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Use of Night Vision Goggles Increases in Civilian Helicopter Operations

Technological advances during the past decade have produced night vision goggles (NVGs) that amplify the brightness of a nighttime scene thousands of times. Nevertheless, NVGs have human-performance limitations, including decreased field of view, decreased visual acuity and altered sensitivity to colored lights.

Clarence E. Rash

Since the 1970s, night vision goggles (NVGs; also referred to as night vision imaging systems [NVIS]) have become common in military aviation night operations. As the weight and bulk of NVGs have decreased and their sensitivity and resolution have improved, civilian helicopter operators have incorporated NVGs into their flight operations.[1]

Data are scarce on civilian NVG use, but suppliers of NVG equipment and training say that the number of operators that have purchased NVGs and/or have enrolled pilots in training programs has increased dramatically in the past five years.[2,3,4,5]

Today, most non-military users of NVGs are pilots for law enforcement agencies; others are involved in emergency medical services flights, search-and-rescue work and other flight operations. Some civil aviation authorities have recommended that helicopter operators consider introducing NVGs as aids to visual flight rules (VFR) flight — with NVG-compatible lighting in helicopter cockpits and training for helicopter pilots in NVG use.

For example, the U.K. Civil Aviation Authority (CAA) said, in agreeing to a 2003 recommendation by the U.K. Air Accidents Investigation Branch (AAIB), that CAA would "require police air operator certificate holders to review the safety benefits provided by the use of helmet-mounted … NVGs with a view to the introduction of NVGs for helicopter operations conducted at night in support of the police in areas of limited cultural lighting, particularly in hilly or mountainous regions."[6] The AAIB recommendation was included in a report on a Feb. 17, 2002, accident in which a Eurocopter EC 135 struck the ground on a cloudy night in Scotland. The report said that the accident might have been prevented if the pilot of the law enforcement helicopter had worn NVGs.

Nearly a decade earlier, a 1994 U.S. Federal Aviation Administration report had said that NVGs, "when properly used, can increase safety, enhance situational awareness, and reduce pilot workload and stress normally associated with night operations."[7]

Scott Baxter, assistant chief NVG flight instructor at the Bell Helicopter Training Academy in Fort Worth, Texas, U.S., which first offered NVG special operations courses in 2002, said that safety is the primary reason for the continuing increase in NVG use.

"Pilots who are out there flying around at night without goggles [NVGs] truly understand how dark it is in some of these remote areas," Baxter said. "NVGs let them go out there and see the ground and see the open fields and realize that if the engine fails, they're going to be able to take the helicopter to a field instead of a pond or a creek bed or a row of trees."[8]

Marty Marshall, director of emergency services, director of flight operations and a pilot for Enloe Medical Center in Chico, California, U.S., said that the difference between night emergency medical services (EMS) operations with NVGs and without them is "dramatic."[9]

"It's a huge advantage," Marshall said. "We fly in the mountains, and there are a lot of nights when there's no moon. It was very stressful because it was so dark. Now we can see what we never saw before — the mountains, the flocks of geese. Once pilots put NVGs on, they don't want to go back up at night without them."

Mike Atwood, president of Aviation Specialties Unlimited in Boise, Idaho, U.S., which sells NVGs, conducts training programs for their use, and modifies cockpits with installation of NVG-compatible lighting, agreed that flight safety is the primary motivation of those who want to introduce NVGs into civilian flight operations.[10]

"If you look at [helicopter] statistics since 1990, the number of controlled-flight-into-terrain (CFIT)[11] accidents in night operations in VFR and marginal VFR weather, there are probably 200 fatalities," Atwood said. "Many of these accidents might have been avoided if the pilots had night vision goggles."

Massimo Mazzoletti, rotorcraft and balloons certification manager for the European Aviation Safety Agency, said, "While only limited cues are available to a crew during an unaided night flight, [NVG] usage improves those cues, supplying the crew with an enhanced means of orienting the aircraft … and avoiding terrain and obstructions. Within the boundaries of the [NVG] equipment in use, the flight crew's awareness of the surrounding world and of aircraft attitude is much improved."[12]

Nevertheless, he said that, although the performance and reliability of NVGs and related equipment have improved, "these positive aspects should not make us forget that some disadvantages exist and have to be taken into account."

Those disadvantages include a decreased field of view for pilots wearing NVGs, decreased visual acuity (resolution of detail) and an altered sensitivity to colored lights — all factors that limit performance capabilities.

Visual Acuity, Color Vision Decrease in Darkness

With unaided vision, the eyes function as follows: When a person looks at an object, light coming from the object enters the cornea (the curved front surface of the eye). The cornea bends the light to channel it through the pupil (the black area in the center of the eye) to the lens, which focuses the light on the retina (the eye's innermost lining), where images are processed by two sets of light-sensitive receptors called cones and rods. The images then are transmitted to the brain, where they are interpreted. The cones function best during the day; they provide daylight vision (photopic vision) and the best resolution, and are responsible for color vision. The dimmest light in which the cones can function is equivalent to a night with a half moon. The rods are the primary source of vision in dim light (scotopic vision); they are distributed mostly in the peripheral regions of the retina.[13] The dimmest light level at which rods can function effectively is equivalent to that of an overcast night with no moonlight.

Darkness has an adverse effect on several elements of vision, including visual acuity. In darkness, visual acuity can decrease from a normal level of 20/20 vision to 20/200 vision or less. (People with 20/20 vision [or the metric equivalent of 6/6 vision] have what is considered normal visual acuity; their eyes see clearly at 20 feet [six meters] what someone with normal vision sees at 20 feet. In comparison, people with 20/200 vision [or the metric equivalent of 6/60 vision] see clearly at 20 feet what someone with normal vision sees at 200 feet [about 60 meters].) This effect, in combination with reduced contrast sensitivity resulting from loss of photopic vision, causes a decrease in the ability to detect objects such as other aircraft, obstacles and wires.

Color vision deteriorates when the illumination level decreases below the sensitivity range of the cones. When this happens, blue-green lights appear brighter and red lights appear dimmer than they would with more illumination.

Depth perception, which is essential in determining the height and distance of objects within the visual field, is best with cone vision, which is dominant during daytime illumination levels. As illumination levels decrease, the ability to judge distance decreases; this can lead to visual illusions.[14]

Glare (uncomfortably bright light) and flash blindness (a temporary vision impairment that follows a brief exposure to bright light) can interfere with the ability to detect or to identify an object, especially in darkness.[15]

A unique trait of night vision (at illumination levels below those of dim starlight) is the presence of a central blind spot.[16] The part of the retina responsible for the best visual acuity is the fovea, which is located at the center of the retina and has a high density of cones and no rods; therefore, if the illumination level is below the cone sensitivity threshold, a small object in the central one-degree of the visual field cannot be seen.

Military Led Night Vision Enhancements

Historically, military forces have led efforts to improve the effectiveness of aviation operations in darkness. One of the first modern techniques to enhance night vision was the use of searchlights during World War I. Searchlights were simple and effective. Nevertheless, they were difficult to transport and to set up, required large amounts of electrical power to operate and made their users vulnerable to attack, because opposing forces could easily detect them — a disadvantage inherent in any *active* night vision enhancement technique (i.e., a technique that generates visible light).

During World War II, searchlights were modified with infrared filters that blocked visible light and allowed the passage of only near-infrared radiation (energy). A simple image converter tube — a precursor to the primary imaging element of NVGs — was used to view the illuminated scene. Initially, these devices were difficult for opposing forces to find; nevertheless, opposing forces were able to develop similar devices to detect the lights.

Later, image intensification tubes were developed using a passive technique (i.e., a technique that intensifies [amplifies] all available light, including moonlight and starlight)[17] to allow the human eye to see more easily during darkness or low light. The quality of the resulting image depends on the level of amplification by the image intensification tubes and the level of available light. (Image intensification devices do not function in total darkness; some light must be present.)

First-generation image intensification devices (GEN I) were introduced by the U.S. military in the mid-1960s and were used by the infantry for night observation and reconnaissance missions (Table 1). Early in the 1970s, the U.S. Army tested a modified version of a second-generation (GEN II) helmet-mounted image intensification device for aviation use; these devices were the first to be identified as NVGs. In the mid-1980s, third-generation (GEN III) image intensification tubes — capable of being operated at starlight levels and of amplifying the brightness of a night scene thousands of times — were introduced. Further improvements have resulted in enhanced third-generation (GEN III+) tubes.[18] Most NVGs in use today use GEN III+ or GEN III image intensification tubes and sell for about US$9,000 to $10,000.

Image Intensification Tubes Have Three Basic Components

The basic components of an image intensification tube are a photocathode, a microchannel plate (MCP) and a phosphor screen (all within a vacuum envelope). Light from the scene being viewed is collected by an objective lens (the light-gathering outer lens on NVGs, as opposed to the eyepiece, the lens nearest the eye) and is focused upon the photocathode, a light-sensitive material that, when struck by incoming photons of light, emits electrons proportional to the amount of light striking the photocathode from each point in the scene. The emitted electrons are accelerated toward a phosphor screen by an electric field. The path toward the phosphor screen is through an MCP — a glass plate with millions of microscopic holes (channels). Each channel in the MCP corresponds to a picture element (pixel) in the final image. Within the MCP, the number of electrons is increased (amplified), producing 1,000 or more electrons for every incoming electron. These electrons strike the phosphor screen, producing photons of light that create an intensified image viewed through the eyepiece.

The NVG-intensified image is similar to a black-and-white television image but appears in shades of green, instead of shades of gray.[19]

As cost has decreased and availability has increased, new products have proliferated that incorporate image intensification tubes in binoculars (for use by both eyes), monoculars (for use by one eye), pocket scopes and tubes mounted on cameras.[20] NVGs used in aviation consist of two image intensification tubes with associated optical lenses that are mounted in a binocular arrangement and are attached to a helmet (photo, page 4).

NVG Characteristics Determine What Can Be Seen

What can be seen through NVGs and what cannot be seen is determined by several specific characteristics of the NVGs including the following:

- The typical field of view (the area that is visible through NVGs, or any viewing device) through each of the image intensification tubes in NVGs is a circular, 40-degree field of view. The parallel alignment of the two tubes produces

Table 1
Generations of Image Intensification Tubes[1]

Generation (GEN)	Characteristics
GEN I	Introduced in mid-1960s. Oldest technology; considerable distortion, short tube life.
GEN II	Introduced in late 1960s. Incorporated microchannel plate (MCP)[2]; provided improved gain,[3] smaller size.
GEN II+	Introduced in 1970s. Improvements in gain, resolution. (+ indicates enhanced.)
GEN III	Introduced in 1980s. Significantly improved gain and spectral sensitivity in the near-infrared region; improved MCP; improved photocathode.[4]
GEN III+	Introduced in 1990s. Slight improvements in photocathode; improved gain, resolution. (+ indicates enhanced.)

[1] Image intensification tubes are the basic components of night vision goggles (NVGs). They intensify reflected light or emitted light to allow the human eye to see more easily in near-darkness or low light.

[2] A microchannel plate (MCP) — a glass plate containing millions of microscopic holes (channels) — is a major component of an image intensification tube.

[3] Gain is a measure of how the image intensification tube multiplies the input signal level.

[4] A photocathode — a light-sensitive material that converts photons of light into electrons — is another major component of an image intensification tube.

Source: Clarence E. Rash

Night vision goggles use image intensification tubes to amplify existing light to allow the human eye to see more easily in darkness. (Photo: Aviation Specialties Unlimited)

a 100 percent overlap of the right image and left image for distant viewing; thus, the total field of view is 40 degrees. A single human eye has a field of view that is oval and extends approximately 120 degrees vertically and 150 degrees horizontally. When both eyes are used, the overall human field of view extends approximately 120 degrees vertically and 200 degrees horizontally;[21]

- The resolution (resolving power, defined as the ability of an optical system to reproduce the points, lines and surfaces [the details] of objects within a scene)[22] of the most advanced NVGs can provide for visual acuity of 20/25 (6/8) under optimal flight conditions. Visual acuity with NVGs — like visual acuity with unaided eyes — is affected by altitude and airspeed. Crews of helicopters that are flown below 200 feet above ground level and at airspeeds of less than 150 knots benefit the most from the use of NVGs. At flight altitudes above 300 feet and at faster airspeeds, visual acuity with NVGs diminishes and provides less night-vision enhancement;[23]

- Distortion is a variation in magnification across an image. If a straight line is viewed through an optical medium that has a moderate level of distortion, the straight line appears wavy or broken. Distortion is measured at 1 percent or less in third-generation NVGs; it has become less likely since the development during the mid-1990s of more precise specifications for image intensification tubes.[24,25] Excessive distortion may result in illusions, such as poor distance estimation and a false perception of motion;[26]

- Luminance uniformity is the presence of a relatively constant amount of light across the field of view. A uniformity variation of less than 20 percent usually is acceptable;

- Although many image intensification tube characteristics are not easily perceived when viewing through NVGs, one characteristic is quite apparent — image noise, defined as false and detrimental information within the imagery. Image noise, which is less common in third-generation NVGs than in earlier equipment, can be constant and fixed in position within the image (fixed pattern noise) or random in both position and time. A common fixed-pattern noise is a faint hexagonal (honeycomb) pattern. Image noise is a result of the structure of the MCP and is most prevalent under high light levels.

  Random noise results from scintillations, a random, often faint, sparkling effect present throughout the image. Sometimes referred to by users as video noise, it also is a normal characteristic of the MCP and is more pronounced under low-light-level conditions; and,

- Other characteristics of NVGs that can result in decreased visual performance include mismatches between the two image intensification tubes in magnification, orientation, luminance and alignment of optical axes. For example, disparities between the two image intensification tubes can prevent the human visual system from incorporating the two inputs into one image. This results in either double vision, suppression of one of the inputs, or eye fatigue, nausea and/or headaches after prolonged viewing.

Manufacturing processes can create other defects:

- Black spots (dark spots) are usually cosmetic blemishes of various sizes in the image intensification tube, but they also can be dirt on the image intensification tubes. If the black spots are small and not overly abundant, they may not adversely affect pilot visual performance; if they are larger and more numerous, they may be visual distractions and may mask the presence of other aircraft;[27] and,

- Halos (similar to the rings of light that sometimes appear to encircle street lamps) can be seen when a light source is viewed through NVGs. The intensity of the halo is determined by the closeness of the light source and the ambient lighting environment. Halos can obscure objects near the location of the light source and can interfere with distance estimation.[28]

NVG Imagery Has Limitations

NVG imagery has limitations that affect many aspects of visual performance.

For example, there is a likelihood that binocular depth perception and distance estimation may be degraded when NVGs are used. The ability to estimate distance and rate of closure is associated with stereopsis (the ability to perceive relative differences in the distances of objects resulting from viewing with both eyes) and depth perception (the ability to judge one object's position with respect to another object, based on both monocular cues and binocular cues).[29] *Theoretically*, stereopsis is possible when viewing through NVGs because the two image intensification tubes produce two images that are viewed at the normal separation distance of the eyes.[30]

Almost since their introduction into aviation, image intensification devices have produced a number of visual phenomena that have annoyed pilots and have caused visual effects that have contributed to accidents.[31]

Among the annoying phenomena is "brown eye syndrome" — brown vision or pink vision that occurs for a short time after extended use of NVGs — reported by pilots in the early 1970s. "Brown eye syndrome" was a misnomer; the problem later was identified as an afterimage that resulted in no damage to the eyes. The cause was the eye's adaptation to the green output of the NVGs' phosphor.

In 1989, a study of visual illusions associated with NVGs documented reports of pilots who experienced the illusion of landing their helicopter in a hole or a depression when the aircraft actually was approaching a flat landing site.[32] Some pilots reported that they experienced the illusion that the helicopter was drifting or that they failed to recognize that drift was occurring. Pilots also reported that movement of the head while scanning could cause the illusion of trees bending.

A more significant visual performance risk associated with NVGs is spatial disorientation, defined as loss of situational awareness regarding the position of the aircraft or the motion of the aircraft. Spatial disorientation has been found to be a major contributor to military aviation accidents in which NVGs were being used. For example, between 1987 and 1995, data show that NVGs were used in 37 percent of U.S. Army helicopter accidents in which spatial disorientation was considered a major factor; depth perception and limited field of view often were cited as causal factors.[33]

Visibility With NVGs Is About 1,100 Feet

Visibility with GEN III+ NVGs on a night with a quarter moon is nearly 1,100 feet (336 meters), although this varies, depending on lighting level, weather conditions and contrast. (By comparison, visibility with GEN III NVGs is about 925 feet [282 meters]). Overconfidence in NVG imagery can cause a pilot to "over-fly" the visual range (i.e., to fly the helicopter faster than his or her reaction time will allow the detection and avoidance of obstacles). For example, a helicopter being flown at 80 knots travels 1,100 feet in about eight seconds.

Although a pilot using NVGs may be able "see through" light rain, light fog and thin clouds, image quality generally is degraded by rain, sleet, snow, clouds, mist, smoke and fog. An inadvertent entry into instrument meteorological conditions is possible. In such situations, NVG imagery can deteriorate or be lost completely.

Landing in dusty areas or sandy areas can result in a condition called a "brownout," in which clouds of disturbed dirt or sand obscure all visual cues; a similar condition, a "whiteout," can occur in snow.[34] NVGs cannot help a pilot see into shadows and cannot aid in the detection of power lines.

Some military helicopters pilots use a head-up display (HUD) when using NVGs to help maintain situational awareness during conditions such as a brownout. The HUD provides information such as altitude and attitude, overlaid on the NVG imagery so that a pilot can observe the information while maintaining visual attention outside the cockpit.

Equipment Weight Contributes to Fatigue

Use of NVGs increases head-borne mass (weight placed on the head) by about 1.2 pounds (0.5 kilogram). Additional mass may be required to achieve a suitable mount to attach the NVGs to the helmet. Increased head-borne mass can cause neck muscle strain and fatigue and can increase the risk of neck injury in an accident.

The additional weight placed on the head by the NVGs and the mount is not centered but is shifted forward on the head. To balance the additional weight, some military pilots add counterweights to the back of their helmets, further increasing the head-supported mass. A survey of U.S. Army helicopter pilots found an average added counterweight of 0.8 pound (0.4 kilogram), with a range of 0.6 pound to 1.4 pounds (0.3 kilogram to 0.6 kilogram).[35] This implies that some pilots wore helmets with a total NVG-added mass of as much as 2.5 pounds (1.2 kilograms).

To reduce loading on the neck and head and thereby reduce the risk of neck injury during accidents, NVG mounting mechanisms are designed to break away at load levels between 10 g (i.e., 10 times standard gravitational acceleration) and 15 g. To further reduce possible facial injuries, breakable NVG components must be constrained.[36]

User Adjustments Are Important

NVGs are equipped with several mechanical adjustments and optical adjustments that, if improperly set, can degrade image quality and user performance (see "NVGs Require Care, page 6).[37] For example, the fore-aft adjustment setting (typically 0.6 inch to 1.1 inches [16 millimeters to 27 millimeters]) can affect field of view; when this adjustment is at the optimal sighting-alignment position (the maximum viewing distance that provides the full field of view), increasing the fore-aft distance from the eye proportionally decreases the field of view.[38]

NVGs have a vertical tilt adjustment of approximately eight degrees; tilt should be adjusted according to the wearer's seat

NVGs Require Care

The following are guidelines for proper handling of night vision goggles (NVGs):

- Ensure that NVGs are turned off before replacing batteries;
- Protect the objective lenses and eyepiece lenses from moisture, dust and large fluctuations in temperature;
- Store NVGs in their protective case;
- Do not operate NVGs in daylight without covering the objective lenses;
- Do not try to modify or repair NVGs; and,
- Never touch the objectives lenses with bare fingers; use lens-cleaning paper instead.

The following are guidelines for preflight procedural checks of NVGs:

- Remove loose dirt and dust from lenses with a soft brush. If necessary, use moist lens-cleaning paper;
- Check interpupillary device (IPD) setting;
- In a dark area, don NVGs and turn on power;
- Center the field-of-view using the vertical adjustment;
- Level NVGs using the tilt adjustment;
- Adjust the focus using a target at least 20 feet (six meters) away;
- After becoming seated in the aircraft, adjust the fore-aft position of the NVGs to the optimum position. Confirm look-under capability, moving fore-aft position forward as little as possible.♦

— Clarence E. Rash

position relative to the line of sight and flight. Maladjustment of tilt has little effect on the effectiveness of NVGs, but the field of view may be displaced.

The interpupillary distance (IPD; the distance between the pupils of the eyes) can be adjusted from about two inches to three inches (51 millimeters to 76 millimeters). Misalignment of the IPD setting (the distance between the two image intensification tubes, which should match the distance between the two eyes) decreases the field of view in the direction opposite the direction of tube movement. This results in a reduced binocular field of view but does not decrease the total horizontal field of view.[39] IPD maladjustment has been associated with reduced depth perception.[40]

Both the eyepiece and the objective lens of NVGs must be adjusted for optimum visual acuity. The objective lens focus is independent of the eyepiece focus and functions similarly to the focusing mechanism on a typical camera. The eyepiece focus adjustment is used to compensate for the pilot's (minor) refractive error. If crewmembers require corrective lenses for flight, NVGs do not preclude the need for those lenses. Pilots generally adjust to improper focus settings, but prolonged flight can lead to eyestrain, blurred vision and/or headache.

Aircraft Lighting Presents Unique Challenges

NVGs function best in high-light-level conditions with high-contrast objects and in cockpits equipped with lighting that is compatible with the use of NVGs. Because NVGs are designed to filter out light in the blue spectrum, NVG-compatible lighting produces blue-green light; this light is visible to the unaided eye but is not visible through NVGs.

In the cockpit, flight instruments, floodlights, console lighting, warning and advisory signal lamps, jump lights, electronic displays and electro-optical displays, and auxiliary lighting devices such as flashlights can interfere with the use of NVGs. All lights within the cockpit, even those that are used briefly, must comply with the requirements for NVG-compatible lighting; if the helicopter is not manufactured with NVG-compatible lighting, the cockpit can be modified with installation of compatible lighting and/or light filters. The cost of cockpit modification varies, according to the complexity of the aircraft. For example, modification of a Bell 206 costs about $20,000, and modification of a Bell 412 could cost as much as $40,000 to $50,000.[41]

Without NVG-compatible cockpit lighting, a pilot using NVGs unknowingly may be operating with less than optimal "gain" and, therefore, with impaired visual performance. (Gain is a measure of how the image intensification tube multiplies the input signal level.)

NVG-modified exterior lighting must be visible to the crews of other aircraft not using NVGs, but the lighting must not emit excessive light energy within the spectral sensitivity wavelength range of NVGs because this would interfere with their performance.

Any bright light source within the viewing area can overpower the image intensification tubes, producing high levels of veiling glare (scattered light in an optical system that results in reduced contrast and reduced resolution), which can damage the image intensification tubes. Thus, NVGs are equipped with a bright-source-protection (BSP) circuit, which decreases the gain of the image intensification tubes when they are exposed to bright lights. (The BSP is designed to maintain a steady output signal level even when the input signal level fluctuates; this minimizes damage to the tube caused by high-input illuminations. The tube's automatic brightness control limits the average output brightness to a predetermined maximum value.)

Most aircraft windshields are not designed for the effective use of NVGs. Some windshields absorb light in the near-infrared part of the light spectrum where NVGs are most sensitive; the result is a reduction in the effective gain.[42]

Next Generation Expands Field of View

The U.S. Air Force and U.S. Army are developing panoramic NVGs[43] using four image intensification tubes designed to provide a 100-degree by 40-degree field of view. This design includes a circular central binocular 30-degree field of view (derived from the center two tubes) and two 35-degree fields of view (seen by the right eye or left eye). Using special smaller and lighter-weight objective image intensification tubes, the head-supported weight of panoramic NVGs (estimated at 1.25 pounds [0.57 kilogram]) would be slightly more than that of NVGs now in use.

Rules and regulations for use of NVGs also are being revised. In 2001, a multinational advisory committee of RTCA (organized in 1935 as the Radio Technical Commission for Aeronautics but now known only by the abbreviation) recommended guidelines for NVG use in civilian flight operations. The guidelines have provided a framework for the continuing development in Europe and North America of NVG-related regulations, including associated requirements for training and aircraft lighting.

Despite advances in NVG technology in recent years, performance limitations remain. Nevertheless, an understanding of those limitations — combined with experience and regular training in the use of NVGs — is expected to contribute to the continuing increase in the use of NVGs as worthy safety tools in civilian helicopter operations.

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