

Civilian Use of Night Vision Goggles

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Civil aviation operators have expressed an increased interest in conducting night operations with night vision imaging systems. The development of special operational concepts, hardware requirements, training requirements, and regulatory change and oversight is necessary to control for the known performance constraints associated with these devices. In 2001, the Aerospace Medical Association initiated an internal request to review the human factors issues concerning the use of night vision goggles (NVGs) in civilian flight operations. This paper provides some basic information on night vision imaging systems to highlight the Association's position for supporting the appropriate use of NVGs in civilian aviation while concurrently expressing the need for a judicious and studied approach to their deployment.

Keywords: night vision goggles, NVG, civilian flight operations.

CIVIL AVIATION operators have expressed an increased interest in conducting night operations with night vision imaging systems, specifically night vision goggles (NVGs). However, NVGs have known performance limitations and at a minimum would require the Federal Aviation Administration (FAA) and international aviation authorities to develop special operational concepts, hardware requirements, and training requirements, along with regulatory change and oversight. In 2001, the Aerospace Medical Association* initiated a review of the issues concerning the use of NVGs in civilian flight operations. This document is not intended to be a detailed technical discussion of NVGs, nor will it discuss other night vision systems such as forward-looking infrared. The paper will, however, provide some basic information on NVGs to highlight the Association's position supporting the appropriate use of NVGs in civilian aviation while concurrently expressing the need for a judicious and studied approach to their deployment.

BACKGROUND

Since the introduction of the first night vision devices in the 1930s, design improvements have decreased their size and weight, improved their resolution, and increased their reliability. These devices have become indispensable for a variety of night operations, both civil and military.

The early imaging devices were cumbersome and required use of powerful infrared lamps, hence making them "active" systems. However, those early devices were replaced in the 1960s by "passive" devices utilizing image-intensifying technology. Current aviation

NVGs are highly efficient, operating on batteries and weighing between one and two pounds. They are capable of intensifying electromagnetic energy greater than 35,000 times, and may provide an aided visual acuity as good as 20/40 under optimal conditions. In spite of the fact that development was driven by military requirements, civilian uses for these devices have greatly expanded in the last decade.

In 1971, the U.S. Army introduced NVGs for aviation. The enhanced effectiveness of nighttime flight operations afforded by the use of NVGs created a demand for these devices by civil operators who have round-the-clock flight requirements. Specific applications include airborne emergency medical service (EMS) operators, pipeline and powerline surveillance crews, and news teams. In 1989, Rocky Mountain Helicopters, an air ambulance operator, requested a supplemental type certificate (STC) from the FAA to use NVGs during single-pilot EMS operations. In an attempt to better understand the possible impact of these devices, the FAA commissioned several technical reports on the subject of civil use of night vision devices in flight operations (2,3,4,6). However, no decision on approval of an STC for Rocky Mountain Helicopters was reached.

In 1996, Rocky Mountain Helicopters again approached the FAA with a plan to use NVGs. Based on the previous technical reports, the FAA identified several critical issues concerning the civilian use of NVGs such as pilot certification standards, training requirements, cockpit and external aircraft lighting requirements, and continued air-worthiness of both the lighting and the NVGs. In January 1999, after Rocky Mountain Helicopters satisfied the FAA that it had an adequate plan to deal with these concerns, the agency

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issued the first STC to permit the use of NVGs by a civilian helicopter operator. Since then, other STCs have been approved and several more are pending approval. Nevertheless, a larger issue remains unresolved, that of widespread use of these devices by people other than commercial pilots. Several attempts to issue a Notice of Proposed Rulemaking to permit use of these devices by private pilots under Part 91 of the Federal Aviation Regulations have failed because of significant concerns over safety and other regulatory issues.

The FAA needed to decide how best to approach the use of this expanding technology. In 1999, the agency asked the Radio Technical Commission for Aeronautics, Inc. (RTCA), a private, not-for-profit corporation that serves an advisory function to the FAA, to look into the matter. RTCA Special Committee SC-196 was formed "to bring the industry and the FAA together to develop appropriate requirements that can be used within the FAA, as well as other governments and organizations." Membership included representatives from the government, military, industry, Europe, and Canada. Their findings and recommendations for implementation of night vision imaging systems by civilian operators in the national airspace system were issued in March 2001 (1) and in October 2001 (5).

Relevant NVG Technology Issues

Night vision goggles designed for aviation use are electro-optical systems consisting of two monoculars with identical optical trains and functions. Each monocular has an objective lens, an image intensifier assembly, and an eyepiece lens. The objective lens collects the ambient light-energy (e.g., moon, stars, man-made or cultural lighting, etc.) reflected from the scene, and focuses the image on the image intensifier. Inside the image intensifier, a photocathode converts the energy to electrons, a microchannel plate amplifies the electron image, and the electrons then strike a phosphor screen. The phosphor screen creates a visible image, which is turned right-side-up by a fiber optic twister (the image had been inverted by the objective optics). The fiber optic twister transmits the image to the eyepiece lens where the operator can see the intensified image in its proper 1:1 perspective (unity magnification). The resultant image is monochromatic (shades of green) and is 40° circular. This design has been used in military aviation since the 1970s and is recommended for civilian use in the Minimum Operations Performance Standards (MOPS) (5).

Any bright or near light sources that enter the NVG intensification process can cause image problems, affect the automatic gain (power) control, and degrade image quality. In order for cockpit lighting not to cause these types of problems, military NVGs incorporate one of three types of objective filters. The Class A filter is the original filter incorporated and it has a fifty percent cutoff at 625 nm, which means energy below (shorter) than 625 nm is filtered from entering the image intensifier. This meant that colors other than blues and greens (e.g., yellow, orange, red) would pass through the filter and enter the intensification process. To allow more colors in the cockpit (an important consideration

with increased use of color displays), a Class B filter was developed that would block energy below 665 nm. This allowed for more yellows and orangish-reds to be used in the cockpit lighting design without adversely affecting the goggle image. Later a notch or pass-band filter was added to the Class B filter, which allows approximately 1% of the green energy around 550 nm (green) into the intensification process. This is called a Modified Class B filter, and was developed so pilots would be able to see a fixed head-up display symbology and imagery in the NVG image. The MOPS (5) recommends that NVGs approved for civilian use incorporate either Class B or Modified Class B objective filtration.

Aircraft interior and exterior lighting must be modified for the safe and effective use of NVGs. As discussed, the NVG has an objective filter that eliminates certain wavelengths from entering the intensification process. Since blues and greens are filtered, most lighting designs compatible with NVGs make use of these two colors. Since green focuses on the retina more readily, it has been chosen as the color for most systems, and the military developed specifications providing specific guidance for the use of these colors based on coordinates in appropriate color charts. However, color is only part of the consideration when designing night lighting systems. The NVG is sensitive to near-infrared energy, which is not eliminated by the objective filter. Consequently, any night lighting design needs to also include methods for eliminating the near-infrared energy from all light sources, which can sometimes be complicated given that there are various types of light sources in most cockpits (e.g., CRT, incandescent, LED, etc.). Exterior aircraft lighting considerations for civilian aircraft are centered around the location of the lights and whether or not the energy would reach the NVG and degrade the image (e.g., reflections in the cockpit from the strobe light, etc.). Modifications to exterior light components (e.g., position lights, landing lights, etc.) to make them NVG-compatible are also very important and addressed in section 4.4.2.4.1 of the MOPS (5).

NVG Human Factors Issues

Some human factors issues relevant to NVG design and use include: image field of view; field of regard; system resolution and aided visual acuity; image peculiarities resulting from the optics and the image intensification process; increased operator workload; and the integration of the NVG mounting system. Each of these is described in some detail below.

Field of view: The field of view of NVGs is considerably less than that provided by normal aided vision and requires the user to scan the outside scene constantly in order to maintain an accurate visual picture. This can result in physical and mental fatigue over time and may contribute to spatial disorientation unless the outside scan is integrated with a routine crosscheck of flight instruments. Additionally, there is a significant reduction in ambient (peripheral) vision, which has the potential for exacerbating spatial disorientation in the absence of adequate outside visual cues and a dedicated instrument crosscheck.

Field of regard: The field of regard is defined as the

total area that an operator can view while scanning with the NVG. The field of regard available to an operator using NVGs is dependent on the NVG field of view, when coupled with the crewstation design (e.g., presence of structures that impede outside viewing, seating layout, forward visibility over the instrument panel, etc.), aircraft design (e.g., low or high wing, etc.), and restrictions to operator movement (e.g., seat design, shoulder harness restrictions, etc.).

Image resolution: When discussing the operational use of NVGs, the image resolution is typically described in terms of NVG-aided visual acuity (VA). Consequently, for testing and for training descriptions, letter-chart or SNELLEN acuity is utilized. Although many people tend to compare NVG-aided VA to photopic (light-adapted) VA, the appropriate comparison is with unaided scotopic (dark-adapted) VA. Military experience, for example, has shown that a typical NVG used in aviation has a useable aided VA in the neighborhood of 20/40 (considering good illumination, a proper adjustment, compatible cockpit lighting, and no adverse impact from windscreens or windows). This compares to an unaided scotopic VA of 20/200 at best, which means that aided vision is at least five times better than unaided vision given the stated variables. Of course this will depend on the values of the variables, but on average NVGs will provide the operator with improved vision during nighttime operations. When compared with photopic vision, it is obvious that NVGs will perform at best, half as well if compared with an operator with 20/20 vision. This is important mainly from a training perspective in getting the operator to understand that aided vision is not the same as photopic vision.

One of the shortcomings in using resolution and VA as the main source of describing image performance is the absence of other variables such as contrast, chromaticity, and the wide variation among individuals in their mesopic vision capability. It has been noted during NVG testing that, at times, aided VA may not change during a lowering of illumination while a significant change is noted in contrast discrimination. This has a relevant impact when operating over low contrast areas such as water or the desert, when the lack of contrast variation in the image can have an adverse impact on depth perception and distance estimation. The brightness of the NVG image results in the operator using mesopic vision to view and interpret the image content. The wide variation in mesopic vision capability likely means that some people may not see as much detail in the image as others. Some of these issues have been studied to varying degrees, but others have not been adequately addressed.

Image intensification effects: Effects secondary to the image intensification process that have an impact on operator interpretation include, but are not limited to the following: point light source halos, blooming effects, gain effects on image quality, interpretation of distances to and between light sources, and viewability through some weather conditions. Of these, the last three pose the most problems with operator interpretation. As the illumination level changes, the system gain

will adjust the image brightness, and gain limitations will result in a reduction of image quality as the illumination is reduced to low levels. Distances to and between point light sources in the image (e.g., aircraft exterior lights, ground-based vehicles, environmental lights, etc.) are difficult to accurately assess, and inaccurate assessments have resulted in mishaps. Since the image intensifier is sensitive to near-infrared energy, and since this energy passes through light moisture (e.g., light fog) more readily than visible energy, it is possible for the operator to inadvertently enter degraded weather conditions. This has been a known problem for years during military operations and has been the cause of several mishaps. On the other hand, the ability to see through some types of moisture has provided great benefit under some operating conditions (e.g., emergency landing during obscured weather conditions).

Increased workload: In order to interpret the NVG image, the operator must use focal vision, which requires conscious thought. This may compete with other tasks also requiring focal attention, such as interpreting flight instruments, communications within and outside the aircraft, chart reading, and navigating. Generally speaking, the more difficult the operation, the more likely task-shedding will occur. Since vision is such a strong sense and one on which operators rely, it is probable that operators occasionally will depend on the visual image too much and shed other critical tasks such as an instrument crosscheck. This has been documented many times during military mishap investigations.

Helmet/mount/NVG integration: The fit of the helmet ultimately has an effect on correct NVG image placement, stability during operations, and comfort during extended NVG use. Counterweights, integrated nape/chin straps, flexible tubing, and tightly fitting oxygen masks have all been used to help stabilize the NVG and provide a comfortable system during operations. However, some of these will not be available (e.g., oxygen mask) or should not be considered for use (e.g., flexible tubing strapped to the helmet and affixed to the overhead). A counterweight system will help offset the forward center of gravity effects of having the NVG attached to the front of the helmet, but at the cost of added weight. A helmet designed with an integrated nape/chin strap will provide added helmet stability, especially given the lack of excessive Gs expected in the expected civilian operating profile. However, the most critical consideration in stability and comfort is helmet fit. The helmet must be fitted to the individual operator. Once that is accomplished, a properly designed mount can be effectively located in order to ensure the NVG image can be correctly positioned. If a helmet is not used, these critical stability and positioning issues should be taken into consideration in the design of a head mount system.

Night operations: Since NVGs are used at night, all issues relevant to night operations are applicable (e.g., fatigue and circadian rhythm). Though the specific interaction effects of NVG use and fatigue are not well documented it should be assumed that degradation in

performance would occur as found with night operations in general. As previously noted, the use of NVGs may increase pilot workload, which may then exacerbate these other considerations and increase the operators susceptibility to task shedding, poor decision making, decreased communications and crew resource management, spatial disorientation, etc.

Important Aeromedical Considerations

As with military operations, several important operational and human factors issues must be considered for civilian flight operations with NVGs. Some of these issues are common to both military and civilian flight operations: NVG equipment maintenance, the impact of weather and other environmental conditions, light level impact on terrain detail, aircrew coordination, pilot and non-pilot aircrew training and certification, and appropriate aircraft internal and external lighting, to list a few.

Other issues, however, may be unique to the civilian environment, for example, visual pathologies, health status, screening and selection of NVG users, or the wide variation in maintenance and training practices among different NVG operators. It must be anticipated that each civil operator's particular circumstance for requiring NVG use will present unique challenges that will need careful consideration. The following list is by no means complete, but introduces some of the most important topics.

Vision: Discussions of NVGs and vision invariably address issues related to acuity, contrast sensitivity, field of view, monocular and binocular depth perception, and stereopsis. Extensive research of visual physiology already exists to document the impact of NVG use on vision; however, an area that will be mentioned later and may not have been adequately studied is the impact of visual pathology on goggle use.

The primary source of aviation NVG experience rests with studies conducted with military aircrew, which is a highly select group of users with well-defined health and vision standards. This raises questions about generalizing the military experience to a civilian population with a much broader range of visual and other health problems. For example, all the military experience with NVGs is based on the assumption that the operators have 20/20 vision (natural or corrected). In the U.S., Title 14 Code of Federal Regulations (14 CFR) Part 67 permits pilots with a third-class airman medical certificate, i.e., general aviation, to fly with near and distant visual acuity of 20/40 or better. The regulation also permits select monocular pilots to continue flying even in commercial and air transport operations. But it is not well understood how pilots with less than 20/20 vision will be able to interpret the NVG image in flight. And since some pilotage requires unaided binocular vision (e.g., while hovering, landing in close quarters, etc.), the currently written MOPS (5) require civilian pilots applying for NVG use to have both 20/20 and unaided binocular vision. This is certainly one area of research that needs to be undertaken in order to address what will surely be a future issue.

Maintenance: To ensure optimal performance, night

vision devices must be meticulously maintained, preferably in specialized maintenance facilities. The military has invested substantial resources to ensure this is the case for the equipment it has purchased. This factor could present a significant problem in civilian environments and may lead to wide variations in maintenance practices and equipment reliability. The MOPS (5) section on Continued Airworthiness addresses these concerns though it is recommended that the maintenance issues be carefully reviewed to ensure comprehensiveness.

Weather and Seasonal Changes: As discussed previously, an operator may be able to "see through" some forms of weather such as light fog, thin clouds, and very light rain. Consequently, an operator could inadvertently enter instrument meteorological conditions, which could result in sudden and unexpected degradation to or loss of the NVG image. If not prepared and/or if not proficient at instrument flying, this in turn could lead to spatial disorientation and loss of aircraft control. Changes in seasons also have an impact of NVG usage. For example, during the summer, the hours of darkness are shortened. This results in flights late into the night and early morning, which may affect fatigue and work/rest cycles. Additionally, the latitude at which NVGs are used may have a significant impact on usability during certain times of the year. For example, in Alaska, the sun may not descend very far below the horizon for extended periods of time making it difficult to look toward the western horizon with NVGs.

Crew Resource Management: Military experience demonstrated that communication among crewmembers is made even more difficult when some members are using NVGs and others are not; a highly likely scenario in civilian operations. This issue is addressed in a training document that is currently in development.

Training: The U.S. armed forces have all developed rigorous training and refresher training programs to prepare personnel in the use of NVGs. Similarly, as part of the civilian approval process, in the U.S., all current civilian operators utilizing NVGs had to develop and maintain curricula for initial and refresher training of their pilots. However, there is not at present, general training guidance for those applying or wanting to apply. Training is a crucial requirement for the civilian sector, and one that may prove difficult given the wide variation in pilot experience levels and types of operations. Additional consideration must be given to the initial (and potentially great) costs associated with setting up and maintaining a training program. Cost savings at the expense of initial training and refresher training program requirements should be avoided. Lessons learned from the military demonstrate that a good training program is vital if mishaps are to be avoided. This may be even more important in the civilian environment where the level of control may not be as rigorous (e.g., ensuring quality of training programs, control of students entering NVG training).

Preflight Planning and Operating Procedures: Preflight planning should include a careful consideration and appreciation of the special characteristics of the opera-

tional environment that will impact NVG use. Such considerations should include illumination levels, weather, moon angles, environmental lighting, terrain types, and cultural features. Preflight planning should be tied to the event, and, although a generic preflight planning guide can be generated, it will not cover every situation for every operation. Given the varying requirements of civilian operators, the development and implementation of standardized operating procedures for particular flight operations will be extremely difficult if not impossible. While large-scale operators may have the financial and operational capabilities to provide some degree of standardization in flight operations, smaller operators or consortia of like-operators may not.

Testing of NVG-compatible Interior Lighting: The MOPS (5) provides guidance for the design of night interior lighting. However, the test procedures provide for a wide range of methodologies, some of which are not very rigorous. Also, it is not evident how the FAA will take these recommendations and develop regulations governing the testing of modified lighting systems. For example, who will be responsible for training the test personnel, where will they be located (Fixed Base Operator, etc.), who will be responsible for examining and certifying test sites or transportable test capabilities, and how often will these test sites be examined after being certified? These are important issues due to the many types and models of aircraft in civil aviation, which makes it impossible to develop a "standard" interior lighting kit that could be easily tested and controlled. Also, since the FAA likely will not be certifying night lighting vendors, the only method for ensuring compatibility and compliance with the MOPS is to perform rigorous testing (more than that currently described in the MOPS).

Medical Standards: Medical standards and personnel selection standards are closely related. Military aircrew must meet well-defined medical and performance standards. As such, the population of military NVG users is relatively homogenous in terms of age, good health, and absence of significant visual pathology. As alluded to earlier, this will not be the case with civilian pilots (e.g., pilots with cataracts or lens implants/IOLs). There may be a general tendency to separate military experience with projected civilian use, but regardless of the difference in operation requirements, strict medical standards must be maintained.

Significant variations in general health and visual pathology exist among licensed civilian pilots. The experience base for how these pathologies impact NVG use may not be fully known given the good health of military aircrew. For example, what is the impact of color vision anomalies, in particular if they happen to coincide with the spectral output of the NVG phosphor? Or what is the impact of cranial or cervical pathology on the user's ability to sustain the added weight for long periods of time? It is also important to note that depending on the class of medical certificate issued, 20/20 vision may not necessarily be a requirement for civilian pilots. Also, the importance of these issues may vary internationally due to differences in visual acuity/

color vision requirements. Additionally, the FAA does not medically certify civil aircrew other than pilots, an important consideration to note particularly when these individuals might be providing flight guidance to pilots during critical phases of flight such as hover in confined spaces. The introduction of NVGs into more diverse user groups will invariably require careful evaluation.

Future Regulatory Issues

The introduction of NVGs in the National Airspace System and in international aviation will undoubtedly raise a number of questions concerning accountability, legal responsibilities, authority, and control. For example, the issue of deployment of NVG-compatible lighting on/in aircraft or for helicopter landing sites, or the question of enforcement actions for operators who do not comply with NVG maintenance or training requirements, to list just two. Additionally, determinations will have to be made on the type of civil operations where NVGs will be permitted (i.e., helicopters and/or fixed-wing) and during which phases of flight. Because current approvals do not permit landing or takeoff with NVGs, does this limitation diminish the intended safety advantage a user might want to gain? If so, how can the limitation be expanded or removed? If and when private pilots are eventually permitted to use NVGs, who monitors their training and proficiency? The military obviously never faced issues like these, but these and many more issues could become commonplace in a civilian environment and will provide topics for discussion and research as more widespread deployment of the technology occurs.

Recommendations

The Aerospace Medical Association considers the use of NVGs by civilian aircrew to be acceptable under circumstances in which the appropriate regulatory oversight agency has granted special operational approval, and where operators have met the recommendations and requirements of the RTCA *Concept of Operations, Night Vision Imaging System for Civil Operators* (4) and the *Minimum Operational Performance Standards for Integrated Night Vision Imaging System Equipment* (5). Appropriate and judicious use of NVGs has greatly enhanced the effectiveness of nighttime military flight operations. If appropriately utilized, NVGs could offer a similar degree of increased effectiveness in a variety of civilian operations. Nevertheless, many potential problems associated with the introduction of NVGs into the civilian aviation environment remain. Moreover, it can be expected that some problems arising from the use of NVGs in civilian operations will be unprecedented, and possibly unpredicted.

Additional information and research is needed to better understand the potential effects of a variety of visual pathologies and other health effects on NVG utilization. In addition to some of the factors mentioned earlier, other possible areas for research might include:

- a. human factor issues with operation of NVGs in different urban environments;

- b. training curriculum development targeted to diverse users and circumstances;
- c. accident prevention techniques tailored to a wide variety of NVG users;
- d. standardization of maintenance practices; and
- e. accident investigation techniques for civil NVG-related mishaps.

Just as important as additional research is the regulatory framework for introduction of these devices to a wider range of users than are currently approved. To name a few examples:

- a. standardized training and equipment maintenance requirements must be developed and implemented;
- b. specific operational guidelines for use of the goggles must also be provided for users, particularly those in commercial operations;
- c. testing of night lighting modifications must be thorough and accomplished by appropriately trained and certified individuals;
- d. selection and training of aviation safety inspectors to use the goggles and their capacity to provide pilots with flight checks and advice in the safe and appropriate use of the devices.

As has been tragically learned by the military, night vision devices are not a panacea to solve the problems inherent with night flight. Although extremely valuable, the military lessons learned should serve as an excellent starting point for the international aviation regulatory authorities, academia, and private industry to continue research and regulatory efforts that will permit the safe deployment of this technology for civil aviation.

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