Chapter 5 – SD AVOIDANCE TRAINING FOR NIGHT VISION DEVICES

5.1 GROUND-BASED DEMONSTRATION OF SD ASPECTS OF NIGHT VISION DEVICES

5.1.1 Introduction

Night vision devices, such as night vision goggles and thermal imagers, have their limitations that result in an impairment of visual perception. The perception is not only degraded, it regularly also leads to *visual illusions*, the misjudgement of visual features, which may cause SD. The experience of a visual illusion can make a big impression, even an emotional impression. When the world is not as our eyes tell us, our confidence decreases. Hands-on demonstration of these effects greatly enhances the NVG training program. There is a clear need for an entry-level NVG training program to familiarize inexperienced personnel with these fundamental and surprising NVG issues. Such training shows the visual limitations experienced with NVGs, and provides methods to identify and deal with these limitations, preventing SD. On the surface, NVG imagery appears to have a structure similar to daylight imagery. However, in actuality its characteristics differ significantly from those of daylight imagery, inducing frequently visual illusions. In general, existing NVG courses mainly adopt a classroom approach, with relatively little hands-on experience. The majority of the training takes place in the air during NVG flights. Moreover, the main focus of the courses is on NVGs with little attention for the combination with thermal imagers.

The essential SD provocative visual limitations of real NVG imagery can be demonstrated in the ground-based SD demonstration program.

5.1.2 Image Degradation

The basic psychophysical parameters that determine the quality of NVGs are visual acuity, field-of-view, and contrast sensitivity. Using simple psychophysical tests these parameters can easily be measured by observers. By also measuring the same parameters in daytime, the quality of an NVG can be compared to standard daytime vision as is shown in Figure 5.1 [60].

Not only is intensified imagery of lower quality, it is also different due to the following four effects:

Reflectivity by Chlorophyll. Chlorophyll is a green pigment found in most plants and is responsible for light absorption to provide energy for photosynthesis. It reflects most of the near-infrared light where NVGs have their peak sensitivity, just outside the visible part. As a result chlorophyll looks very bright in NVGs which gives scenes an unnatural appearance.

Shadows. The degradation of image quality is not uniform all over the scene, but depends on local scene illumination. Details that are normally well lit remain visible at low light levels, whereas details that are in the shadows are much more reduced in visibility when the light levels drop.

Color. NVGs do not provide color, just greenish images. As a result untrained observers are inclined to interpret terrain as being vegetated.

Halos. NVG images usually represent luminous objects with bright circles around them, called halos. The size of these halos is independent of the distance to the bright object, and can therefore not be used as a distance cue. Moreover, halos wash out all details in the direct surrounding of the bright object.

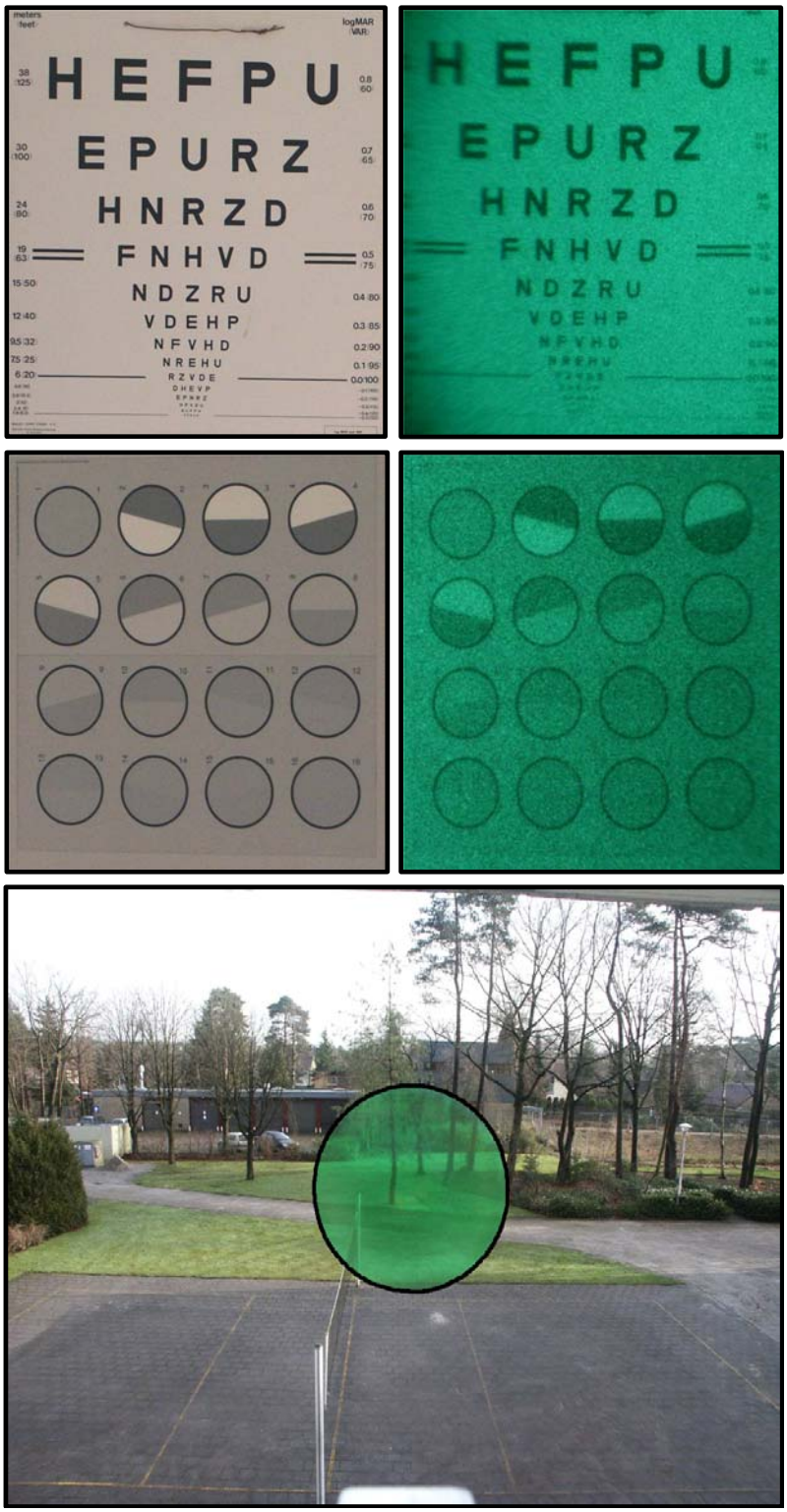

Figure 5.1: Visualization of the Degradation of Image Quality of a Modern NVG Relative to Normal Daylight Vision, without the Characteristic Photon Noise. Upper row: The naked eye in daytime can read 2 to 5 rows further down than the NVG aided eye on respectively clear and dark nights. Middle row: Daytime vision reaches to 4 to 8 times lower contrasts than NVG vision. Lower row: Field of view. The greenish inset represents the standard 40° NVG field-of-view, relative to the 180x120°field-of-view of the naked eye. A neutral density filter was used to register the intensified image during the day.

5.1.3 Terrain Board

A *terrain board* is suitable to demonstrate a variety of visual illusions, in particular to a helicopter crew. The terrain board provides a more active and a more realistic experience than the passive activity of watching videos or photos. Video's show how someone else must have experienced the world. The terrain board allows the student to experience the miniature world for himself. The didactic technique is to let the students misperceive a particular aspect and to uncover the misperception by themselves. Theoretical knowledge does not prevent the visual illusions. The terrain board therefore serves to confirm and accentuate the theoretical knowledge. It allows the students to actively look at the miniature world by changing viewing position, coming closer, or by changing the lighting conditions. Secondly the terrain board allows the student to experience the effects of NVG adjustment errors: some features become imperceptible while others remain unchanged. A well designed terrain board clearly shows all terrain features during (simulated) daylight, while many change appearance or disappear with NVGs. By changing the lighting conditions (moon phase and altitude, haziness) it is possible to demonstrate the various lighting effects. One instructor can simultaneously teach a group of students, whose common experience aids the learning process. A terrain board should include a variety of ground features (e.g. hills), a variety of terrain types (e.g. desert), presence of streetlights and extended cultural lighting, and objects containing the green chlorophyll.

5.1.4 Meteorological Demonstrations

The terrain board alone is not sufficient, particularly for F-16 pilots who typically fly at high altitudes. The primary visual effects that occur in the air are the unpredictable perception of meteorological conditions (e.g. haze) and of other aircraft. With simple means, one can develop a series of stand-alone demonstrations that each show one of the fundamental NVG visual limitations, in addition to the effects possible with a terrain board. Such demonstrations consist of physical objects whose geometry is easy to interpret with the naked eye in daylight but hard to interpret with an NVG and night-time illumination. The demonstrations have in common that the NVG percept deviates dramatically from the daytime view. In addition, the NVG percept is misleading while the scene during daylight is immediate and easy to interpret correctly. A questionnaire distributed among RNLAF Chinook flight personnel confirms the practical implications of the demonstrations illustrated here, in particular the lack of visibility in shadows, the lack of color, and the halos.

5.1.4.1 Spectral Density

One of the demonstrations concerns the *difference in spectral sensitivity* between the unaided eye and the NVG. The setup consists of five differently colored light emitting diodes, arranged according to the rainbow, from blue to green to yellow to orange to red (Figure 5.2). The NVG image is monochrome, showing all lights as green. The NVG is particularly sensitive to red light, also sensitive to near-IR light, and relatively insensitive to blue and green light.

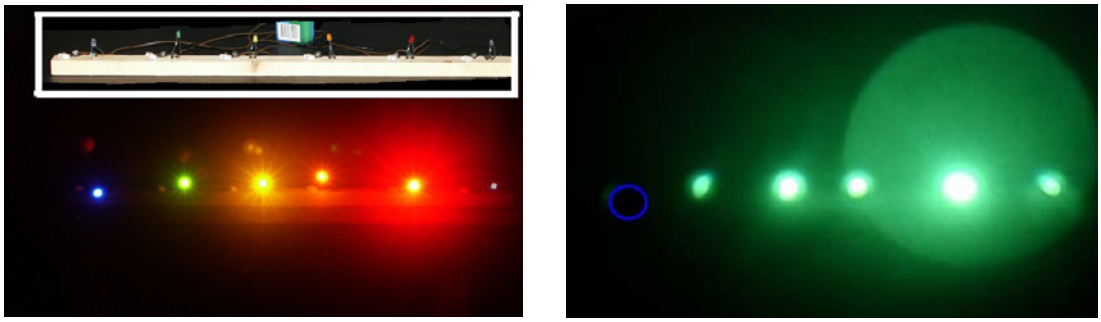

Figure 5.2: Effect of Lights with Different Colors.

5.1.4.2 Halos

Another demonstration is on the *absence of color and the occurrence of halos*. This demonstration employs a flickering light representative of an aircraft marking hangs in front of a projected scene of a lighted heliport at sea. The flickering light is easily visible with the unaided eye in daytime but hard to spot with the NVG at night. The absence of color, the glare due to the presence of halos, and the reduced visibility of temporal change in the NVG cause this difference. The perception of flicker is masked by the intrinsic noise of the image intensifier. When the observer moves sideways, the yellow marker distinguishes itself from the background by motion parallax and becomes easy to spot through the NVG.

5.1.4.3 False Perspective

The third demonstration is on how *halos and the dominance of light sources* can cause a dramatically distorted NVG depth perception. This can be shown by a wire frame to which several light sources have been attached (Figure 5.3). With the naked eye the correct geometry is apparent, but with the NVG the perceived geometry flips. When the observer moves sideways it appears as if the construction becomes fluid: the geometry distorts. The correct perspective does not re-appear as is usually the case with geometrical illusions. This demonstration is particularly powerful because the viewer cannot overcome the illusion even when he is aware of the correct geometry.

Figure 5.3: Line of Sight.

5.1.4.4 Shadows

The fourth demonstration is on the lack of NVG image quality in shadows. A scene represents a soldier standing just behind the opening of a doorway. The soldier can easily be seen with the unaided eye in daytime, but is almost invisible when seen with NVGs at night. The difference between black and dark grey disappears as a result of the poor contrast transfer of NVGs.

5.1.4.5 Reflections

A fifth demonstration concerns the effects of the high reflectivity of chlorophyll in the near-IR. During the day dark tree branches provide a strong contrast with the background reflecting the light of the sky and the sky itself. This obvious visual distinction disappears in the NVG image because the trees and background lack luminance as well as color contrast.

5.1.5 Conclusion

Summarizing, the purpose of these demonstrations is to show the main categories of illusions that occur with NVGs and are potentially hazardous to provoke SD. Stand-alone demonstrations can be easily deployed to train observers how to cope with the fundamental limitations of NVGs. Such stand-alone demonstrations can supplement the terrain boards.

5.2 SD TRAINING SCENARIOS FOR NIGHT VISION DEVICES

5.2.1 Helmet Mounted Systems Training, Ground-Based

Currently, there are no ground-based facilities for NVG training. A NVG simulator for training research has been developed by the Air Force Research Laboratory at Mesa AZ. This is a unique facility. It has been shown to be an effective tool for training aircrews to experience NVGs in a dynamic flight environment via visual simulation. This training offers pilots a unique flying experience on the ground. It is anticipated that these NVG simulators can be proliferated, especially at bases where the pilots are flying with NVGs.

It is anticipated Helmet Mounted Systems (HMSs) will become more and more common to the pilot as these technologies evolve. The head-up-display will be reproduced on the visor of the pilot in the next few years, eliminating the need to mount a glass-combiner on the fuselage of the aircraft. Attitude information will be displayed on the visor of the pilot and will be readily available regardless of where the pilot is looking. The obvious problem with this transition is the display of attitude information when the pilot is looking one direction while the aircraft's velocity vector is in another direction. This advancement will free the pilot from having to look at the HUD and then return his/her vision to a target of interest outside the cockpit. The problem is it adds another cognitive task by requiring the pilot to interpret a display that is not aligned with the aircraft's velocity vector. The final displays may be intuitive and simple to interpret when viewed off-axis. However, the new HMS will most likely require some ground-based training. Such training can be included in a ground-based simulator.

5.2.2 Night Vision Device Effects on Pilot Vision

It is indisputable that pilots flying while aided by night vision devices, such as night vision goggles (NVGs) and FLIR (forward-looking infrared), have enhanced the capability of military flight operations. Unlike unaided night flying during which flights are generally conducted at relatively higher altitudes and lower airspeeds, aided night flight has allowed aircrews to operate during low ambient light levels at terrain flight altitudes and at greater speeds. These advantages in night visual and operational capabilities, however, impose significant limitations to the aircrews' spatial orientation of which they must be aware [61].

Vision is considered the primary sense in orientation and is, therefore, vitally important to any aircraft operations. A pilot's ability to resist spatial disorientation is enhanced by adequate visual references [62]. Any factor that contributes to the degradation or reduction of normal day visual capability can be a contributor to SD. Specifically, aircraft accident research has shown that there is an increased risk of SD while flying with night vision devices [61]. Therefore, awareness of visual illusions and the limitations imposed by the use of these devices is necessary as a countermeasure to the SD hazard.

5.2.2.1 Visual Acuity

Depending on the model, the best acuity that can be expected from NVGs procured since 1996 is 20/25[1] [63]. This best acuity (or resolution) is achieved when the NVGs are used at the optimal sight adjustment point, under ideal environmental conditions, and when viewing high contrast targets. As conditions deteriorate, so does the acuity.

5.2.2.2 Limited Field of View (FOV)

Generally, most night vision goggles provide no more than 40-degrees FOV, both vertically and horizontally. This loss of peripheral vision may contribute to increase incidents of fixation (particularly

[1] Older goggles provide no better than 20/40, with 20/70 in the periphery of the field of view.

during landings) and to the loss of orienting visual cues such as motion parallax. Future generations of NVGs promise greater fields of view. Current prototypes provide 95 to 110 degrees [63].

5.2.2.3 Color Discrimination

Current NVG image intensifiers are monochromatic (single color). Most provide a green hue, but the color is dependent on the type of phosphor screen. This monochromatic scene reduces the ability to recognize contrasts of color, e.g., red lights on ground obstructions or aircraft.

5.2.2.4 Illumination

The performance of NVGs is directly related to the ambient light available. High ambient light (natural and cultural) improves resolution and therefore, objects can be identified at greater distances [64].

Moon illumination, phase and angle are the most important factors in NVG mission planning and flight operations. Caution should be taken to minimize the time flying directly into a rising or setting moon. The angle of the moon may have a positive or negative effect on the appearance of objects on the ground when viewed with NVGs. The moon at very low angles may distort the shape of terrain features while higher angles and high illumination levels can cause washout of terrain detail with a corresponding decrease of visual cues [65].

NVG gain automatically adjusts output brightness to a preset level to restrict peak display luminance. When an area with bright lights is viewed, the display luminance will dim. This is normal and is caused by the goggle's Bright Source Protection or its Automatic Brightness Control. The crewmember may experience this dimming effect, which results in a significant reduction in the resolution of the visual scene. Normal NVG function can immediately be regained by looking away from the light source.

Using landing lights and searchlights during periods of low illumination can cause an effect similar to tunnel vision. Peripheral orientation cues may be lost and fixation on the lighted "tunnel" may occur. During landings, apparent ground speed and rates of closure are difficult to judge [66] and crews may experience crater illusion.

Aircraft instrument lighting and supplemental cockpit lighting (flashlights, finger and lip lights, etc.), if not NVG compatible, may actually degrade the pilot's ability to see outside of the cockpit. Care should be taken to ensure that any lights used by the crew and/or passengers do not compromise NVG image intensification.

5.2.2.5 Weather Considerations

NVGs can see through light obstructions, such as light fog, rain, haze, or smoke. This capability increases the likelihood of inadvertently entering instrument meteorological conditions and possibly experiencing some type of SD. Increased moisture in the air can be detected by the inability to view the moon, stars or other light sources without the aid of goggles. Other indications include the lowering of the ambient light level, cloud shadows on the ground, and fog over water. As obscurations build, the NVGs will display increased video "noise" (scintillation) and decreased acuity [64]. A good indication that visibility restrictions are being encountered is the halo that forms around sources of illumination. If the halo becomes noticeably larger, visibility is deteriorating [66].

5.2.2.6 Depth Perception and Distance Estimation

Both depth perception and distance estimation are reduced while wearing NVGs. Depth perception in a given situation depends upon available light, type and quality of the goggles, degree of contrast in the field of view, and the viewer's experience [64]. In order to overcome these inherent difficulties in depth

perception and distance estimation, aircrew knowledge of monocular and binocular cues is critical to maintaining spatial orientation.

5.2.2.7 Obstruction Detection

Obstructions that have poor reflective surfaces, such as wires and small tree limbs, are difficult, if not impossible, to detect [64]. Wires are difficult to detect with NVGs because of their small, circular reflective surfaces. Associating wires with man-made features will aid in detection. Watch for poles, long linear openings in wooded areas, or buildings in the middle of an open area. Comprehensive hazard map plotting and planning will help avoid these areas. Knowing your geographical position is essential [66].

5.2.2.8 Types of Surfaces

Operations over areas of limited contrast such as open grass- and asphalt/ concrete- covered areas, deserts, and water provide the NVG-aided aviator with additional challenges. Hovering flight maneuvers are particularly difficult due to the inability to correctly judge height and detect horizontal movement. Accurate estimation of height is nearly impossible without a radar altimeter. Frequently, in these areas of limited contrast, fixation on the few references available may cause SD. Pilots should avoid staring at a particular reference. Moving grass and water (waves) create the illusion of aircraft movement [66] and can contribute to SD and can cause incorrect, unnecessary, and dangerous control inputs.

5.2.3 Considerations and Strategies for Flying with NVGs

5.2.3.1 Considerations for Fixed-Wing Flight with NVGs

Compensation for the narrow FOV of NVGs is achieved by employing a constant, aggressive scan to enlarge the total field of regard. An effective scanning technique is essential for maintenance of good situational awareness and spatial orientation, including altitude awareness. For example, a dramatic loss of altitude awareness may occur if the scan is interrupted (e.g., if the neck is “splinted” during a high G maneuver). Experience has also shown that improving scan technique is one of the most effective methods for overcoming a misperception or illusion that has already occurred [66].

Additionally, proper preflight adjustment of the NVG is critical. Personal factors that could contribute to SD are low experience and inadequate currency in NVG flying, fatigue and other stressors. One must be prepared to transition to instrument flight at any time, and one therefore must maintain an aggressive instrument crosscheck complementary to the NVG scan. Aside from the potential SD traps common to anyone using NVGs, such as misperception of motion and distance cues, terrain contour or elevation, there are two SD traps that may be more important to aircrew in fast jets. Because of their operating airspeeds, changes in perception of scene flow can prove illusory. For example, transitioning from a cultural landscape to water, such as crossing a coastline, could give a sensation of a sudden deceleration in groundspeed or change in altitude. Another SD problem is unperceived flight into IMC, with concurrent loss of horizon signaled by only subtle cues in the NVG image such as a decrease in scene detail or increased scintillation.

Overcoming SD while using NVGs is no different than any other instance of SD. First, one must recognize the SD, with the immediate need to ascertain aircraft orientation by reference to the appropriate flight instruments. At the same time, the aviator must overcome the urge to maintain visual orientation using NVGs – the reason why SD occurred in the first place. The phase of flight is important, with more urgency at a very low altitude or during a rendezvous with another aircraft than when operating as a single ship at a medium altitude level. A prepared pilot will rehearse reactions to SD by knowing exactly what instruments to use for spatial orientation, how to coordinate with other crewmembers, and practicing different scenarios in a simulator. Safe execution of the mission is enhanced by knowledge and preparation, tempered by practice.

5.2.3.2 Considerations for Helicopter Terrain Flight with NVGs

This section concentrates on NOE operations including ground cushion maneuvers. It is strongly recommended that only helicopters equipped with a functional radar altimeter (preferably one with an audio low altitude warning alarm) be flown during NVG operations. An audio warning on the radar altimeter was the most frequently cited technological requirement to control the hazard of SD during military flight operations [6] and is considered by the authors to be a prerequisite for the effective maintenance of height awareness during rotary-wing NVG flight. Standard operating procedures should be developed and practiced using this device. A constant aggressive scanning technique [66] and good CRM are perhaps even more important for rotary-wing operations than they are for fixed-wing flight, because operations are conducted much closer to the ground and the margin for error is therefore less. An inadequate scanning technique and poor CRM were attributed to the genesis of 79.7% and 68.6%, respectively, of U.S. Army helicopter accidents [6].

5.2.3.3 Strategies for Safe Aided Night Flight

The following recommended strategies are primarily preventive, but suggestions on dealing with SD once it has been recognized are also given. Just as with daytime flight, NVG flight requires aircrew to perceive adequate visual cues in order to fly safely and effectively. Spatial disorientation occurring during rotary-wing NOE (nap-of-the-earth) flight with NVG is essentially due to a failure to acquire or recognize the visual cues that are essential to the maintenance of spatial orientation in the NOE environment.

Generally, the closer one is to the ground the better are the available visual cues, as long as they exist in the first place. Anticipation of a visually degraded environment, and thus the techniques that will be required to maintain orientation, is essential. A common problem is the failure to appreciate when there is little or no contrast or ground texture, two of the most “reliable” depth cues during NVG flight when close to the ground given that many of the 3-D visual cues are lost during NVG flight. The best advantage of the resulting 2-D environment must, therefore, be taken to prevent SD. For example, it would be reckless to plan an NVG approach to a single visual reference point in a snowfield. The crew should plan to follow known “solid” line features such as hedgerows rather than transit across open spaces with little or no orientation information available. In these circumstances it is also advisable in “side-by-side” helicopters for the pilot who is immediately adjacent to the feature to take control. Flying with NVGs is a skill that is easily lost and therefore, currency and competency are significant factors affecting orientation. The more skilled pilot should therefore undertake the more difficult task.

Although many NVG standard operating procedures allocate flight instrument monitoring duties (particularly speed and altitude) to the non-handling pilot, two pairs of eyes directed “outside” the cockpit are strongly advised in the final stages of the approach to land and during hovering maneuvers. The specific characteristics of an individual pair of NVGs and the external illumination conditions also contribute to SD. If the NVGs are not functioning properly, or if flight is planned for a particularly dark night, the pilot is already placing himself or herself at a disadvantage. The fixed-wing “lost wingman” procedure may be adopted during helicopter NVG flight at transit altitude. However, transit flights in helicopters are usually at a significantly lower altitude than fixed-wing flights and so, as the visual scene is more likely to be “cluttered” by terrain features, the technique of “sky-lining” the lead aircraft by slightly reducing altitude is a useful way for the wingman to maintain or regain his/her orientation within the formation.

When in NOE flight, military helicopters tend to operate as a single ship in a “group” and so the strategies for overcoming SD need only concern that particular aircraft (providing the pilot has a good situational awareness of the location of the other aircraft in the mission). As far as coping strategies are concerned, a handling pilot who loses visual should immediately inform the non-handling pilot. If the non-handling pilot has maintained visual references, he or she should take control immediately. If both pilots have lost visual references, the previously planned overshoot must be initiated. If solo, the pilot must initiate the

previously planned overshoot without delay, based on lower threshold of "uncertainty" than in a two-seat aircraft. The majority of rotary-wing accidents and serious incidents that have arisen [6] suggest that aircrew did not appreciate the particular environmental and equipment limitations and subsequently failed to modify their visual scanning technique. The importance of maintaining excellent visual reference with the ground and neighboring obstacles at all times cannot be overstressed.

The Apache helicopter's Integrated Helmet And Display Sighting System (IHADSS) presents peculiar circumstances in that it incorporates a monocular display in which a visual image from a FLIR sensor is combined with flight and target acquisition symbology and presented to the pilot's right eye during night flight while vision in the left eye remains unaided. Once again, the emphasis must be upon avoidance of SD and most of the recommendations made in the NVG section are pertinent to flight using FLIR [66]. The primary advantage of the Apache IHADSS over the NVG is the inclusion of flight reference symbology (although symbology into NVGs has recently been introduced in some military aircraft). However, it must be noted that the scanning technique is both within the HMD (head mounted display) – moving the eye(s) around the display – as well as moving the eyes and head around the cockpit and external environment. Recovery from SD can therefore be assisted by this technology and it is possible (with appropriate training) to "control the aircraft to make the instruments read right" even during NOE and hovering flight. When HMDs are used in the modern Apache helicopters (U.S. Army AH-64D and the British Army's Apache AH Mk 1), recognized SD "coping" strategies once visual cues are lost at any stage of flight are as follows:

- Use the aircraft visible light source (landing lamp).
- Use the secondary FLIR sensor – there is both a FLIR pilot's night vision system (PNVS) and a Target Acquisition and Designation System (TADS), although the latter's resolution and lateral slew rate is not as good as the former.
- Hand over control to the other pilot.

If both aircrew have lost references, execute a recovery procedure. This is summarized as follows:

- Apply collective power to initiate a climb using the HMD's instrument reference;
- Declare to the other pilot that one is "executing a recovery procedure";
- Ensure that the climb is clear of obstacles;
- Select the flight page on the left-hand multi-purpose display so that the unaided left eye now has an instrument reference, while still using the HMD's instrument reference; and
- Change instrument reference from the HMD to the multi-purpose display flight page and continue as a "traditional" instrument recovery.

5.2.4 Conclusions

NVGs have certainly improved night flying capabilities, but along with the benefits come an increase in the risk of an SD experience. Awareness and knowledge of the limitations imposed by NVGs and the illusions one might encounter are critical to aviation operational safety. Training, proficiency and experience with the use of these devices is the key to the successful completion of an NVG mission.