measured at the center of the image and at the periphery of the image.

Signal-to-Noise-Ratio (SNR). A measure of the light signal reaching the eye divided by the perceived noise as seen by the eye. A tube's SNR determines the low-light resolution of the image tube, therefore, the higher the SNR, the better the ability of the tube to resolve objects with good contrast under low light conditions. Because SNR is directly related to phosphor efficiency and MCP operating voltage, it is the best single indicator of image intensifier performance.

Scintillation. A faint, random sparking effect throughout the image area. Scintillation is a normal characteristic of microchannel plate image intensifiers and more pronounced under low light level conditions. Scintillation is sometimes called video noise.

3.0 BASELINE PERFORMANCE CRITERIA.

MOPS NVG Optical Performance Criteria. Information contained in the following paragraphs was extracted from Section 2 of the draft MOPS which specifies the detailed NVG optical performance criteria. These specifications represent the baseline from which all candidate NVGs will be considered in order to be approved for civil use.

System Resolution. The system resolution shall be a minimum of 1.0 cycles per milliradian (cy/mR) on-axis under optimum light conditions using a nominal 100% contrast dark bar on white background resolution target chart. At 14° off axis, the resolution shall be not less than 0.81 cy/mR. If each monocular has a variable focus objective lens, then it shall focus through infinity, and at the through-infinity mechanical stop shall maintain an on-axis resolution of not less than 0.49 cycles per milliradian. If each monocular has fixed focus objective lenses, then 1.0 cy/mR will be maintained at infinity.

System Luminance Gain. The luminance gain at 1 x 10^{-4} foot-Lamberts input light level, shall not be less than 2,500 foot-Lamberts (fL) per foot-Lambert. The output luminance averaged across the full field of view shall not exceed 4 foot-Lamberts. The ratio of luminance gain between the two monoculars shall not exceed 1.5.

Field-of-View. The field of view of each monocular shall be at least 38 degrees horizontal and at least 38 degrees vertical.

Magnification. System magnification shall be unity (1X) +/- 2 percent.

Distortion. Linear distortion for each monocular shall be no greater than 4 percent across the total field of view. Gross distortion and/or sheer distortion shall not exist to the extent that they detract from normal performance.

Collimation. When two parallel beams of collimated light are projected into the objective lenses, the conjugate beams emerging from the two eyepieces shall be parallel to within 1.0 degree eye-convergence and 0.3 degrees eye-divergence and dipvergence. The objectives shall be set at the infinity focus position and both eyepieces (if adjustable) shall be set at zero diopter.

For systems that overlay the intensified image on the unintensified scene, the image of an object point at infinity seen through the center of the intensified channel shall be coincident with the position of the same point seen through the see-through channel within 4 milliradians for each monocular.

Spectral Transmission. The objective lens shall have a Class B Filter applied. If a fixed head-up display cannot be seen with a Class B Filter then a "leaky green" filter is permitted.

Veiling Glare. A high intensity point light source located anywhere between two degrees through seventy degrees outside the field of view shall not cause reflections/glare to be present in the intensified image to the extent that they detract from normal performance.

Image Cosmetic Defects. No dark or bright spots shall be discernible within the field of view to the degree that it detracts from normal performance.

There shall be no bright spots or discernible field emissions in the image. At low light levels there shall be no bright spots or discernible field emissions brighter or larger than the background scintillations visible in the intensified image. With the light level on the photocathode adjusted to obtain the best contrast, there shall be no bright spots visible in the intensified image.

With the field of view uniformly illuminated, graininess, channel-to-channel gain variations, or other irregularities shall not be discernible over the useful diameter of the image to the degree that they detract from normal performance.

Image Stability. The NVG shall not exhibit any instability in the image such as flickering, flashing or intermittent operation that impacts user performance under all operational conditions. When operated in very bright light conditions (i.e., ambient room light and civil twilight), the intensifiers shall continue to operate and the NVG shall continue to provide a positive intensified image to the user. Image resolution degradation in such conditions is permitted.

Halo Size. Halos shall be no greater than 1.25 mm in diameter at the output of the image intensifier tube.

Eyepiece Diopter Range. If adjustable, the minimum diopter focus range shall be from +1.0 to –2.0 diopters. If fixed, the diopter setting shall be between 0 and –1.0 diopters.

Objective Focus Range. For objective lenses having variable focus, the objective lens focus shall be continuously adjustable from beyond infinity to a close distance no greater than 45 cm. Through-infinity focus capability shall be provided. Fixed focus objective lenses shall be focused at infinity.

Eye Relief.

Direct view (Type I). Each eyepiece shall have at least a 6 mm diameter exit pupil at 25 mm nominal eye relief distance (from the vertex of the rear most optical element to the cornea of the eye at which the full field of view can be seen).

Projected Image (Type II). Each eyepiece shall have at least 20 mm nominal eye relief. Eye relief is the distance from the eyepiece to the front of the eye, where the exit pupil is defined as a 1.0 mm point or hole through which the full FOV can be seen.

Mount. The binocular assembly shall attach to and detach from the mount, and shall provide a quick detach mechanism. The binocular assembly or mount/binocular assembly shall be capable of being detached from the helmet or head mount quickly using only one hand. A mounting system shall permit one-handed (either hand with equal facility) operation of adjustments.

Automatic Breakaway. Unless crash safety is otherwise demonstrated, an automatic breakaway system shall be incorporated as part of the mount. Automatic breakaway shall not occur during normal flight maneuvers.

Adjustment Capability. Sufficient adjustment capability shall be provided to ensure the exit pupils of the eyepieces can be correctly positioned and optical axes correctly aligned with respect to the user's eyes at all times.

Interpupillary Adjustment. Individual Interpupillary adjustment capability shall be provided which allows each monocular to be adjusted independently. In the event there is no interpupillary adjustment mechanism, the size of the exit pupil shall be large enough to accommodate the specified range of interpupillary distance.

Power Source. If operator action is required to regain a backup or secondary source of power regarding total loss of external view, then an indicator or enunciator shall be provided to the operator with sufficient time to allow operator action without complete loss of power and /or degradation of NVG performance.

4.0 NVG TECHNOLOGY COMPARISON and ANALYSIS.

A list and comparison of current and developmental NVG devices was compiled. The minimum performance requirements that a device had to meet in order to be included on this list were the performance specifications for the ANVIS 6 NVG, manufactured under the OMNI III contract. The ANVIS 6 OMNI III NVG meets the OMNI III contract specifications for both goggle form factor and electro-optical performance. The MOPS baseline is in some respects more stringent than the OMNI III contract, as will be seen below. Thus, not all devices that meet the OMNI III contract specifications will also meet the MOPS baseline. The OMNI III-compliant devices in the initial list were analyzed for compliance with the MOPS baseline to determine which of the devices currently on the market and available to the civilian consumer may be suitable for civil aviation use.

There are two subsections to the analysis. The first analyzes those NVGs that meet the ANVIS-6, OMNI III or MOPS requirements. These are typically GEN III goggles with state-of-the-art intensifier tubes. The second subsection analyzes goggles on the market that could be proposed for aviation and that meet some but not all MOPS requirements. These are typically GEN I or II goggles and are not considered adequate for civil use because of their failure to meet all MOPS requirements.

NVGs that meet ANVIS 6, OMNI III or MOPS requirements. This subsection offers a comparison and analysis of the NVGs on the market that meet ANVIS 6, OMNI III specifications or MOPS baseline, which is to be the standard of performance for use in civil aviation. The design attributes of each candidate goggle are shown in comparison with the MOPS as a baseline. Note that goggles with the ANVIS 6 form factor may be fitted with intensifier tubes with varying levels of performance, hence the differences between ANVIS 6, OMNI III and ANVIS 6, OMNI IV NVGs.

The following chart is presented to give the reader a clear indication of what the technical differences are between the MOPS baseline and ANVIS 6, OMNI III.

SPECIFICATONS	MOPS BASELINE	AN/ANVIS 6 OMNI III
Manufacturer		ITT
Technology	Intensifier tubes not specified	GEN III Image intensifier tubes
Photosensitivity	Not specified	1350 uA/lm
Spectral Response	Meet Class B filter requirements	Meets Class A filter
Field-of-View	38 degrees vertical and horizontal	40 degrees
Magnification	1:1 +/- 2%	1:1
System Resolution	1.0 cy/mr. At 14º off axis = 0.81 cy/mr. With a variable focus @ through infinity = 0.49cy/mr	1.0 cy/mr
Tube Resolution	Not specified	45 lp/mm
Signal to Noise Ratio	Not specified	19:1
Brightness Gain	= 2,500 foot-Lamberts (fL) per fL at an input light level of 1 x 10?4 fL	5000 fl/fl min
Collimation	1º convergence and 0.3º divergence/dipvergence	1º convergence and 0.3º divergence/dipvergence
Diopter Adjustment	Adjustable +1.0 to –2.0, Fixed –0.5 and –1.0	+2 to -6
Interpupillary Adjustment	Desired but not required. If not installed, exit pupil must be large enough to see full FOV	51 to 71mm (meets)
Fore-and-Aft Adjustment	Sufficient to align with users eyes	27mm total (meets)
Tilt Adjustment	Sufficient to align with users eyes	10 degrees (meets)
Objective Lens	Adjustable from beyond infinity to = 45 cm close range	F/1.2, 25 mm close range
Exit Pupil/Eye Relief	Type I - 25 mm, Type II - 20mm	25 mm
Focus Range	Adjustable from beyond infinity to = 45 cm close range	Meets
Flip-Up/Flip Down	Required capability	Required capability
Automatic Breakaway	Required at 15g	Required at 15g
Voltage Required	Backup power supply required	Backup required, 2 AA Batteries
Weight of Binocular	Not specified	590 gm
Cost	N/A	Estimate $6500
Date Available	N/A	Currently on the market

Table 1. Comparison of MOPS to ANVIS 6, OMNI III

Analysis. This comparison was revealing in that it was the first attempt to look at the technical content, completeness and usability of the MOPS in a comparison study with the typical information published by manufacturers concerning their product performance. This directly reflects the usability of the MOPS in making field determinations of whether a candidate NVG meets MOPS requirements.

The list of system performance topics was taken from a typical product performance specification sheet published by a major NVG appliance manufacturer. The topics are typical of specification sheets published by the more prominent vendors or manufacturers. The information is comprehensive enough to provide the reader a performance picture of the night vision aid being described. The image intensifier tube performance indicators/discriminators are spectral response, resolution, gain, and signal to noise ratio, essentially the electro-optical performance characteristics. The usability indicators are collimation, various adjustment specifications, lens size information, flip-up/down data, weight, and power requirements, especially the goggle form factor characteristics.

An analysis of the MOPS verses ANVIS-6, OMNI III from an intensifier tube performance perspective showed that the OMNI III specification met or exceeded the MOPS requirements in every case except type of filter. From the documentation that was available, it appears the OMNI III contract specified a Class A filter, at least for Army users. The MOPS specifies a Class B filter. It is not certain whether the OMNI III contract allowed for either Class B or "Leaky Green" notch type filters. From a usability perspective, the MOPS requirements do not specify many of the important adjustment, lens size, and weight criteria that were described in the manufacturer's literature. ANVIS-6, OMNI III would meet the few usability requirements that were specified in the MOPS.

AV4949UL commercial NVG. ITT markets the Model AV4949UL with the F9800N tubes for commercial use. The comparison of this model with the MOPS baseline is shown in the chart below.

SPECIFICATONS	MOPS BASELINE	AV4949UL COMMERCIAL
Manufacturer		ITT
Technology	Intensifier tubes not specified	GEN III Image intensifier tubes
Photosensitivity	Not specified	1550 uA/lm
Spectral Response	Meet Class B filter requirements	Class B filter
Field-of-View	38 degrees vertical and horizontal	40º FOV
Magnification	1:1 +/- 2%	1:1
System Resolution	1.0 cy/mr. At 14º off axis = 0.81 cy/mr. With a variable focus @ through infinity = 0.49cy/mr	1.3cy/mr
Tube Resolution	Not specified	64 lp/mm
Signal to Noise Ratio	Not specified	19.5 to 1
Brightness Gain	= 2,500 foot-Lamberts (fL) per fL at an input light level of 1 x 10?4 fL	TBD
Collimation	1º convergence and 0.3º divergence/dipvergence	TBD
Diopter Adjustment	Adjustable +1.0 to –2.0, Fixed –0.5 and –1.0	+2 to –6
Interpupillary Adjustment	Desired but not required. If not installed, exit pupil must be large enough to see full FOV	51mm-72 mm
Fore-and-Aft Adjustment	Sufficient to align with users eyes	27mm total adjustment
Tilt Adjustment	Sufficient to align with users eyes	10 degrees
Objective Lens	Adjustable from beyond infinity to = 45 cm close range	TBD
Eyepiece Lens	Not specified	TBD
Exit Pupil/Eye Relief	Type I - 25 mm, Type II - 20mm	25mm
Focus Range	Adjustable from beyond infinity to = 45 cm close range	TBD
Flip-Up/Flip Down	Required capability	Push button
Automatic Breakaway	Required at 15g	11g – 15g
Voltage Required	Backup power supply required	2 AA batteries. Required backup
Weight of Binocular	Not specified	590 grams
Cost	N/A	Estimate $9000
Date Available	N/A	Currently on the market

Table 2. Comparison of MOPS to AV4949UL

Analysis. The AV4949UL Model F9800N was built to a civilian Government use specification. This specification exceeds the OMNI III requirements but specifies a lower performance than OMNI IV. There are several areas where an increase in image intensifier performance was achieved over the ANVIS-6 OMNI III. Photosensitivity was increased from 1350 uA/lm to 1550 uA/lm. Total system resolution was increased from 1.0 cy/mr to 1.3 cy/mr. The signal to noise ratio went from 19:1 to 19.5:1. The combination of these attributes results in better visual acuity under less favorable ambient light.

An analysis of usability features such as adjustment parameters, lens size collimation weight or power requirements showed no major design improvement. The technical focus for OMBI IV was on seeing more clearly, at greater ranges and with less light.

Features worth mentioning on the 4949UL, many of which were common to the ANVIS 6, OMNI III begin with the 25mm adjustable eyepieces. These larger eyepieces provide a higher quality image without the need for precise eye positioning. Most importantly, they ensure that all aircrew members retain the full 40º FOV, even those with deeply set eyes and those who wear eyeglasses.

The binocular provides individual interpupillary adjustment, which greatly simplifies the user task of centering the eyepiece in front of each eye. It also has both a fore-aft adjustment over a range of 27mm and a tilt adjustment over a range of 10º. These features all better enable the crewmembers to precisely adjust their night vision system for maximum viewing and comfort.

Limitations. This goggle was designed to provide the highest level of performance possible while not exceeding the specification of the military version. The major difference between this goggle and its military counterpart is the number and size of blemishes allowed. These blemishes are not expected to affect aviator mission performance.

Suitability for Civil Market. The performance of this NVG is adequate for the most demanding civil aviation applications such as emergency medical services.

Recommendations for Human Performance Testing. Recommend this goggle be tested using subjects who have vision that is not correctable to 20/20 to determine the effects of lack of visual acuity on pilot performance.

ANVIS 6, OMNI IV NVG. ANVIS 6, OMNI III was previously shown in a comparison with the MOPS requirements. The chart below shows a comparison of the ANVIS 6, OMNI IV specification with the MOPS requirements.

SPECIFICATONS	MOPS BASELINE	ANVIS -6 OMNI IV
Manufacturer		ITT and Litton
Technology	GEN III Image intensifier tubes	GEN III Image intensifier tubes
Photosensitivity	Not specified	1800 uA/lm
Scene Illumination	Not specified	10 to the - 6 to 1fc
Spectral Response	Meet Class B filter requirements	Visible to 0.90 um
Field-of-View	38 degrees vertical and horizontal	40º FOV
Magnification	1:1 +/- 2%	1:1 unity
System Resolution	1.0 cy/mr. At 14º off axis = 0.81 cy/mr. With a variable focus @ through infinity = 0.49cy/mr	1.3cy/mr minimum
Tube Resolution	Not specified	64 lp/mm
Signal to Noise Ratio	Not specified	21: 1
Brightness Gain	2,500 foot-Lamberts (fL) per fL at an input light level of 1×10^{-4} fL	5,500 fl/fl minimum
Collimation	1º convergence and 0.3º divergence/dipvergence	≤ 1 degree convergence ≤ 0.3 degrees dipvergence/divergence
Diopter Adjustment	Adjustable +1.0 to –2.0, Fixed –0.5 and –1	+2 to –6
Interpupillary Adjustment	Desired but not required. If not installed, exit pupil must be large enough to see full FOV	51mm-72 mm (meets)
Fore-and-Aft Adjustment	Sufficient to align with users eyes	27mm total adjustment (meets)
Tilt Adjustment	Sufficient to align with users eyes	10 degrees minimum (meets)
Objective Lens	Adjustable from beyond infinity to = 45 cm close range	EFL 27 mm F/1.23, T/1.35
Eyepiece Lens	Not specified	EFL 27mm
Exit Pupil/Eye Relief	Type I - 25 mm, Type II - 20mm	On axis: 14 mm @ 25mm distance Full field: 6mm @ 25 mm distance
Focus Range	Adjustable from beyond infinity to = 45 cm close range	25 mm to infinity (meets)
Flip-Up/Flip Down	Required capability	Push button release
Automatic Breakaway	Required at 15g	11g – 15g
Voltage Required	Backup power supply required	2 AA batteries. Required backup
Weight of Binocular	Not specified	590 grams
Cost	N/A	Approximately $9000
Date Available	N/A	Currently available to military users

Table 3. ANVIS-6 OMNI IV Comparison to MOPS

Analysis. The ANVIS-6 NVG built to the OMNI IV specification represents the current state-of-the-art for fielded Army systems. OMNI IV intensifier tubes can be used as a drop-in retrofit to replace the image tubes of earlier OMNI I,II, and III systems. The intensifier tube offers improved resolution, greater photosensitivity, spectral response, SNR performance, increased gain and other performance enhancing characteristics over the OMNI III specification. Total improvement over the original OMNI I specifications show a 78% improvement in resolution, 80% improvement in photoresponse, and a 30% improvement in the SNR.

The OMNI IV tube also offers improved cosmetics, with the maximum allowable spots seen in the tube reduced from 52 (OMNI I) to only 6 (OMNI IV). The usability features such as adjustments, objective and eyepiece lens remain relatively the same as the OMNI III specification with some minor changes to increase efficiency.

Limitations. This goggle was designed to provide the highest level of performance possible for the most demanding military missions.

Suitability for Civil Market. This product represents the current state-of-the-art military use NVG. It is suitable for civilian use and is available to the civil aviation industry in selected tubes. This goggle is relatively light weight and has a breakaway capability for crashworthiness. The eye relief, large exit pupil, and extensive adjustment capability will permit use by pilots of varying physical characteristics such as deep set eyes or those requiring spectacles. The helmet mounts available will accommodate most of the popular helmets used in the rotorcraft industry.

Recommendations for Human Performance Testing. Recommend this goggle be tested using subjects who have vision that is not correctable to 20/20 to determine the effects of lack of visual acuity on pilot performance.

Commercial AV 4949UL comparison with OMNI III & IV specifications.

Specifications	OMNI III	AV4949UL	OMNI IV
Manufacturer		ITT & Litton	
Technology	GEN III	GEN III	GEN III
Photosensitivity	1350 uA/lm	1550 uA/lm	1800 uA/lm
Spectral Response	Class A	Class B	Class A/B
Field-of-View	40 degrees	40 degrees	40 degrees
Magnification	1:1	1:1	1:1
System Resolution	1.0 cy/mr	1.3 cy/mr	1.3 cy/mr
Tube Resolution	45 lp/mm	64 lp/mm	64/lp/mm
Signal to Noise Ratio	19:1	19.5:1	21:1
Brightness Gain	10,000-20,000	10,000-20,000	10,000-20,000
Collimation	≤1°Convergence ≤0.3° Dip/Diverg	≤1°Convergence ≤0.3° Dip/Diverg	≤1°Convergence ≤0.3° Dip/Diverg
Diopter Adjustment	+2 to -6	+2 to -6	+2 to -6
Interpupillary Adjustment	51mm to 72 mm	51mm to 72mm	51mm to 72mm
Fore-and-Aft Adjustment	27mm total	27mm total	27mm total
Tilt Adjustment	10° minimum	10° minimum	10° minimum
Objective Lens	Adj. from beyond ∞ to 45cm close range	F/1.2	F/1.2
Eyepiece Lens			
Exit Pupil/Eye Relief	25mm	25mm	25mm
Focus Range	Beyond ∞ to 45cm close range	25cm close	25 cm close
Flip-Up/Flip Down	Push button	Push button	Push button
Automatic Breakaway	Required 15g	15g	15g
Voltage Required	Backup Power required	Backup available	Backup available
Weight of Binocular	590 gm	590gm	590m
Cost	N/A	Appox. $9000	N/A
Date Available		Currently on market	

Table 4. Commercial NVG Comparison

Analysis. The information on the above chart was obtained from ITT Night Vision. It is intended to show a comparison of the military OMNI III specification, the commercial AV4949UL, Model F9800N, and the military OMNI IV specification. This chart clearly shows the commercial NVG to have superior image intensifier performance over OMNI III and shows less tube performance when compared to the OMNI IV. The difference between the 4949UL and OMNI IV in the areas of signal to noise ratio and photoresponse would be very difficult to discern in most flight conditions.

From a cosmetic viewpoint, the 4949UL F9800N differs from the OMNI IV 9800P in allowable blemishes that can be detected in the tube, particularly in zone 2 and zone 3. The commercial NVG allows a greater number of blemishes in the outer zones of the tube than are allowed by the OMNI IV specification.

From a cost and availability perspective, the commercial goggle is much less expensive and the waiting times much shorter than those of the OMNI IV due to the military priority and Government pricing.

This chart also clearly indicates that it is the technology of the design and manufacture of the intensifier tube that is being protected for military use, not the mechanical features. The specifications in the usability technical areas such as various adjustments, weight, flip-up capability, break-away, etc. are basically the same across all models. Most of these usability specifications have remained unchanged since 1992.

Limitations. The 4949 goggle is very much state-of-the-art with no limitations that would prevent civil use. It does allow for more blemishes in selected zones over the OMNI IV and the photoresponse is slightly less but barely noticeable. The cheaper cost makes up for both of these differences neither of which will affect mission performance.

Suitability for Civil Market. These goggles would be an excellent choice for any commercial operator who is looking for near OMNI IV performance at a lower price and better market availability. This goggle is relatively light weight and has a breakaway capability for crashworthiness. The eye relief and extensive adjustment capability should permit use by pilots of varying physical characteristics such as deep set eyes or spectacles. The helmet mounts available will accommodate most of the popular helmets used in the rotorcraft industry.

Recommendations for Human Performance Testing. Recommend this goggle be tested using subjects who have vision that is not correctable to 20/20 to determine the effects of lack of visual acuity on pilot performance.

The chart below shows the different tubes and performance levels that are available in non-U.S. Government versions of the Model 4949 NVG.

	Standard	Enhanced		Highest Performance	
Model	F9800B (Standard)	F9800C	F9800J GEN III Plus	F9800N GEN III Ultra	F9800P OMNI IV
Resolution (minimum)	57 lp/mm	57 lp/mm	57 lp/mm	64 lp/mm	64 lp/mm
Photocathode Sensitivity	1000 uA/lm	1350 uA/lm	1500 uA/lm	1800 uA/lm	1800 uA/lm
Signal/noise (minimum)	16.2	18.0	19.2	21.0	21.0
Luminous Gain fl/fc	4000-7000 10000-20000	4000-7000 10000-20000	4000-7000 10000-20000	4000-7000 10000-20000	4000-7000 10000-20000
Output Brightness at 1 and 20 fc	2.0 - 4.0	2.0 - 4.0	2.0 - 4.0	2.0 - 4.0	2.0 - 4.0
MTF (min)					
@2.5 lp/mm	90%	90%	90%	92%	92%
@7.5 lp/mm	75%	75%	75%	80%	80%
@15.0 lp/mm	48%	48%	48%	61%	61%
@25.0 lp/mm	28%	28%	28%	38%	38%
Photocathode Diameter (min)	17.5mm	17.5mm	17.5mm	17.5mm	17.5mm
Reliability, Hrs.	10,000 hrs.	10,000 hrs	10,000 hrs	10,000 hrs	10,000 hrs
Phosphor	P-43	P-43	P-43	P-43	P-43
Max Spots Allowed in Each Zone	Zone	Zone	Zone	Zone	Zone
Spot Size (in.)	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
>.015-.020	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0
>.012-.015	0 1 1	0 1 1	0 0 0	0 0 1	0 0 0
>.009-.012	0 1 2	0 1 2	0 0 0	0 1 2	0 0 0
>/006-.009	1 2 3	1 2 3	0 1 1	1 2 3	0 1 1
>.003-.006	3 4 5	3 4 5	0 2 2	2 3 4	0 2 2

Table 5. Model 4949 Non-U.S. Government Intensifier Tubes

The chart clearly shows the increase in visual performance as the chart is read from left to right. It also clearly indicates the older (left) verses the newest technology (right). The highest performing tubes (F9800N & F9800P) meet MOPS requirements. The standard and enhanced tubes shown meet most but not all of the MOPS requirements.

An interesting observation concerning this chart is the section presenting the maximum number of spots allowed in each zone of the intensifier tube. Zone 1 is the most critical and falls in the central viewing area of the tube. The tolerance for blemishes in Zones 2 and 3 are consecutively greater because the further out from the central viewing area the less distracting the blemish or spot is with size of the spot taken into consideration in each zone. Comparing this chart to the MOPS requirements is not a one-to-one translation. The MOPS specifies the size of the spots in milliradians not inches. The MOPS also describes the zones in terms of the number of spots that fall within the annulus bounded by two circles of specific diameter, the size of each specified in milliradians.

AN/AVS-9 Night Vision Goggle. The chart below compares the AN/AVS-9 with two different intensifier tubes with MOPS requirements.

Specifications	MOPS	AN/AVS-9 F9800J Tubes	AN/AVS-9 F9800P Tubes
Manufacturer		ITT & Litton	ITT & Litton
Technology	Not specified	GEN III	GEN III
Photosensitivity	1350 uA/lm	1500 uA/lm	1800 uA/lm
Spectral Response	Class B	Class B	Class B
Field-of-View	38°	40°	40°
Magnification	1:1 ± 2%	1:1	1:1
System Resolution	1.0 cy/mr	1.3 cy/mr	1.3 cy/mr
Tube Resolution	Not specified	64 lp/mm	64/lp/mm
Signal to Noise Ratio	Not specified	19.5:1	21:1
Brightness Gain	2,500 fl/fl at input light level 1x10fl	4000-7000 & 10,000-20,000	4000-7000 10,000-20,000
Collimation	1° Convergence 0.3 diverg/dipvergence	≤1° Convergence ≤0.3 diverg/dipverg	≤1° Convergence ≤0.3 diverg/dipverg
Diopter Adjustment	+2 to -6	+2 to -6	+2 to -6
Interpupillary Adjustment	51mm to 72 mm	51mm to 72mm	51mm to 72mm
Fore-and-Aft Adjustment	27mm total	27mm total	27mm total
Tilt Adjustment	Sufficient for eye alignment	10° minimum	10° minimum
Objective Lens	Adj. from beyond ∞ to 45cm close range	EFL 27mm F/1.23, T1.35	Adj. from beyond ∞ to 45cm close range
Eyepiece Lens	Not specified	EFL 27 mm	EFL 27mm
Exit Pupil/Eye Relief	Type I - 25mm Type II - 20mm	25mm (Type I)	25mm (Type I)
Focus Range	Adj. from beyond ∞ to 45cm close range	25mm to ∞	25mm to ∞
Flip-Up/Flip Down	Push button	Push button	Push button
Automatic Breakaway	Required by 15g	11-15g	11-15g
Voltage Required	Backup required	3V with backup available	3V with backup available
Weight of Binocular	Not specified	590gm	590gm
Cost	N/A	Appox. $9000	Approx. $9000
Date Available		Available	Available

Table 6. Commercial AN/AVS-9 Comparison

Analysis. The information on the above chart was obtained from ITT Night Vision. Similar specifications were found for Litton's version of the AN/AVS-9 in their Model M949 NVG. The chart is intended to show a comparison of the MOPS requirements with two different tube options for the AN/AVS-9 goggle. The 9800J series tube is an enhanced performance tube built under an older specification with less performance than the 9800P. The 9800P is the highest performing tube available to non-U.S. Government customers. These customers would typically be law enforcement or other official civil agencies. Both tubes exceeded MOPS requirements in every area.

There are several technical areas in the comparison that are worth mentioning that genuinely affect the quality of the visual image. The first is photosensitivity. The photosensitivity was 1500 uA/lm and 1800 uA/lm respectively for the 9800J and 9800P tubes. The MOPS only required 1350 uA/lm. Photosensitivity is the ability of the tube to detect light energy and convert it to an electron image. The higher the value the better the ability to see under darker conditions. Both tubes exceeded the MOPS requirement by an order of magnitude.

The second area worth mentioning was the signal to noise ratio (SNR). The signal to noise ration is probably the single most significant factor in determining a system's ability to see when it gets dark. It should be noted that SNR is not specified in the MOPS. SNR takes into account the photosensitivity, as well as the efficiency of the phosphor screen in reconverting the electron image to visible light and the "noise" contribution of the microchannel plate. Because the SNR determines an image intensifier's low-light-resolution, the higher the ratio, the clearer will be the signal compared to the background noise. The result is an increased ability to see under increasingly darker conditions. The SNRs for the 9800J and 9800P tubes respectfully are 19.5:1 and 21:1. These figures are an indicator of the tubes excellent performance under extreme low-light conditions.

The third area worth noting is resolution. Resolution is measured in line pairs per millimeter (lp/mm) tube resolution or in cycles per milliradian (cy/mr) for system resolution. The more significant measurement is system resolution as this is what the viewer will actually experience. It takes into account the quality of the system's optics. When evaluating systems with similar optical quality and filters, the tube resolution is an important criteria. Most systems produce an optimal resolution at some point between very high light and very low light conditions. The higher the values (lp/mm or cy/mr) the better the ability to present a sharp picture to the user. Older generation tubes produced a sharp image in the center of the tube and a less sharp image toward the periphery of the tube.

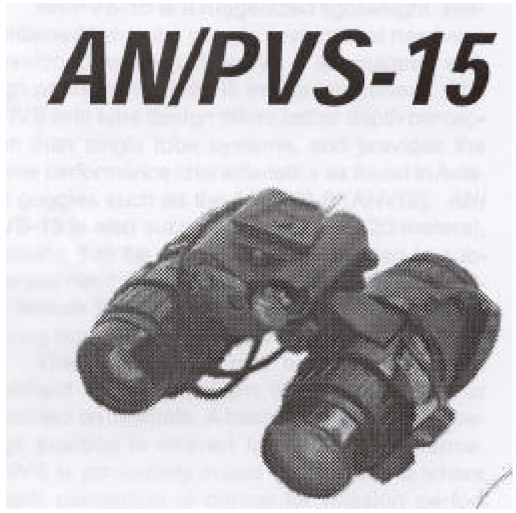
The resolution provided by both the 9800J and 9800P tubes is 1.3 cy/mr system resolution and 64 lp/mm tube resolution. The 1.3 cy/mr exceeds the MOPS requirement of 1.0 cy/mr for system resolution. This indicates that the viewer should have a very sharp picture across the entire viewing area even in low light conditions. The MOPS does not specify and individual tube resolution requirement for comparison.

Limitations. The AN/AVS-9 goggle is state-of-the-art with no limitations that would prevent civil use.

Suitability for Civil Market. These goggles would be an excellent choice for any commercial operator who is looking for near OMNI IV performance at a lower price and better market availability. This goggle is relatively light weight and has a breakaway capability for crashworthiness. The eye relief and extensive adjustment capability should permit use by pilots of varying physical characteristics such as deep set eyes or spectacles. It offers good look down, look around capability. The helmet mounts available will accommodate most of the popular helmets used in the rotorcraft industry.

Recommendations for Human Performance Testing. Recommend this goggle be tested using subjects who have vision that is not correctable to 20/20 to determine the effects of lack of visual acuity on pilot performance.

AN/PVS-15 Submersible Binocular Night Vision System (BNVS).



Analysis. This goggle was designed primarily for ground and sea operations but could easily be used as an aviation NVG. It is basically an ANVIS style goggle with a submersible capability down to 66 ft. This goggle can be stowed or transported in submersed conditions. It is a ruggedized, light weight, self-contained twin tube goggle system that was developed by the Navy. It is particularly useful for use during boat and amphibious operations.

The AN/PVS-15 is equipped with high performance GEN III intensifier tubes with the same visual capabilities and adjustment features as the aviation AN/AVS-9, and therefore, no comparison with MOPS requirements is presented. This goggle can be operated as a handheld binocular, worn on a headstrap, or mounted on various helmets and has a flip-up capability
.

Limitations. The design of this goggle is similar to that of the ANVIS 6 or AN/AVS-9. This goggle can be mounted with various interchangeable tubes that are available to get the desired visual performance needed for the particular mission, including aviation. The price is unknown. The rugged nature of the design and the submersible capability will most likely increase the price over a standard aviation version not to mention the potential for increased weight.

Suitability for Civil Market. This goggle is more than capable of handling aviation applications without modification. It is basically a ruggedized version of the ANVIS goggle. The weight of this goggle was not determined but is estimated to be comparable to the aviation model. The eye relief and extensive adjustment capability should permit use by pilots of varying physical characteristics such as deep set eyes or spectacles. It offers good look down, look around capability. The helmet mounts available will accommodate most of the popular helmets used in the rotorcraft industry.

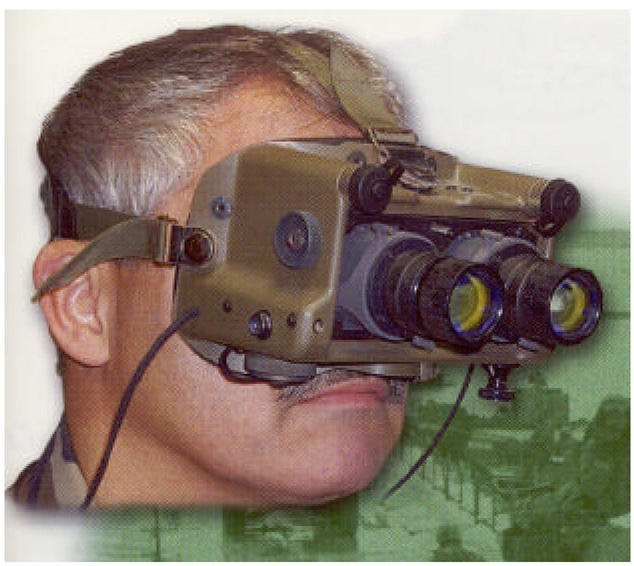
Recommendations for Human Performance Testing. Recommend this goggle be tested using subjects who have vision that is not correctable to 20/20 to determine the effects of lack of visual acuity on pilot performance.

NVGs that did not meet ANVIS 6, OMNI III or MOPS requirements.

The previous section examined the NVGs on the market that meet the OMNI III and or MOPS requirements. The NVGs listed in this section are those that are available on the market but do not meet the MOPS requirements. There are basically three minimum requirements to qualify for listing in this section. First the NVG has to have dual intensifier tubes, secondly it must be head mounted, and third it must have GEN I or later tubes.

The reason for presenting this information is to make the reader aware of what the MOPS has eliminated from the cockpit by establishing high minimum standards. Some of the goggles presented in this section were not specifically designed for aviation use. They do however, present enough of the technical attributes to be considered having potential for aviation use.

AN/PVS-5. The chart below compares the AN/PVS-5 goggle to MOPS requirements.



Specifications	MOPS	AN/PVS-5
Manufacturer		ITT
Technology	Not specified	GEN II & III
Photosensitivity	1350 uA/lm	Not specified
Spectral Response	Class B	Class B
Field-of-View	38°	40°
Magnification	1:1 ± 2%	1:1
System Resolution	1.0 cy/mr	Not specified
Tube Resolution	Not specified	3X10(3)fl(lp/Mr) 0.6
Signal to Noise Ratio	Not specified	Not specified
Brightness Gain	2,500 fl/fl at input light level 1x10fl	Not specified
Collimation	1° Convergence 0.3 diverg/dipvergence	Not specified
Diopter Adjustment	+2 to -6	+2 to -6
Interpupillary Adjustment	51mm to 72 mm	58-72mm
Fore-and-Aft Adjustment	27mm total	26.6mm
Tilt Adjustment	Sufficient for eye alignment	No tilt
Objective Lens	Adj. from beyond ∞ to 45cm close range	25 mm to ∞
Eyepiece Lens	Not specified	Not specified
Exit Pupil/Eye Relief	Type I - 25mm	15mm
Focus Range	Adj. from beyond ∞ to 45cm close range	25mm to ∞
Flip-Up/Flip Down	Push button	Stationary
Automatic Breakaway	Required by 15g	No breakaway
Voltage Required	Backup required	Backup available
Weight of Binocular	Not specified	34oz
Cost	N/A	$1100 to $7700 (tube dependent)
Date Available		Available

Table 7. AN/PVS-5 Comparison

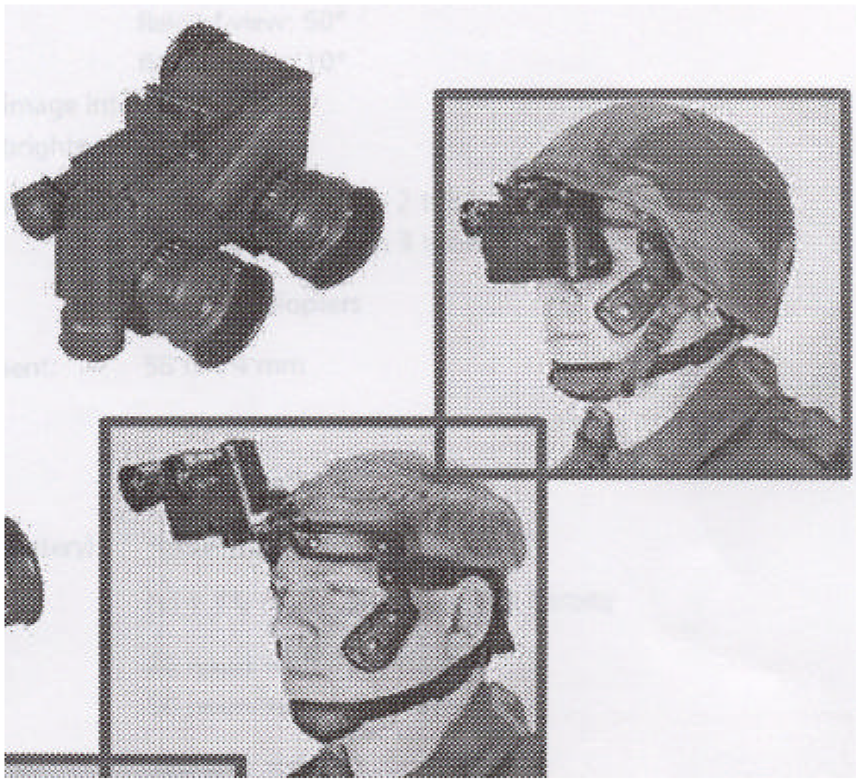
Analysis. The AN/PVS-5 is the original night vision goggle developed for rotary wing aviation use by the Army in the early 1970's. It comes in various models from AN/PVS-5 to 5A thru 5C. Model 5C is available in different intensifier tubes that range from GEN II to GEN III in capability. There are hundreds of these goggles available on the open market. These goggles come closest to being acceptable (GEN III model) than any other goggle listed below. They were originally designed specifically for aviation and are more capable now than they were when in use by the military. Many of the important comparison specifications were not available in vendor specification sheets. In spite of that, it is clear that the NVG would not meet the MOPS requirements in many areas, even though it is available in a GEN III tube.

Limitations. This goggle is available in state-of-the-art GEN III tubes. In spite of this fact, the limitations that made this goggle marginally useable for the Army remain in the design. The biggest detractor is the "full face" design. This goggle rests against the face and a rubber foam seal prevents outside light from entering. This blocks all downward (instrument panel) and peripheral views which are critical for maintaining situational awareness in flight. The tubes will normally be focused to infinity for outside viewing during flight. Looking at cockpit instruments and overhead switches requires a manual refocus of at least one lens for close viewing. This is unacceptable. The Army tried flying with one tube adjusted close and the other adjusted to infinity. This was obviously unsafe and negated the depth cues provided by dual combiners. There is no tilt capability. The only way to get the goggle out your face is to remove it which is not acceptable in most emergency situations. There is no breakaway capability meaning increased risk of head and face injury in a crash sequence. In addition, there is inadequate eye relief to accommodate pilots with variable facial features and will not accommodate spectacles. The tubes are 18mm. The MOPS requires a 25mm diameter tube. The smaller tube makes adjustments to center on the smaller exit pupil more critical. The adjustments and helmet fit must be exact for the pilot to get a full 40° FOV. This design was abandoned by the military many years ago and for good reason.

Suitability for Civil Market. Due to the limitations stated above, many of which are safety related, the AN/PVS-5 goggle is not considered adequate for civil use.

Recommendations for Human Performance Testing. This would be an excellent candidate for tests that examine the importance of peripheral vision and look-down capability in the cockpit, and how the lack of those visual cues may affect performance.

Lucie Night Vision Goggle. This is a light weight, low profile NVG that is capable of using GEN II or GEN III intensifiers tubes. The specifications are shown on the chart below.



Specifications	MOPS	Lucie NVG
Manufacturer		ITT
Technology	Not specified	GEN II or III
Photosensitivity	1350 uA/lm	Not specified
Spectral Response	Class B	Class B
Field-of-View	38°	50°
Magnification	1:1 ± 2%	1X to 4X
System Resolution	1.0 cy/mr	1.5mr/lp Gen II 1.2 mr/lp Gen III
Tube Resolution	Not specified	Not specified
Signal to Noise Ratio	Not specified	Not specified
Brightness Gain	2,500 fl/fl at input light level 1x10fl	Not specified
Collimation	1° Convergence 0.3 diverg/dipvergence	Not specified
Diopter Adjustment	+2 to -6	+3 to -5
Interpupillary Adjustment	51mm to 72 mm	56mm to 74mm
Fore-and-Aft Adjustment	27mm total	27mm total
Tilt Adjustment	Sufficient for eye alignment	Not specified
Objective Lens	Adj. from beyond ∞ to 45cm close range	Not specified
Eyepiece Lens	Not specified	Not specified
Exit Pupil/Eye Relief	Type I - 25mm Type II - 20mm	>20mm
Focus Range	Adj. from beyond ∞ to 45cm close range	20cm to ∞
Flip-Up/Flip Down	Push button	Push button
Automatic Breakaway	Required by 15g	Not specified
Voltage Required	Backup required	50 hrs. with 1.5v battery
Weight of Binocular	Not specified	450gm
Cost	N/A	Not specified
Date Available		Available

Table 8. Lucie Comparison

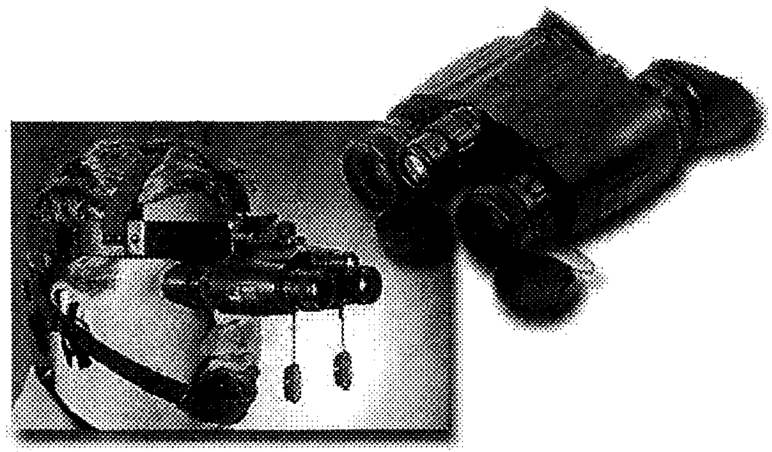
Analysis. Lucie is a compact, low profile NVG offering a full 50° FOV. This is 10° greater than the best aviation specific NVG. This goggle was specifically designed for ground use, however, it appears to be adaptable for aviation use. The attributes are a dramatically reduced forward projection. This keeps the center of gravity closer to the head and reduces the amount of counter weights required to balance the system when head mounted. It is very light weight, over 100 grams lighter than the average aviation goggle. It has an optional 4X magnifier lens which would not be particularly useful for aviation applications. A large benefit however, is the 50° FOV capability. This is greater than the 38° MOPS requirements. The system can be equipped with either GEN II or GEN III intensifier tubes, depending on customer performance requirements. For aviation applications, Lucie would have to be equipped with GEN III tubes.

Limitations. This goggle was designed specifically for ground use. There was not enough technical information available to adequately compare this product to the MOPS in some of the critical performance areas. Its full face design may present look down - look around problems although the specifications list a greater than 20 mm eye-relief capability.

Suitability for Civil Market. With a GEN III tube, this product has some potential for use in the civil market. The wider FOV, slim profile, and lighter weight are attributes that make this product attractive. It is not clear what the look down- look around limitations may be with this close to the face design. It would be worth exploring the technical and functional attributes more closely. The literature states that a GEN III tube is available but there is no information concerning the model or capability of that tube.

Recommendations for Human Performance Testing. Look down, look around testing would be required due to the close to the face profile of this goggle.

DIPOL-2MV 2. The chart below presents a comparison of the Russian 2MV2 goggle with MOPS requirements.



Specifications	MOPS	
Manufacturer		Russia
Technology	Not specified	GEN 1+
Photosensitivity	1350 uA/lm	Not specified
Spectral Response	Class B	Class A
Field-of-View	38°	40°
Magnification	1:1 ± 2%	1:1
System Resolution	1.0 cy/mr	Not specified
Tube Resolution	Not specified	40 lp/mm
Signal to Noise Ratio	Not specified	Not specified
Brightness Gain	2,500 fl/fl at input light level 1x10fl	35,000 (3500fl/fl)
Collimation	1° Convergence 0.3 diverg/dipvergence	Not specified
Diopter Adjustment	+2 to -6	+4 to -4
Interpupillary Adjustment	51mm to 72 mm	Not specified
Fore-and-Aft Adjustment	27mm total	Not specified
Tilt Adjustment	Sufficient for eye alignment	Not specified
Objective Lens	Adj. from beyond ∞ to 45cm close range	26mm F1.4
Eyepiece Lens	Not specified	Not specified
Exit Pupil/Eye Relief	Type I - 25mm	Not specified
Focus Range	Adj. from beyond ∞ to 45cm close range	20 cm to ∞
Flip-Up/Flip Down	Push button	Flips up
Automatic Breakaway	Required by 15g	Not specified
Voltage Required	Backup required	3V with backup
Weight of Binocular	Not specified	530 gm
Cost	N/A	$820
Date Available		Available

Table 9. DIPOL-2MV Comparison

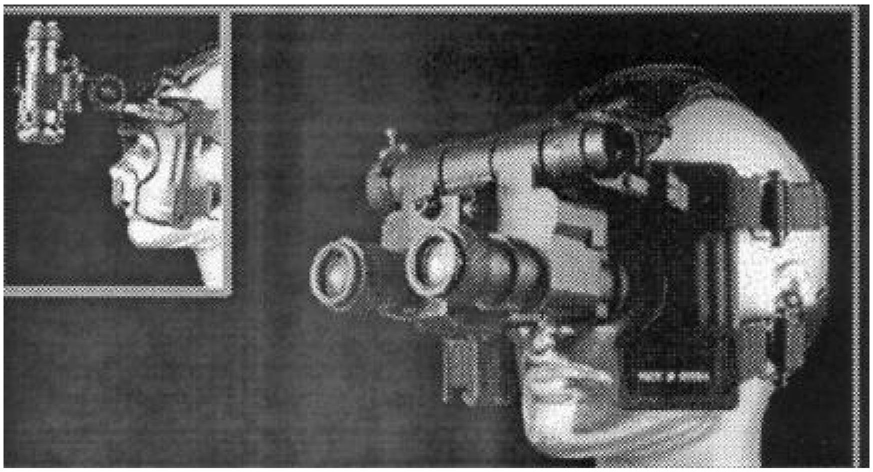
Analysis. This is a Russian manufactured goggle with older GEN 1+ intensifier tubes. It is head mounted but not helmet mounted. This goggle was not specifically designed for aviation applications but could be used with its head strap mount and an aviator head set. This dual function goggle was designed to be used either head-born or as a hand held binocular device. It is lighter weight (530 gm) than the AN/AVS-9 (590 gm). It has an automatic shut down control to reduce gain when spiked with bright light.

Limitations. There was not enough data available to know all of the potential limitations of this goggle. However, the poor performance of the GEN 1 intensifier tubes is enough to eliminate it from consideration for civil use under the MOPS requirements. In addition, this goggle mounts to the head by use of straps. A helmet mount may be required. There is no mention of a breakaway feature or the availability of a backup power source which would be limiting factors if not included in the design. In addition, the rubber eyepiece grommets would have to be removed to provide a look-under, look-around capability.

Suitability for Civil Market. The GEN I intensifier tubes eliminate this product from consideration for civil use under the MOPS.

Recommendations for Human Performance Testing. None

NTZ/22. The chart below compares the Russian made NTZ/22 with the MOPS requirements.



Specifications	MOPS	
Manufacturer		Newcon Optik (Russian)
Technology	Not specified	GEN I+
Photosensitivity	1350 uA/lm	Not specified
Spectral Response	Class B	Class A
Field-of-View	38°	36°
Magnification	1:1 ± 2%	1:1.15
System Resolution	1.0 cy/mr	Not specified
Tube Resolution	Not specified	3.5 lp/mm
Signal to Noise Ratio	Not specified	Not specified
Brightness Gain	2,500 fl/fl at input light level 1x10fl	Not specified
Collimation	1° Convergence 0.3 diverg/dipvergence	Not specified
Diopter Adjustment	+2 to -6	± 5
Interpupillary Adjustment	51mm to 72 mm	54mm-74mm
Fore-and-Aft Adjustment	27mm total	Not specified
Tilt Adjustment	Sufficient for eye alignment	Not specified
Objective Lens	Adj. from beyond ∞ to 45cm close range	25mm to ∞
Eyepiece Lens	Not specified	Not specified
Exit Pupil/Eye Relief	Type I - 25mm Type II - 20mm	Not specified
Focus Range	Adj. from beyond ∞ to 45cm close range	25mm to ∞
Flip-Up/Flip Down	Push button	Flips up
Automatic Breakaway	Required by 15g	Not specified
Voltage Required	Backup required	3V Backup not specified
Weight of Binocular	Not specified	0.740kg
Cost	N/A	\$600 - \$900
Date Available		Available

Table 10. NTZ/22 Comparison

Analysis. The NTZ/22 is a Russian made GEN 1+ goggle that was originally designed for use by helicopter pilots. It would most likely be the equivalent of the original AN/PVS-5 developed by the Army. This goggle is a "full face" design. It is bulky and heavy and fits to the head with a combination of adjustable straps and side face plates. A flight helmet apparently fits over the head straps. The goggle does flip up which is a feature not available in the PVS-5. Many of the important comparison specifications were not available in vendor specification sheets. In spite of that, it is clear that this NVG would not meet the MOPS requirements in many areas. There are hundreds of these goggles available on the market and the price is well under $1000. Reliability and supportability is questionable although the manufacturer (Newcon Optik) does offer a 1 year warrantee.

Limitations. This limitations associated with this goggle are probably even greater than those of the PVS-5. GEN I tubes are a big limiting factor. GEN I tubes do not see well enough in starlight conditions to be acceptable for civil use. In addition, poor tube and system resolution reduce the visual acuity and scene clarity. These performance characteristics would clearly not meet MOPS requirements. Blooming due to bright light sources is a big problem with older generation intensifier tubes.

The limitations that made the AN/PVS-5 goggle unacceptable to the Army are clearly present in this goggle design. The biggest detractor is the "full face" design. This goggle rests against the face and a rubber foam seal prevents outside light from entering and large side mounted face plates. This blocks all downward (instrument panel) and peripheral views which are critical for maintaining situational awareness in flight. The tubes will normally be focused to infinity for outside viewing during flight. Looking at cockpit instruments and overhead switches requires a manual refocus of at least one lens for close viewing. This is unacceptable. The Army tried flying with one tube adjusted close and the other adjusted to infinity. This was obviously unsafe and negated the depth cues provided by dual combiners.

The only way to get the goggle out your face is to remove it which is not acceptable in most emergency situations. Looking at the head mounting system, there does not appear to be a goggle breakaway capability meaning increased risk of head and face injury in a crash sequence. The eye relief was not specified but appears inadequate to accommodate pilots with spectacles. The FOV of this goggle is only 36°, a full 4° less than ANVIS and other modern goggles. Flight tests conducted at the Army's Aeroflightdynamics Directorate (AFDD) show that pilot performance increases with increased FOV. The strap adjustments and helmet interface must be exact for the pilot to get a full 36° FOV with this system. Head born weight and center of gravity is an issue with this goggle. These deficiencies will cause pilot fatigue and could contribute to face and neck injuries in a crash. The "full face" design was abandoned by the military many years ago and for good reason.

Suitability for Civil Market. Due to the limitations stated above, many of which are safety related, the NZT/22 goggle is not considered adequate for civil use.

Recommendations for Human Performance Testing. This would be an excellent candidate for tests that examine the importance of peripheral vision and look-down capability in the cockpit, and how the lack of those visual cues may affect performance.

ON1X20/IR. The following chart compares the Russian made ON1X20/IR goggle with MOPS requirements.

Specifications	MOPS	
Manufacturer		Russian
Technology	Not specified	GEN I
Photosensitivity	1350 uA/lm	Not specified
Spectral Response	Class B	Class A
Field-of-View	38°	40°
Magnification	1:1 ± 2%	1:1
System Resolution	1.0 cy/mr	Not specified
Tube Resolution	Not specified	28 lp/mm
Signal to Noise Ratio	Not specified	Not specified
Brightness Gain	2,500 fl/fl at input light level 1x10fl	35,000x
Collimation	1° Convergence 0.3 diverg/dipvergence	Not specified
Diopter Adjustment	+2 to -6	± 4
Interpupillary Adjustment	51mm to 72 mm	58-74 mm
Fore-and-Aft Adjustment	27mm total	Not specified
Tilt Adjustment	Sufficient for eye alignment	Not specified
Objective Lens	Adj. from beyond ∞ to 45cm close range	20 mm/1/5
Eyepiece Lens	Not specified	Not specified
Exit Pupil/Eye Relief	Type I - 25mm	Not specified
Focus Range	Adj. from beyond ∞ to 45cm close range	Not specified
Flip-Up/Flip Down	Push button	Flips up
Automatic Breakaway	Required by 15g	Not specified
Voltage Required	Backup required	2 x AA Back up not specified
Weight of Binocular	Not specified	1000 gm (2lbs)
Cost	N/A	\$550 - \$650
Date Available		Available

Table 11. ON1X20/IR Comparison

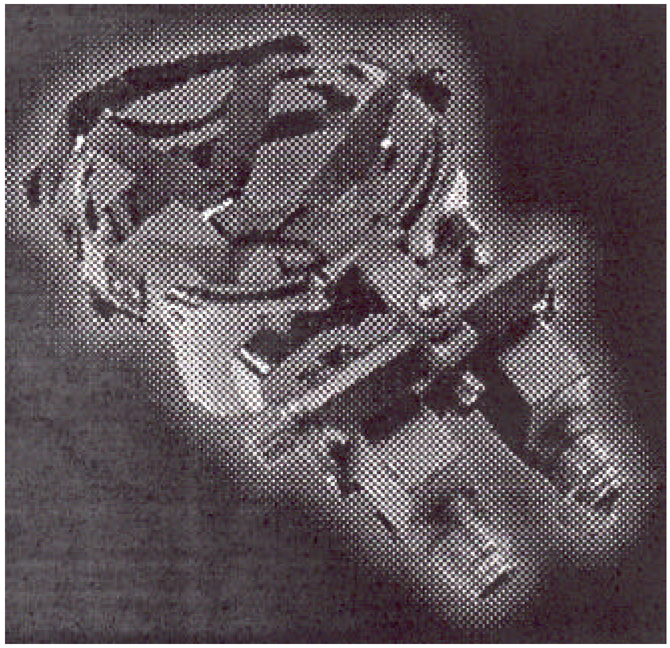
Analysis. The ON1X20/IR is a Russian made GEN 1+ goggle that was originally designed for use by helicopter pilots. It is very similar in design and capability with the previously listed NZT/22 goggle. The analysis of this goggle is basically the same as for the NZT/22. This goggle is most likely be the equivalent of the original AN/PVS-5 developed by the Army. This goggle is a "full face" design. It is bulky and heavy (2lbs) and fits to the head with a combination of adjustable straps and side face plates. A flight helmet apparently fits over the head straps. The goggle does flip up which is a feature not available in the PVS-5. This goggle has an IR illuminator which will come in very handy for viewing out of focus cockpit instruments. Many of the important comparison specifications were not available in vendor specification sheets. In spite of that, it is clear that this NVG would not meet the MOPS requirements in many areas. There are hundreds of these goggles available on the market and the price is in the $550-$650 range.

Limitations. This limitations associated with this goggle are probably even greater than those of the PVS-5. GEN I tubes are a big limiting factor. GEN I tubes do not see well enough in starlight conditions to be relevant for civil use. In addition, poor tube and system resolution reduce the visual acuity and scene clarity. These performance issues would clearly not meet MOPS requirements. Blooming due to bright light sources is a big problem with older generation intensifier tubes. The limitations that made the AN/PVS-5 goggle unacceptable to the Army are clearly present in this goggle design and worse in some areas. The biggest detractor is the "full face" design. This goggle rests against the face and a rubber foam seal prevents outside light from entering. This blocks all downward (instrument panel) and peripheral views which are critical for maintaining situational awareness in flight. The tubes will normally be focused to infinity for outside viewing during flight. Looking at cockpit instruments and overhead switches requires a manual refocus of at least one lenses for close viewing. This is unacceptable both for normal and emergencies situations. Looking at the head mounting system, there does not appear to be a goggle breakaway capability meaning increased risk of head and face injury in a crash sequence. The eye relief was not specified but appears inadequate to accommodate pilots with spectacles. The strap adjustments and helmet interface must be exact for the pilot to get a full 40° FOV with this system. Head born weight and center of gravity is an issue with this goggle. At 1000 grams, this goggle is twice as heavy as an AN/AVS-9. This heavy weight and forward center of gravity will cause pilot fatigue and could contribute to face and neck injuries in a crash. The "full face" design was abandoned by the military many years ago and for good reason.

Suitability for Civil Market. Due to the limitations stated above, many of which are safety related, the ON1X20/IR goggle is not considered adequate for civil use.

Recommendations for Human Performance Testing. This would be an excellent candidate for tests that examine the importance of peripheral vision and look-down capability in the cockpit, and how the lack of those visual cues may affect performance.

Dipol D2V. The chart below compares the MOPS requirements with the available technical specifications of the Russian made D2V night vision goggle.



Specifications	MOPS	
Manufacturer		Russian
Technology	Not specified	GEN I
Photosensitivity	1350 uA/lm	Not specified
Spectral Response	Class B	Class A
Field-of-View	38°	37°
Magnification	1:1 ± 2%	1:1
System Resolution	1.0 cy/mr	Not specified
Tube Resolution	Not specified	28 ln/mm
Signal to Noise Ratio	Not specified	Not specified
Brightness Gain	2,500 fl/fl at input light level 1x10fl	35,000
Collimation	1° Convergence 0.3 diverg/dipvergence	Not specified
Diopter Adjustment	+2 to -6	± 5
Interpupillary Adjustment	51mm to 72 mm	58-74 mm
Fore-and-Aft Adjustment	27mm total	Not specified
Tilt Adjustment	Sufficient for eye alignment	Not specified
Objective Lens	Adj. from beyond ∞ to 45cm close range	20 cm to ∞
Eyepiece Lens	Not specified	Not specified
Exit Pupil/Eye Relief	Type I - 25mm Type II - 20mm	Not specified
Focus Range	Adj. from beyond ∞ to 45cm close range	20 cm to ∞
Flip-Up/Flip Down	Push button	Flips up and down
Automatic Breakaway	Required by 15g	Not specified
Voltage Required	Backup required	3V
Weight of Binocular	Not specified	1.2 lbs. (0.68kg)
Cost	N/A	$560 - $600
Date Available		Available

Table 12. Dipol D2V Comparison

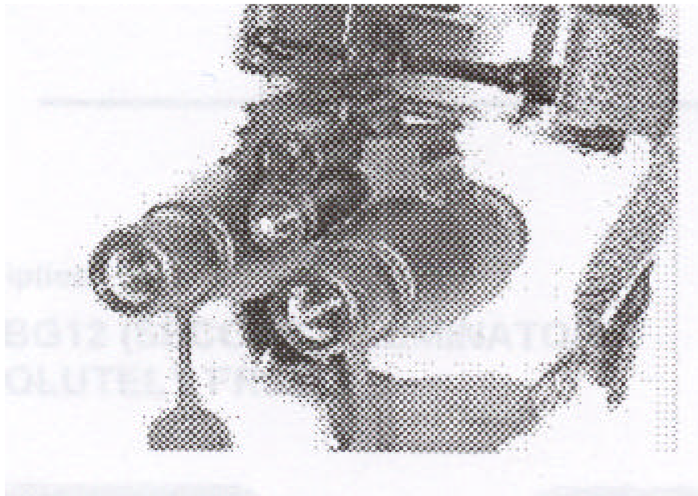
Analysis. This is another Russian made goggle with a similar head strap mounting system as the previous Russian goggles analyzed. In fact, the D2V is similar in many ways to the NZT/22 and ON1X20/IR. It has higher resolution intensifier tubes, is of a more modern design and is lighter weight than the previously mentioned goggles. In spite of these attributes, this is once again, a "full face" goggle design where the flight helmet fits over the head mounting straps and the goggle fits flush with the face resting on a foam rubber cushion frame. All of the negatives associated with a full face goggle apply here.

Limitations. The limitations that apply to the NZT/22 and ON1X20/IR goggles previously discussed apply to this goggle with the possible exception of the weight. The forward center of gravity of this goggle appears more extreme that the others analyzed which may negate some of the value of the weight savings.

Suitability for Civil Market. Due to the limitations stated above, many of which are safety related, the Dipol D2V night vision goggle is not considered adequate for civil use.

Recommendations for Human Performance Testing. This would be an excellent candidate for tests that examine the importance of peripheral vision and look-down capability in the cockpit, and how the lack of those visual cues may affect performance.

UNI-BG12. The chart below compares the MOPS requirements with the available technical specifications of the Canadian made UNI-BG12 night vision goggle.



Specifications	MOPS	
Manufacturer		Canada
Technology	Not specified	GEN I
Photosensitivity	1350 uA/lm	Not specified
Spectral Response	Class B	Class A
Field-of-View	38°	40°
Magnification	1:1 ± 2%	1:1
System Resolution	1.0 cy/mr	Not specified
Tube Resolution	Not specified	40 lp/mm
Signal to Noise Ratio	Not specified	Not specified
Brightness Gain	2,500 fl/fl at input light level 1x10fl	Not specified
Collimation	1° Convergence 0.3 diverg/dipvergence	Not specified
Diopter Adjustment	+2 to -6	± 5
Interpupillary Adjustment	51mm to 72 mm	50-80mm
Fore-and-Aft Adjustment	27mm total	Not specified
Tilt Adjustment	Sufficient for eye alignment	Not specified
Objective Lens	Adj. from beyond ∞ to 45cm close range	0.3m to ∞
Eyepiece Lens	Not specified	20mm f 1.2
Exit Pupil/Eye Relief	Type I - 25mm Type II - 20mm	Not specified
Focus Range	Adj. from beyond ∞ to 45cm close range	0.3m to ∞
Flip-Up/Flip Down	Push button	Flips up and down
Automatic Breakaway	Required by 15g	Not specified
Voltage Required	Backup required	3V Backup not specified
Weight of Binocular	Not specified	500 gr.
Cost	N/A	$600
Date Available		Available

Table 13. UNI-BG12 Comparison

Analysis. This goggle is a head mounted (not helmet mounted) goggle made in Canada that uses GEN I intensifier tubes. Although much of the tube performance specifications on this goggle were not available, the fact that the technology used was GEN I was enough to eliminate this goggle from consideration for U.S. civil use. This goggle is of comparable light weight with modern U.S. built goggles and has an ANVIS type design. It does not have the "full face" typical of the GEN I Russian goggles. The BG12 has flash brightness protection, a flip up mount, and an IR illuminator. The tube resolution is 40 lp/mm witch should produce a fairly sharp image under 1/4 moon light conditions or better. With state-of-the-art GEN III tubes, this goggle may have the potential for adaptation for aviation use. Getting access to all of the specifications concerning this goggle would be required to make that determination.

Limitations. The technical specifications required to know all of the limitations are not available. However, the biggest limitation is the GEN I intensifier tubes. These tubes will not provide the image quality required for civil use during dark (moonless) night operations.

Suitability for Civil Market. Due to the limitations stated above, the UNI-BG12 night vision goggle does not meet the MOPS requirements and is not considered adequate for civil use.

Recommendations for Human Performance Testing. None

5.0 SUMMARY and CONCLUSIONS.

Summary. The purpose of this study was to survey the market and identify NVGs that meet MOPS requirements. This was accomplished and the information provided shows a clear picture concerning the full spectrum of NVG appliances that are available on the market that could potentially be used use by civil operators. The study results let the reader compare the technical specifications of the NVGs listed and to understand the strengths and weaknesses of each product when compared to the MOPS baseline.

The research methodology used was a straight forward presentation of the results of data collection, data analysis and data conclusion and comments. NVG design technical terms were defined and the baseline MOPS requirements were presented to set the "information stage" before presenting the data collection results for comparison. The data collection results were broken down into sections with the first presenting goggles that met the MOPS, and the second section presenting those that did not.

There were 13 different sets of NVGs analyzed. Of these, 6 goggles met the MOPS requirements (with select tubes installed), and 7 goggles clearly did not meet the minimum specification. Prices of these goggles ranged from $550 to $9000. All of the American made goggles had export restrictions, including the oldest model AN/PVS-5, to protect the intensifier tube design technology.

Conclusions. Several facts were made evident by this study. First, the MOPS sets a high standard that can only be met by the highest performing goggles on the market. It is apparent from this research that only two U.S. companies possess the technology to produce the quality of image intensifier tubes required to meet the minimum operational performance standards for civil use of NVGs.

Intensifier tube optical performance was the biggest discriminator in nearly every case. It was obvious that without the latest version of a Generation III tube, the goggle could not produce the system resolution required to provide a sharp image on a dark, moonless night. The latest GEN III tube provides very good to excellent low light level performance and can be used in illumination levels down to starlight only. The image is clean and with excellent contrast, and has a long tube life (10,000 hrs.). The gain, resolution, signal to noise ratios, automatic brightness control, and minimal blooming effects of the modern GEN III tubes offer exceptional performance advantages over older generation tubes.

Most of the goggles that did not meet the specification had GEN I tubes installed. These tubes were developed in the 1960's using vacuum tube technology. They require a full moon to achieve an acceptable level of performance. This tube is characterized by excessive blooming and distortion from light sources in the field of view. GEN I tubes have a light amplification of only 1,000 times in comparison with GEN III tubes at 40,000 times. Operating life is only 2,000 hrs.

A second criterion that proved to be a discriminator involved not the ability to look through the NVG, but instead, the ability to look under and around it. All of the Russian candidates and one older model U.S. goggle have "full face" designs that block all vision under and around the goggle. This design blocks an unaided view of the instrument panel and overhead switches. When looking inside using aided vision (through the NVG), the pilot must re-focus one or both of the intensifier tubes from infinity (normal flight mode) to a close-in focus adjustment to see clearly. This cannot be accomplished quickly enough during normal or emergency operations to be considered safe enough for civil use.

This analysis of commercially available NVG devices has served as a beta test of the utility of the MOPS. In the area of goggle form function, i.e. usability, the MOPS was a good discriminator between acceptable and unacceptable devices. In the area of electro-optical performance the MOPS is currently very limited in its requirements and was not a good discriminator between systems that will or will not provide civil aviation users with the necessary visual cues during flight with NVG devices. A recommendation resulting from this study is that electro-optical performance requirements for OMNI III and OMNI IV be reviewed and adapted as needed for addition to the MOPS.

This analysis has also indicated some areas for human performance testing that would provide useful data for civil NVG requirements. Finally, and most importantly, this report will hopefully provide guidance and technical background information to those who as civil operators and pilots or as government flight standards staff must make decisions as to the acceptability of specific NVG devices for civil aviation.

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2. Szoboszlay Z., Haworth L., Simpson C., A Comparison of the AVS-9 and the Panoramic Night Vision goggles During Hover and Landing, American Helicopter Society 57th Annual Forum, Washington, DC, May 9-11, 2001.

3. RTCA, Inc. 2001. Minimum Operational Performance Standards (MOPS) for Integrated Night Vision Imaging System Equipment, final draft dated 12 July 2001. Washington, D.C.: RTCA, Inc., 1140 Connecticut Ave., N.W., Suite 1020.

4. RTCA, Inc., 2001. Concept of Operations Night Vision Imaging System for Civil Operators, final draft dated 3 March 2001. Washington, D.C.: RTCA, Inc., 1140 Connecticut Ave., N.W., Suite 1020.

The technical information concerning the various night vision goggle appliances in this report was obtained from web site sources. Three different search engines were used to locate and view over 500 different web sites with information concerning night vision devices suitable for various uses including aviation. The short list below is representative of the sites where information was obtained for this report.

ITT Industries, Night Vision, www.ittnv.com
Litton Electro-Optical Systems, www.littoneos.com
Night Vision Equipment Company, www.nvec-night-vision.com
Night Vision Equipment, AN/PVS-5C, www.squonk.net
Stano Night Vision Goggles, www.stano.night-vision.com
Night Vision Technologies, www.nightvisiontech.com
DDN, www.defensedaily.com
21st Century Hard Armor Protection Inc., http://www.hardarmorpolicesupply.com
DRB Enterprises, How Night Vision Works, www.drbnightvision.com
Night Vision Optics, Dipol 2MV, www.nightvisionoptics.com
Russian Optical Systems Online Store, www.rosols.com
Night Vision Goggles Dot Com, www.night-vision-goggles.com
First Defense Systems Inc., www.angelfire.com
Simon's Smokehouse, www.nightvisionexperts.com
Lan Optics International, www.russianoptics.com
Alista Ltd., Night Vision SuperStore Online. www.alista.com
T-Quest Optical, www.tquestoptical.com
Star Lazer, www.starlazer.com
DCG Supply Inc., How Night Vision Works, www.nightvisionsupply.com