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Human Factors of Night Vision Devices: Anecdotes From the Field Concerning Visual Illusions and Other Effects

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To investigate the breadth of visual illusions experienced by aviators flying with night vision devices (NVDs), an open-ended questionnaire was distributed to the military helicopter community in the fall of 1989. Of the 242 returned questionnaires, there were 221 night vision goggle (NVG) reports and 21 thermal imaging system (FLIR) reports. Most sensory events occurred at night, during low illumination, good weather, and over varied terrain. Contributing factors included inexperience, division of attention, and fatigue. Frequently reported illusions were misjudgments of drift, clearance, height above the terrain, and attitude. Also reported were illusions due to external lights, and disturbed depth perception caused by differences in brightness between NVG tubes. Other respondents cited hardware problems and physiological effects. There were no obvious differences between the experiences of NVG users and FLIR users. Although incidence rates cannot be

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inferred from these data, the variety of excerpted aviator anecdotes in this report will be useful to all those concerned with the human factors and safety of NVDs.

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Introduction

Night vision devices (NVDs) are an essential component of modern military aviation. Yet, while permitting flight throughout the night, these electro-optical devices present the aviator with less than perfect visual cues for pilotage. Compared to a pilot flying under day-visual flight rules (VFR) conditions, the NVD user is handicapped in visual acuity, field-of-view, color vision, and depth perception (Price and McLean, 1985). Other problems can include ocular rivalry, (with monocular displays) additional head-supported weight, and the stresses of disrupted circadian rhythms inherent in nighttime operations.

NVDs are based on one of two basic technologies: image intensification (I^2) or thermal imaging (Rash, Verona, and Crowley, 1990; Verona and Rash, 1989). I^2 devices amplify light so that the eye can see a poorly illuminated scene. The AN/PVS-5 series night vision goggle (NVG), first issued to Army aviators in 1971, is still the most common I^2 device in current use (Verona and Rash, 1989). The newer Aviator's Night Vision Imaging System (AN/AVS-6) has the advantage of lightweight high performance third-generation tubes. Another I^2 device used mainly by the U.S. Navy is the "Cat's Eyes." Thermal sensors, on the other hand, detect infrared (IR) radiation emitted by objects in the scene. An example of this type of system is the forward-looking infrared (FLIR) sensor of the Pilot Night Vision System (PNVS) on the AH-64 Apache helicopter. The principles and limitations of I^2 devices (collectively referred to as "NVGs" in this paper) and thermal sensors have been reviewed elsewhere (Rash, Verona, and Crowley, 1990; Verona and Rash, 1989). A brief comparison of the three U.S. Army NVDs is presented in Table 1.

Aviators rely primarily on vision to maintain orientation in the environment (Gillingham and Wolfe, 1986). Degraded visual cues, such as those provided by NVDs, combined with stressful and fatiguing flight profiles, predispose aviators to visual illusions and errors (U.S. Army Safety Center, 1987, 1988; Vyrnwy-Jones, 1988). Previous NVD user surveys have supported this assertion, but have not provided detailed accounts of these sensory experiences (Brickner, 1988; Hale and Piccione, 1990; Hart and Brickner, 1987).

There is a commonly held view that any visual handicaps inherent in the use of NVDs have been thoroughly documented over the past 20 years (Jensen, 1989). Therefore, since aviators are thoroughly briefed on these limitations and how to fly safely with NVDs, the cause of any accident related to errors in visual perception is frequently presumed to be simply human error (Fehler, 1984; Scicchitano, 1989). It is possible, however, that there are visual phenomena related to NVDs that have not yet been described and communicated to the flying community. To investigate this, first-person accounts were solicited from a

Table 1.

Comparison of AN/PVS-5, AN/AVS-6, and PNVS/IHADSS NVDs.

Characteristic	AN/PVS-5	AN/AVS-6	PNVS/IHADSS
Light amplification	1000x	3-4000x	NA
Resolution (line pairs/mm)	24	36	36
Best acuity	20/50	20/40	20/40-60
Magnification	1x	1x	1x
Interpupillary range (mm)	55-72	52-72	NA
Light output (FL)	0.5	1.0	0.3-15.0
Field of view (deg)	40	40	30 x 40
Weight (lbs)	6.7	5.9	4.0

Note: Best acuity is based on optimal conditions (high contrast and scene luminance). AN/PVS-5 and ANVIS weight includes typical counterweights used by aviators to offset center-of-gravity shifts, and the maximum weight of the SPH-4 helmet (3.5 lb). PNVS/IHADSS weight includes the IHADSS (Integrated Helmet and Display Sighting System), helmet display unit, and cathode ray tube (Price and McLean 1985; Rash et al. 1990; Verona and Rash 1989).

large population of aviators regarding visual effects experienced while using NVDs. Although this approach cannot provide estimates of incidence, it can generate a wide variety of interesting and sometimes surprising anecdotes. Such a collection could be of value to safety and aeromedical professionals as well as to aviators and commanders.

Materials and methods

In the fall of 1989, a questionnaire (Appendix A) was mailed to 150 attendees of an international triservice NVG meeting. The questionnaire also was included as an insert in a mailing of a U.S. Army aviation safety publication, Flightfax. A postage-paid mailer was provided with the Flightfax distribution to facilitate return. Recipients were urged to report, on separate questionnaire forms, each sensory experience or illusion noted while flying with NVDs. The form contained questions about environmental conditions and NVD hardware, as well as demographic data. Provision of name and address was optional.

The model

A simple model was conceived to organize the many different subjective reports (Figure 1). The basis of the model is the "NVD-Pilot interface," upon which many various causal influences ("Contributing Factors") may act. Sensory experiences (the main

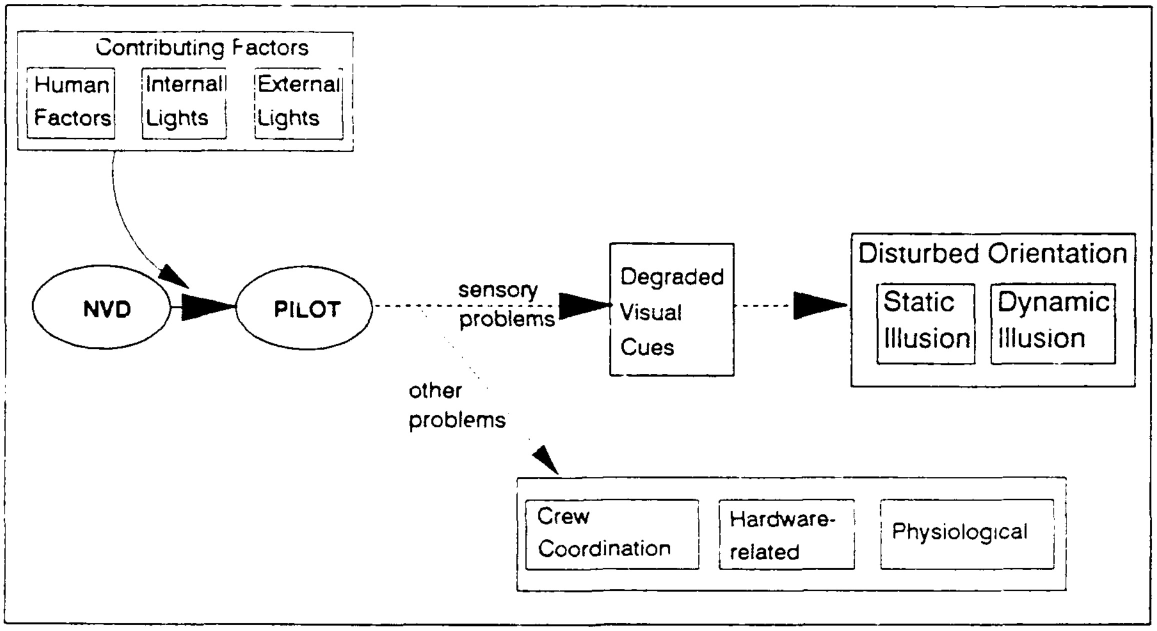

Figure 1. The NVD-pilot model.

object of the questionnaire) are classified as either a simple report of "Degraded Visual Cues" or an account of a more complex difficulty in visual perception, termed "Disturbed Orientation." These problems perceiving orientation of self or the environment are divided further into "Static Illusions" and "Dynamic Illusions," depending on whether motion (real or perceived) was an essential element.

Reports of nonvisual effects related to NVDs are classified as "Other Problems." Within this category are problems with crew coordination, hardware, and various physiological effects. Although these topics were not the focus of the study, they are germane.

Results

Sample characteristics

Two hundred and forty-two completed questionnaires, completed by 223 individuals, were returned; the Flightfax distribution accounted for 90 of these questionnaires. A wide variety of aircraft, organizations, and NVDs were represented (Figure 2). Mean respondent age (at the time of the event) was 33.7 years (s.d.= 5.3), and 83.5 percent were flying as pilot or

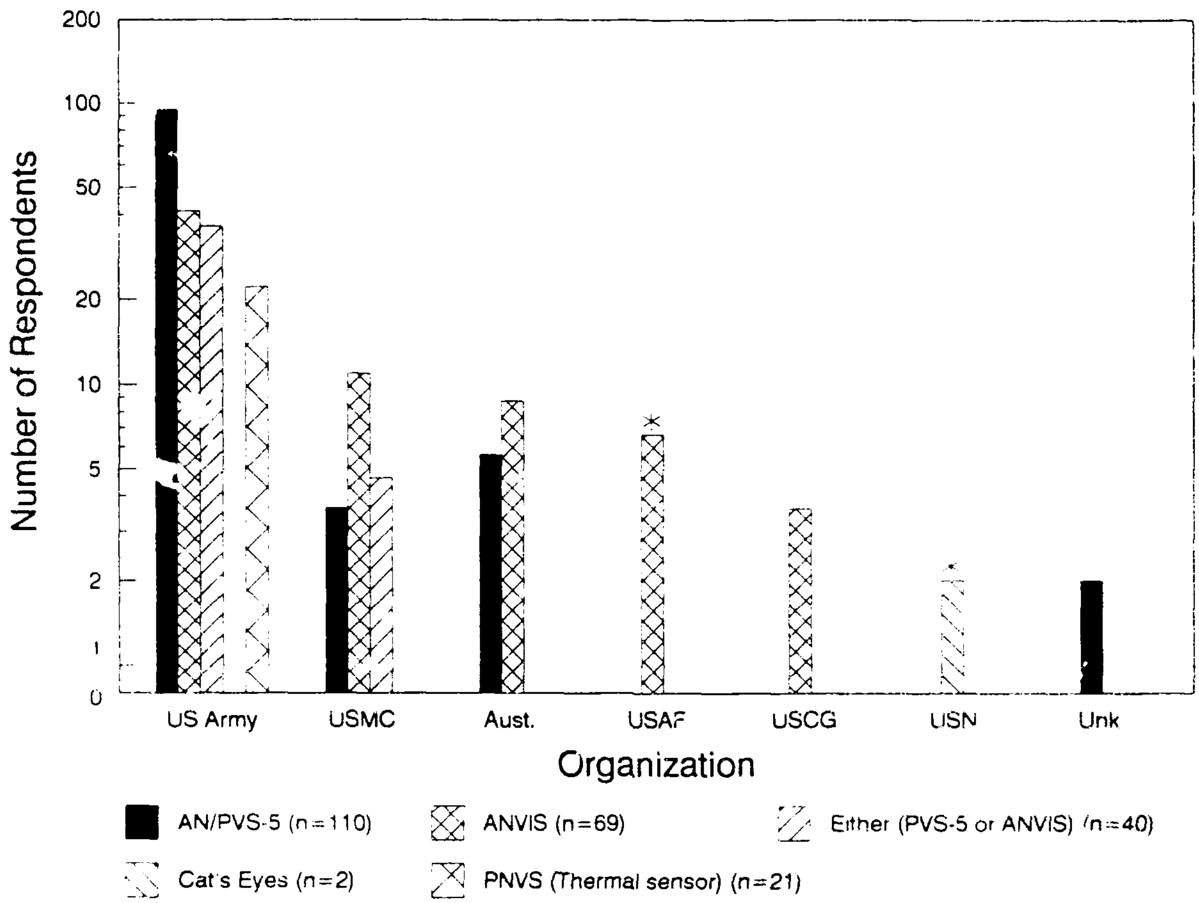

Figure 2. Respondent affiliation and NVG type associated with event.

instructor pilot (copilots and student pilots accounted for 9.5 and 5 percent, respectively). Flight and NVD experience are plotted in Figure 3. (Note: All USAF and USN reports were from fixed-wing aircrew. All other reports were from rotary-wing aircrew. 'Aust.' = Royal Australian Armed Forces.)

Most sensory events occurred at night (Figure 4), during lower levels of ambient illumination (Table 2), during good weather (Table 3), and over many different types of terrain (Table 4). (Note: One AH-64 pilot reported an event that occurred during daylight use of the thermal imaging system.) Illumination levels for AN/PVS-5 events and ANVIS events were similar (Figure 5).

Airspeed and altitude at the time of the event are plotted in Figure 6. Events were reported during all phases of flight, but most frequently in cruise, hover IGE (in ground effect), and during approach/landing (Table 5). If hovering IGE and hovering OGE (out of ground effect) are combined, hovering was the most frequent phase of flight reported.

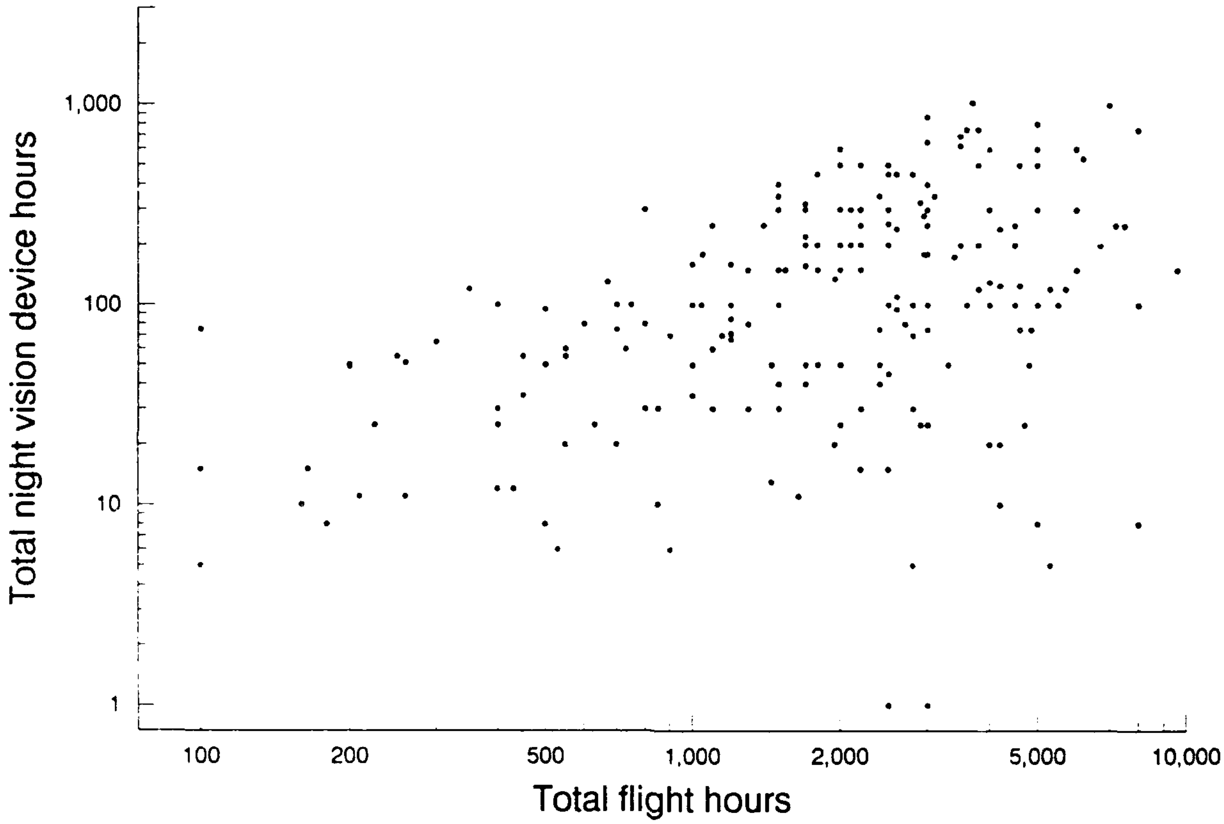

Figure 3. Respondent flight and NVD experience at the time of the reported event (n=228).

Table 2.

Illumination levels at time of event.

	Rotary-wing NVG (n=212)		Fixed-wing NVG (n=9)		AH-64 PNVS (n=21)	
Illumination level	%	(n)	%	(n)	%	(n)
0-24%	36	(77)	67	(6)	24	(5)
25-49%	25	(54)	-		-	
50-74%	6	(12)	22	(2)	-	
75-100%	9	(19)	-		-	
Any	13	(27)	22	(2)	33	(7)

Note: Illumination level is approximated by the percent of the moon surface that is illuminated (e.g., new moon = 0% illumination, full moon = 100% illumination, etc.) (Headquarters, Department of the Army, 1988). Tables reflect the number of responses to each question within NVD/aircraft category. Therefore, column totals may not equal category totals. All table percentages are reported to the nearest integer.

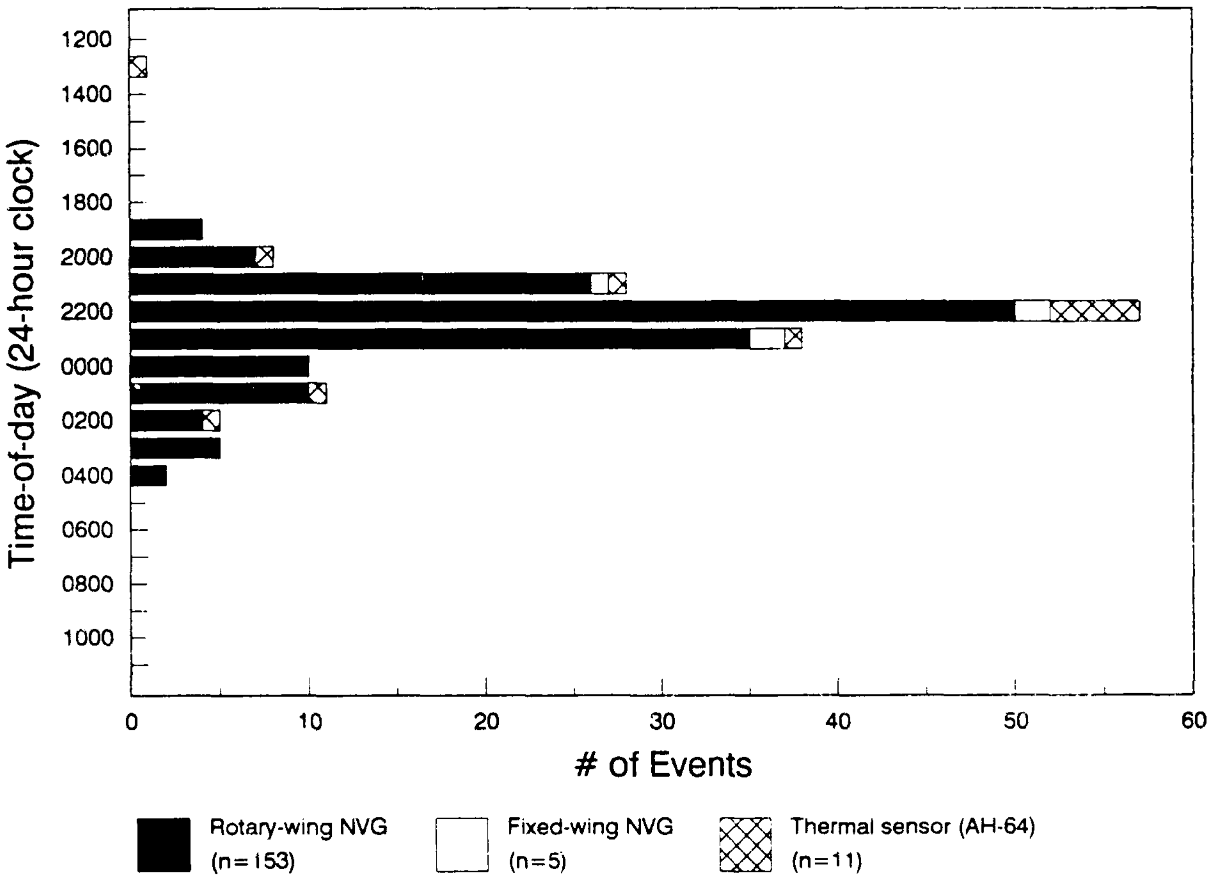

Figure 4. Event time-of-day and aircraft category.

Table 3.

Weather conditions at time of event.

	Rotary-wing NVG (n=212)		Fixed-wing NVG (n=9)		AH-64 PNVS (n=21)	
Weather	%	(n)	%	(n)	%	(n)
Clear	64	(135)	67	(6)	33	(7)
Any	15	(32)	33	(3)	19	(4)
Fog/haze	11	(23)	11	(1)	24	(5)
Rain	6	(13)	11	(1)	14	(3)
Overcast	3	(7)	11	(1)	-	
Clouds	3	(6)	-		-	
Snow	2	(4)	-		5	(1)

Table 4.

Terrain conditions at time of event.

	Rotary-wing NVG (n=212)		Fixed-wing NVG (n=9)		AH-64 PNVS (n=21)	
Terrain	%	(n)	%	(n)	%	(n)
Trees	24	(51)	44	(4)	33	(7)
Open field	17	(37)	22	(2)	19	(4)
Mountains	14	(29)	56	(5)	-	
Water	12	(26)	11	(1)	5	(1)
Tall grass	12	(26)	-		5	(1)
Any terrain	11	(24)	-		19	(4)
Desert	8	(17)	33	(3)	-	
Confined area	8	(16)	-		10	(2)
Snow-covered	5	(11)	11	(1)	5	(1)
Asphalt ramp	5	(11)	-		5	(1)
Dusty	3	(7)	-		-	
Slope	3	(7)	-		-	
Built-up area	2	(4)	-		5	(1)
Loose grass	1	(3)	-		5	(1)
Dry lakebed	1	(3)	-		-	
Canyon	1	(1)	-		-	

Table 5.

Phase of flight at time of event.

	Rotary-wing NVG (n=212)		Fixed-wing NVG (n=9)		AH-64 PNVS (n=21)	
Flight phase	%	(n)	%	(n)	%	(n)
Cruise	28	(59)	100	(9)	29	(6)
Hover (IGE)	25	(53)	-		24	(5)
Approach/landing	25	(52)	-		10	(2)
Hover (OGE)	12	(26)	-		5	(1)
All phases	10	(20)	11	(1)	24	(5)
Formation flight	6	(13)	-		-	
Bank	4	(8)	-		-	
Slingload	3	(7)	-		-	
Nap-of-the-earth	3	(7)	-		-	
Takeoff/climb	3	(6)	-		5	(1)
Hover/taxi	1	(3)	-		-	
On ground	1	(3)	-		5	(1)

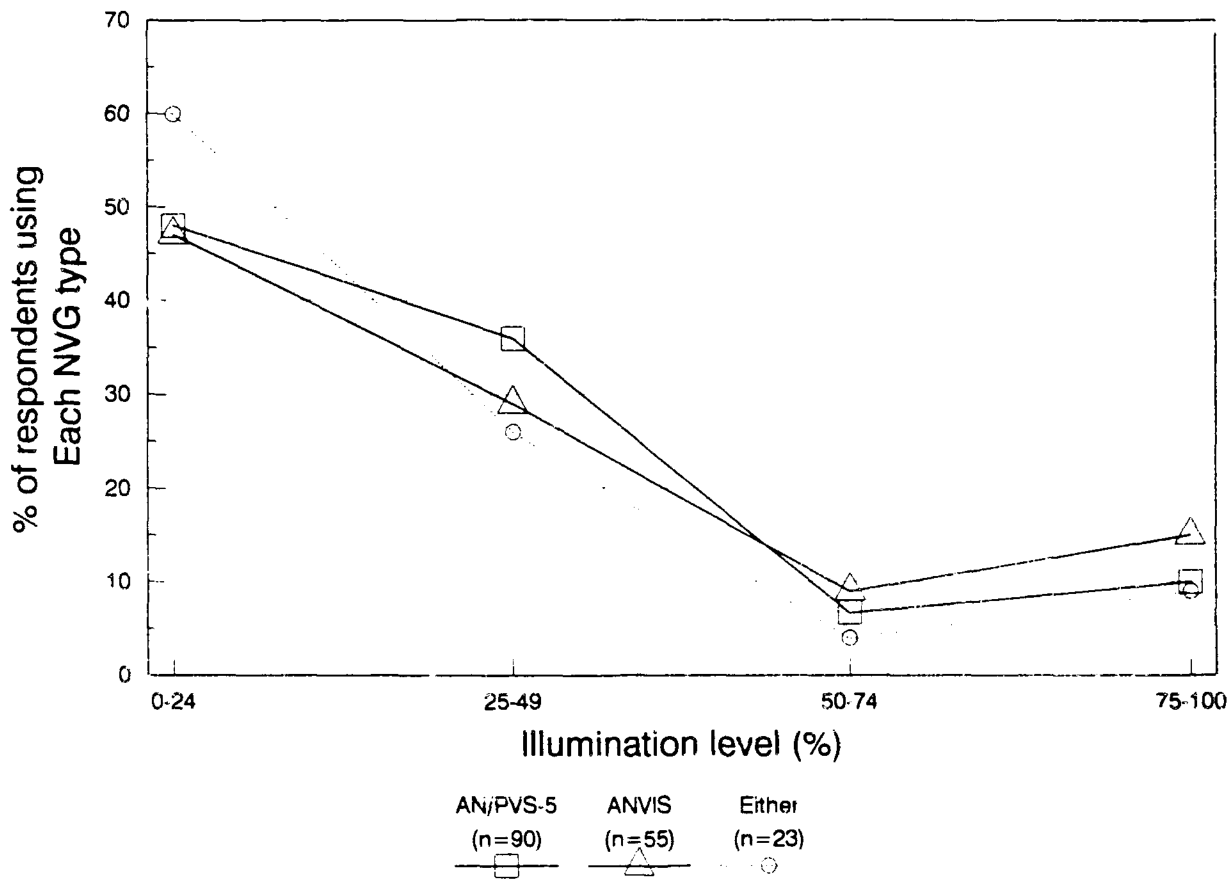

Figure 5. Ambient illumination and NVG type.

Model components

Representative quotations, organized according to the model, are included as Appendix B.

Contributing factors

The most common contributing human factor was inexperience, followed by division of attention ("looking inside cockpit") and fatigue (Table 6). There were 41 reports of NVD effects due to lights (16.9 percent).

Degraded visual cues

Impaired acuity was most frequently reported, often to the point of losing visual contact with the horizon, occasionally requiring transition to instrument flight (Table 7). Inadequate field-of-view and a lack of depth cues also were frequently mentioned.

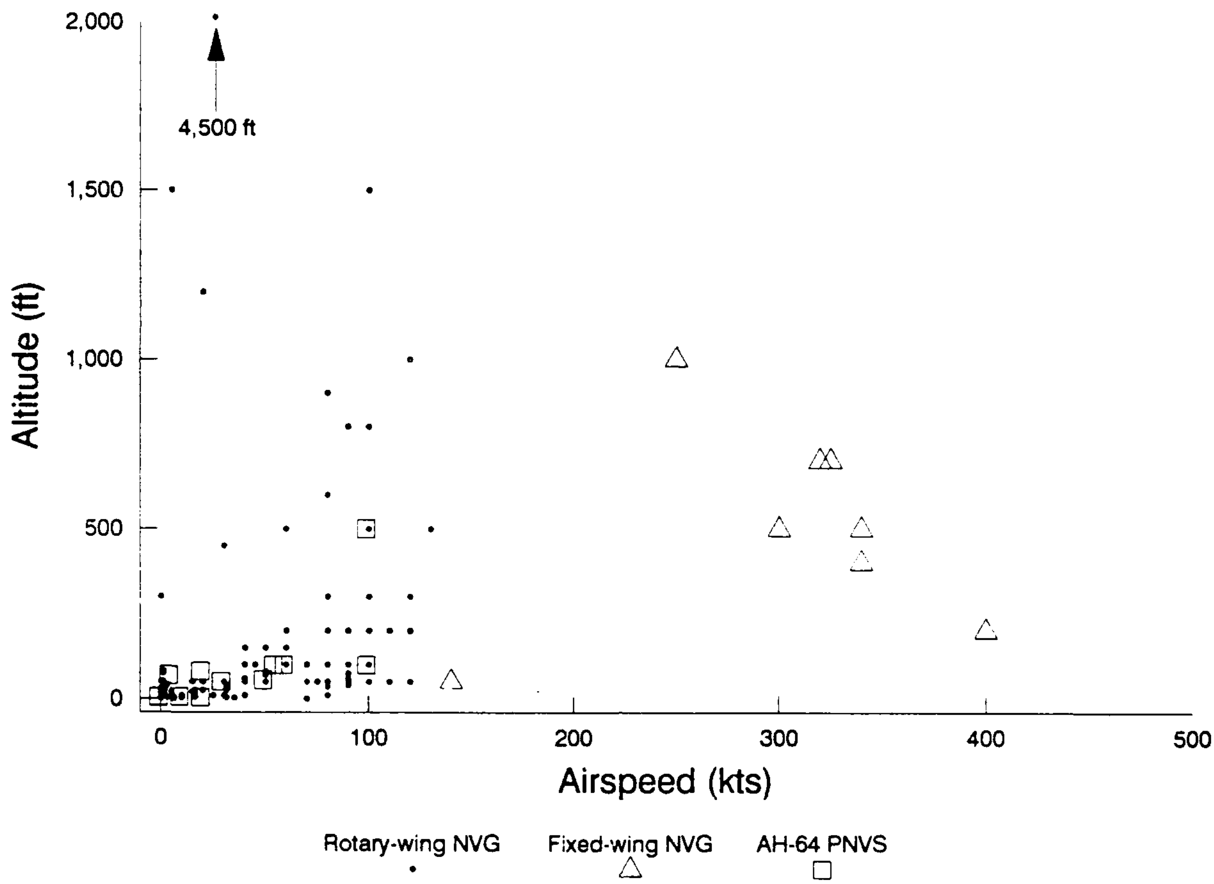

Figure 6. Aircraft airspeed and altitude at the time of the event.

<u>Disturbed orientation: Static illusions</u>

Overall, the most common static illusion reported was difficulty in judging height above the terrain (Table 8), including 10 instances over water. Closely related were problems with estimation of aircraft clearance. Other reports described difficulties perceiving attitude, angle-of-bank, and degree-of-slope. Also reported were perceptual errors related to a variety of external lights (Table 6).

<u>Disturbed orientation: Dynamic illusions</u>

Unawareness of actual aircraft drift was the most frequently reported dynamic visual effect, followed by the illusion of drift when the aircraft actually was stationary (Table 9). In those who specified a direction of drift, both real and illusory drift occurred most frequently to the rear (Table 10). Hovering over

Table 6.

Percentage of respondents reporting contributing factor(s).

Report	Rotary-wing NVG (n=212) %	(n)	Fixed-wing NVG (n=9) %	(n)	AH-64 PNVS (n=21) %	(n)
Human Factors						
Lack of experience	6	(12)	-		5	(1)
Looking inside cockpit	2	(4)	11	(1)	5	(1)
Fatigue	2	(5)	-		5	(1)
Visual fixation	2	(4)	-		10	(2)
Combined IMC/VMC flight	1	(3)	-		-	
Inadequate prebrief	1	(2)	-		-	
Poor display adjustment	<1	(1)	-		5	(1)
Misinterpretation of symbology	-		-		5	(1)
Internal Lights						
Degrade PVS-5 image	1	(3)	-		-	
Reflected on inside of canopy	<1	(1)	-		5	(1)
Cockpit lighting is disorienting	<1	(1)	-		-	
ANVIS floodlights are hard to read by	-		11	(1)	-	
External Lights (source)						
Built-up areas	3	(6)	-		5	(1)
IR searchlight	3	(6)	-		-	
Other aircraft lights	3	(6)	-		-	
Stars	2	(5)	-		-	
Aircraft lights (self)	2	(4)	-		-	
Moon	1	(2)	11	(1)	-	
Automobile lights	1	(2)	-		-	
Lighthouse	<1	(1)	-		-	
Tower light	<1	(1)	-		-	
Ship lights	<1	(1)	-		-	
Beanbag light	<1	(1)	-		-	
Chemlight (lightstick)	<1	(1)	-		-	
Rocket glare	<1	(1)	-		-	
Fireflies	<1	(1)	-		-	
Lightning	<1	(1)	-		-	

Table 7.

Reports of degraded visual cues.

Report	Rotary-wing NVG (n=212) %	(n)	Fixed-wing NVG (n=9) %	(n)	AH-64 PNVS (n=21) %	(n)
Degraded resolution/ insufficient detail	33	(70)	66	(6)	14	(3)
Loss of visual contact with horizon	15	(31)	-		10	(2)
Impaired depth perception	11	(24)	11	(1)	10	(2)
Decreased field-of-view	10	(20)	22	(2)	10	(2)
Inadvertent IMC	8	(16)	22	(2)	5	(1)
Whiteout/brownout	6	(13)	-		-	
Changing acuity due to shadows	3	(7)	-		-	
Blurring of image with head movement	<1	(1)	22	(2)	-	

Table 8.

Reports of static illusions.

Report	Rotary-wing NVG (n=212) %	(n)	Fixed-wing NVG (n=9) %	(n)	AH-64 PNVS (n=21) %	(n)
Faulty height judgement	16	(33)	56	(5)	19	(4)
Trouble with lights	8	(17)	-		5	(1)
Sense of landing in hole	5	(10)	-		-	
Faulty clearance judgement	3	(7)	11	(1)	-	
Faulty slope estimation	3	(7)	-		-	
Bending of straight lines	3	(7)	-		-	
Faulty attitude judgement	3	(6)	-		-	

tall waving grass was the most frequent drift scenario (23 of 78 reports of drift). Errors also were reported in judging airspeed and direction of movement.

Other problems

Hardware-related comments highlighted NVG distortion as a source of visual effects (Table 11). Several respondents noted NVG performance variability. In some cases, differences in brightness and resolution between NVG tubes disturbed depth perception. Other respondents cited helmet weight, NVD retention failure, and battery failure. Physiological reports included eyestrain, headache, and motion sickness.

Outcome of events

Cockpit activities

Aviators reported a variety of cockpit activities in response to the reported NVD event (Table 12). The most frequently reported response was to transfer aircraft control to the other pilot. Some monitored flight instruments or symbology more closely, while others directed crewmembers to cross-check visual estimates of distance or drift.

Table 9.

Reports of dynamic illusions.

Report	Rotary-wing NVG (n=212) %	(n)	Fixed-wing NVG (n=9) %	(n)	AH-64 PNVS (n=21) %	(n)
Undetected aircraft drift	18	(38)	-		24	(5)
Illusory aircraft drift	14	(30)	-		24	(5)
Disorientation ("vertigo")	12	(25)	-		14	(3)
Faulty closure judgement	6	(13)	-		10	(2)
No sensation of movement	2	(4)	11	(1)	-	
Faulty airspeed judgement	1	(2)	-		-	
Illusory rearward flight	1	(2)	-		-	
Illusions of pitch	1	(2)	-		-	
Sensation of stars falling	<1	(1)	-		-	
Illusory sideward flight	<1	(1)	-		-	

Table 10.

Real or perceived direction of drift.

Direction	Real drift (n=43) %	(n)	Illusory drift (n=35) %	(n)
Unspecified	58	(25)	65	(23)
Rearward	14	(6)	17	(6)
Forward	5	(2)	9	(3)
Rightward	2	(1)	3	(1)
Leftward	12	(5)	6	(2)
Sideward (unqualified)	7	(3)	-	
Upward	2	(1)	-	
Downward	7	(3)	-	

Table 11.

Miscellaneous reports.

Report	Rotary-wing NVG (n=212) %	(n)	Fixed-wing NVG (n=9) %	(n)	AH-64 PNVS (n=21) %	(n)
Hardware-related problems						
Distortion	8	(16)	-		-	
Helmet too heavy	3	(6)	-		-	
NVG variability	2	(5)	-		-	
Differences between tubes: resolution	1	(3)	-		-	
Differences between tubes: brightness	1	(3)	-		-	
NVG retention failure	1	(2)	-		-	
Battery failure	1	(2)	-		-	
Distracting symbology	-		-		14	(3)
Differences between tubes: focus	<1	(1)	-		-	
Fogging of NVD	<1	(1)	-		-	
Monochromatic display	<1	(1)	-		-	
Crew coordination problems						
Mixing PVS-5 and ANVIS	<1	(1)	-		-	
Mixing PNVS and NVG	-		-		5	(1)
Physiological effects						
Eyestrain	3	(7)	11	(1)	-	
Headache	2	(4)	11	(1)	-	
Color vision aftereffects	2	(4)	-		-	
Motion sickness/vomiting	2	(4)	-		-	
Blurred vision post-NVD	1	(2)	-		-	
Dizziness	1	(2)	-		-	
Fatigue	<1	(1)	11	(1)	-	
Dark adaptation effects	<1	(1)	-		5	(1)
Conjunct. foreign bodies	<1	(1)	-		-	
Ocular rivalry	<1	(1)	-		-	

Immediate adjustments to flying techniques

Many aviators reported how they changed their technique "on the spot" to counter the reported NVD effect (Table 12). Most concentrated on improving their side-to-side visual scan. A variety of visual strategies were reported.

Adverse mission outcomes

There were 92 reports of a negative result from the NVD event, ranging from simply overcontrolling the aircraft or aborting the mission to actual aircraft accidents and personnel injury (Table 12). The most severe outcomes (near collision, overtorque, hard/unstable landing, tree strike, and personnel injury) were analyzed further separately (Table 13). These serious events were found to occur in a wide variety of environmental and flight conditions.

Lessons learned

Preflight/planning techniques

Many respondents stated that the described effects occurred earlier in their flying careers, and the incidence decreased with accumulated NVD experience (Table 14) or with improvements in NVD technology. However, several commented that they must fly frequently to avoid recurrence of the sensory effect. A good premission brief, including crew responsibilities for aircraft clearance and control, as well as disorientation procedures, was stressed by several aviators.

In-flight techniques

Recommended strategies to reduce the incidence of these effects included improving scan techniques, using extreme caution, and viewing a stable object when hovering (Table 14). A variety of recommendations were made.

Discussion

This small collection of anecdotes can serve as a springboard for planning aviator and flight surgeon instruction, as well as providing direction for future human factors research. However, since there are no denominator data, it is not possible to infer risk or incidence rates. Even if the number of persons surveyed was known, the open-ended questionnaire design precludes reliable estimates of incidence. Only those aircrew who recalled a significant or recurrent event took the time to complete a questionnaire and mail it back. A more objective survey of a known population of aviators with NVD experience would almost certainly document higher incidence rates than those suggested by this study. On the other hand, the attraction of an open-ended questionnaire is that a wide variety of spontaneous responses can be obtained. The strength of this report lies in the actual anecdotes themselves (excerpted in Appendix B).

Using only descriptive statistics, therefore, a few tentative observations about these anecdotes can be made: First, although many NVD visual effects did occur under low illumination

Table 12.

Outcome of events

Outcome	Rotary-wing NVG (n=212) %	(n)	Fixed-wing NVG (n=9) %	(n)	AH-64 PNVS (n=21) %	(n)
Cockpit activities						
Transfer aircraft controls	12	(25)	-		-	
Use other aircrew to crosscheck visually	9	(20)	-		10	(2)
Monitor instruments/ displays more closely	7	(17)	33	(3)	29	(6)
Adjust external lighting	5	(10)	-		-	
Change battery	1	(2)	-		-	
Adjusted helmet	1	(2)	-		-	
Immediate adjustment to flying technique						
Increased scan	11	(24)	11	(1)	-	
Increase margin for error	4	(9)	-		-	
Look at stable object/rock	3	(6)	-		5	(1)
Look around NVD to double check cues	2	(5)	11	(1)	5	(1)
Look through chin bubble	1	(3)	-		-	
Look at point in distance	1	(3)	-		-	
Look at treeline	1	(2)	-		-	
Look at shoreline	1	(2)	-		-	
Look at ground guide	<1	(1)	-		-	
Close one eye	<1	(1)	-		5	(1)
Slow head movements	-		11	(1)	-	
Adverse mission outcomes						
Overcontrolled aircraft	6	(13)	11	(1)	19	(4)
Aborted mission	6	(12)	-		5	(1)
Near collision	5	(10)	11	(1)	5	(1)
Hard/unstable landing	4	(8)	-		-	
Performed go-around	3	(7)	-		-	
Nausea/vomiting	2	(4)	-		5	(1)
Formation disrupted	2	(4)	-		-	
Removed NVD	1	(3)	-		-	
Unnecessary evasive action	1	(3)	-		5	(1)
Incorrectly diagnosed NVD failure	1	(2)	-		-	
Tree strike	1	(2)	-		-	
Increased workload	<1	(1)	-		-	
Engine overtorque	<1	(1)	-		-	
Ground crew injury	<1	(1)	-		-	

Table 13.

Events with severe outcome (n=24)

	% Severe Events	(n)
Ambient weather		
Clear	83	(20)
Rain	13	(3)
Fog	4	(1)
Phase of flight		
Cruise	38	(9)
Approach/Landing	33	(8)
Hover (IGE + OGE)	17	(4)
Terrain		
Trees	21	(5)
Desert	17	(4)
Water	17	(4)
Illumination level		
0- 24%	38	(9)
25- 49%	21	(5)
50- 74%	4	(2)
75-100%	13	(2)
Any	4	(3)

Note: Only the three most frequently cited responses are depicted (except illumination level).

conditions, it appears that they easily can occur during NVD cruise flight in clear weather (favorable flight conditions that might engender aircrew complacency). Second, although most of these illusions have been known to occur in unaided helicopter flight for years (Clark, 1971; Fehler, 1984; Tormes and Guedry, 1974), the specific nature of the effects (particularly those occurring over mountainous terrain or water) are somewhat surprising and may be especially useful in an instructional setting. Finally, there were no dramatic differences in visual effects among the different NVDs represented in this study, although there were relatively few reports from the PNVS community. This is not surprising, since all NVDs are subject to the same general visual limitations (Table 1).

A particularly interesting illusion was described by three respondents who noted a "3-D effect" or "disturbed depth perception" when they used NVGs with brightness differences between the two tubes (Table 6). These individuals may be experiencing the "Pulfrich effect," an illusion of depth thought to result from asymmetrical stimulation of the occipital cortex (Brennan, 1988; Miller, 1982). Classically, the illusion is

Table 14.

Lessons learned.

Strategy	Total respondents (n=242) %	(n)
Preflight/planning techniques		
Adapt with NVD experience	10	(23)
Fly more often to maintain skills	4	(10)
Improve permission brief	2	(4)
Plan disorientation procedures	1	(2)
Don't fly around built-up areas	1	(2)
Plan to verbally announce turns	<1	(1)
Fly unaided if illum. sufficient	<1	(1)
Carefully focus/adjust NVD	<1	(1)
In-flight techniques		
Stress better scan techniques	7	(17)
Use extreme caution	7	(17)
Look at stable object while hovering	5	(11)
Use other crew to clear aircraft	3	(8)
Look around NVG to confirm distance and color cues	3	(7)
Use radar altimeter/instruments more	2	(5)
Keep head movements slow	1	(2)
Judge altitude by watching shadows	1	(2)
Use unaided eye to clear aircraft	<1	(1)
Look away from bright lights	<1	(1)

produced by placing an optical filter before one eye while the subject views a pendulum swinging to-and-fro. Instead of perceiving the pendulum as swinging in a plane, the target will appear to move in an elliptic path. To my knowledge, the Pulfrich effect has not been previously reported in the context of asymmetrical NVG tube performance. The Pulfrich effect may have safety implications: For example, it could degrade the NVG aviator's already impaired ability to judge the rate of closure or flight path of another aircraft. A preflight NVG performance check should include a comparison of tube brightness.

Although the basic sensory effects caused by NVDs could be predicted from a knowledge of the visual illusions encountered in unaided flight (Clark, 1971; Fehler, 1984; Tormes and Guedry, 1974), the breadth of experiences presented herein would have been difficult to imagine beforehand. It is not surprising that aeromedical NVD references (Brickner, 1988; Verona and Rash, 1989) and available aviator NVD training guides (Headquarters, Department of the Army, 1988; USASC, 1987, 1988) do not address every visual effect found in this study (e.g., IMC conditions that may be encountered in shadows, sensations of landing in a hole, 3-D effects when the brightness of the two tubes differs, etc.). The potential visual side-effects of NVDs are as varied as the potential combinations of weather, illumination, terrain, airspeed, altitude, device, and aviator experience and fitness.

It should be noted that NVD flight rules enacted over the last decade have reduced the incidence of some effects reported in this study. To cite only two examples, regulations now prohibit flight with NVGs exhibiting noticeable distortion, and flight crews normally are prohibited from mixing NVD types in the same cockpit.

Night vision devices greatly enhance combat capability on the modern nighttime battlefield. This collection of aircrew anecdotes should help aeromedical and safety professionals further reduce the risks of NVD use through education and training.

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Appendix A.

The NVD illusions questionnaire.

US ARMY SAFETY CENTER
SENSORY ILLUSIONS AND NIGHT VISION DEVICES

Please describe below the details of the sensory effect or illusion that you experienced while using Night Vision Systems. We're interested in any experiences you consider unique to NVD flying: illusions, common errors, aeromedical factors, etc. Please use one sheet for each different illusion; make copies of the blank form if necessary. If you can't remember the details, at least tell the story in narrative form.

Type of Night Vision Device Being Used:

NVG: PVS-5____ ANVIS-6____ Cat's Eyes____ Other (describe)____

Infrared: Helmet-Mounted Display____ Head-Down Display ____
Fixed Head-Up Display (HUD) ____ Other (describe)____________________

Type of Aircraft: __________ Crew Position (P/CP/WSO, etc.)______

Description of Event:

Terrain: (snow, water, trees, mountains, etc.)____
Weather (rain, fog, visibility, etc.)____
Time:(24-hr Clock)_______ Altitude:(AGL, MSL) ______Airspeed: ______
% Illumination: _______ (or Moon Phase: ___________________)

Description of Incident:

____

____

____

____

____

How often does this happen?____

____

What was the outcome of the event? What happened? What did you do to stop it?

____

____

____

Personal Information: (at the time of the event)

Age:______ Total Flying Hours: ________ NVD Hours: ______

OPTIONAL: (but helpful)

Name/Rank: ____________________________ Phone #:____________________________
Affiliation: (Army, Navy, AF, etc)____
Mailing Address: ____
____
____

Please send completed form to: Commander, US Army Safety Center, ATTN: CSSC-SE (MAJ Crowley), Ft. Rucker, AL 36362.

Appendix B.

Aviator anecdotes.

Selected excerpts from the surveys are reproduced below, organized according to the model categories (Figure 2). Anecdotes were altered only to correct punctuation or grammar. Any suggestions or remedies are the opinions of the respondents and are not in any way endorsed by the author. Anecdotes from NVG (I^2) users and PNVS/IHADSS (thermal imaging) users are presented separately.

Part I: NVG anecdotes

A. Reports of degraded visual cues

1. Degraded resolution/insufficient detail

"In fog, the NVGs will give better vision than without using them. This can cause problems . . . You lose your required forward visibility without realizing it."

". . . seemingly perfect NVG conditions: very high illum., moon very high, almost right overhead. . . . there was virtually no shadowing, making it impossible to see contours of terrain below. Land that was quite hilly looked flat."

". . . image in my NVGs appeared to be dimming. Instructor pilot (IP) said his was also--we both tried our 2nd battery with the same result. . . . we removed the goggles and turned on the landing light. We then discovered we were in a snowstorm . . . ."

"Aircraft position lights reflected off the falling and blowing snow, reducing visibility outside aircraft. IR searchlight made situation worse. Turned off all external lighting--snow then became almost invisible."

"Night terrain avoidance [mission]; feels like you are diving into ground if you use only NVGs (without instrument backup)."

-[B-52 pilot]

2. Loss of visual contact with horizon

". . . during OGE hover check [in confined area] could not see ground or horizon above trees. . . . trees started to slide to the left and down. I became completely disoriented."

". . . whenever I launch off this pinnacle (4500' mean sea level (MSL)) under low ambient light conditions, I have no visual horizon or ground reference. The pink light is of no value at altitude. I learned to use the normal landing light in stowed position, for ground reference until descent to within pink light range."

3. Impaired depth perception

"A break in cloud cover allowed a large amount of moonlight to illuminate ground between aircraft and ridgeline (about 10 miles) giving illusion of hills being much closer (only 5 miles away)."

4. Decreased field-of-view

". . . we were nearly hit by a blacked-out UH-60. The vortices caused our OH-58 to spin. Because of being under goggles, was very difficult to maintain control."

5. Inadvertent IMC

"As aircraft crested a ridgeline, all artificial illumination was lost, leaving crew in a black void. Even though the possibility of this situation occurring was known to the crew and the subject was addressed prior to the flight, it still caused an inadvertent IMC flight."

". . . no ground lights were visible and visual flight became impossible. Immediately after transferring my attention to the aircraft instruments I felt slight spatial disorientation. I had no feeling of movement."

6. Shadow effects on performance

"When flying in mountainous terrain, nearly impacted mountain because of shadowing."

"Shadow cast by large mountain, combined with extreme brightness of surrounding terrain, caused a small hill mass to be completely invisible. It was finally illuminated when a right turn was initiated and the red position light shined on it. The right turn was a chance decision, and if it hadn't happened we'd have hit the hill."

B. Reports of static illusions

1. Faulty height judgement

". . . utilizing PVS-5s. I did not recognize myself descending until my copilot told me we were at 10 feet above ground level (AGL) and descending at 70 kts. This is a problem which occurs quite often, requiring close crew coordination."

"Lost altitude perception while landing at stagefield . . .

occurs every time we don't fly NVG within the last 30 days of last NVG flight."

". . . aircraft skids touched water. NVG allowed pilot to see bottom of pond and not water surface."

"We were lead of flight of 2 . . . even though radar altimeter was functioning, both aircraft descended to within 35 feet of ocean surface with no visible change in ocean surface."

"Over desert, impossible to determine altitude over rolling sand dunes. Our radar altimeter was essential. We learned to watch our shadow from the moon to approximate altitude."

". . . terrain flight altitudes over dry lake beds provides absolutely no reference to altitude. The only way to pinpoint your altitude is to descend until you can see the cracks in the dry mud at about 8 feet AGL."

". . . tendency to fly lower than the established minimum altitudes of 500-700 feet AGL because vision improved as aircraft got closer to the ground."

-[B-52 pilot]

2. Trouble with lights

(a) Built-up areas

"A crossing NVG aircraft was not detected until it was within 500 m due to its navigation lights being confused with ground lights."

"As lead aircraft flew near a populated area, the formation lights blended into the lights of the populated area. The result was a total loss of reference to where the lead aircraft was."

". . . in trail formation, tail lights blended in with ground street lights. We slid to the right and found ourselves flying right past the aircraft we were supposed to be following."

(b) Light source identification errors

"noticed a very bright light at my 10:00--same altitude, very close. . . . made a very hard right turn to avoid what I thought was another aircraft. Flight engineer reported that it was an automobile on a hill."

"We were flying dash 2 off another Cobra, when I noticed another aircraft at 12 o'clock and proceeding straight toward us for a possible head-on. . . . informed the other pilot who assessed the on-coming light and yelled 'break right!' I broke right . . . about 20 seconds later we realized it was a car on a highway below, with its bright headlights on."

"A stationary light appeared to be moving on path that would cross the heading we were flying. It was a light on a tower that blinked at about the same frequency as an anti-collision light."

"Forward area refueling points (FARP) were marked with chemsticks. As I hovered to point 1, an OH-58's lighting appeared identical to chem light marker. Within 10 ft of collision, I noticed OH-58 and took controls."

". . . while flying over water, joined on the red running light of oil tanker vice wingman."

(c) Miscellaneous light effects

". . . in the AH-1 while using PVS-5s, lights have to be turned down so low that it is almost impossible to see the instruments. . . . reflections off the windscreens make it impossible to see outside of the aircraft."

". . . target area temporarily "disappears" when firing rockets."

". . . at low illumination fireflies are very noticeable"

"..flying down mountain valley. . . as we turned toward a light source such as a city or moon low on the horizon, the valley, mountains, etc., all disappeared as the goggles adjusted for the higher light source."

3. Faulty clearance judgement

"Depth perception degradation off both sides when hovering in a small landing zone (LZ) near trees. It is extremely hard to judge your clearance off the sides. . . . tendency is to move aircraft laterally away from the trees."

4. Faulty slope estimation

". . . I have noticed the illusion of always landing on a slope."

"Troop insertion . . . misjudged percent of slope on a landing to the ground. Hit left skid high . . . the slope was much more severe than anticipated . . . ."

"A student I was instructing assessed flat ground as nearly 15 degrees and refused to land even when ordered to."

". . . sloping confined area . . . Student commenced liftoff to hover and aircraft rolled into slope . . . I assumed control. Problem caused by lack of visible horizon, compounded by slope."

"Determination of slope limits difficult where no cues such as vertical features (buildings, trees, posts) exist."

5. Faulty attitude judgement

"Ridgelines at various angles behind each other produce false and confusing horizons."

"After coming out of a turn and rolling straight and level, I had the feeling that I was continuing the turn. The ripples on the surface of the water were at an angle when I viewed them through the goggles."

"Copilot was flying down narrow canyon, became disoriented, and realigned the aircraft with the canyon wall, thus placing it in a diving left turn. I recovered the aircraft. The copilot still did not realize that he had been in an unusual attitude."

"While coming into the refuel pad, beanbag light was laying over at an angle . . . . The combination of sloping instrument panel, tilted beanbag light and contrast between the asphalt and white concrete, gave me an overwhelming rolling sensation as I landed. I fought the urge to put in full lateral cyclic and transferred the controls."

C. Reports of dynamic illusions

1. Undetected aircraft drift

". . . pilot in command (PIC) fixated straight ahead and drifted back over 100 meters before I grabbed the controls. . . . happens often, particularly depending on stage of crew rest."

"While hovering over featureless asphalt surface, I didn't recognize the fact that I was actually hovering backwards toward another aircraft. I now look under the goggles at the area illuminated by position lights for reference."

". . . in parking at stagefield, student pilot allowed aircraft to drift laterally when an aircraft ahead of us hovered laterally. We didn't see our drift until a hover line passed under the aircraft."

". . . over airfield taxiway . . . thought I was at a stable hover until I passed a taxiway light going sideways at about 20 knots."

". . . OGE hover during unmasking. Noted tendency to drift, especially if there is not a feature such as a tall tree to "climb up" as aircraft ascends."

"I picked aircraft up to a hover over taxiway. Before I realized what was happening, I was at a 150' hover."

". . . excessive drift due to moving cloud pattern on the ground."

". . . during slingload operations in too dusty LZ, hook-up man was knocked off load due to pilot's inability to acquire the needed visual cues to stabilize the hover."

2. Illusory aircraft drift

"While at hover over tall grass, had sensation of moving when in fact was not."

". . . while landing or hovering in tall grass, rotor wash pushes grass forward giving the illusion of aft drift."

". . . while hovering over tall grass, waving action of grass caused the same phenomenon as hovering over water (sensation of drifting)."

"While descending from OGE hover, I perceived forward movement, when in fact I was stabilized. . . learned to cope with this illusion."

". . . performing an OGE hover check. . . sudden downpour occurred. During descent, I experienced very real feeling that I was drifting to the left, when in fact we were descending straight down."

"During OGE hover check . . . I felt as if I was moving backwards and descending with nose-high attitude. . . . copilot stated there was no drift. I came out from under the NVGs and looked straight down out my door and the sensation ceased after I focused on the ground with unaided vision."

3. Disorientation (vertigo)

"Complete disorientation to both pilots occurred when updraft on tail caused UH-1 to rotate nosedown. . . along with limited field-of-view, lack of depth perception caused us to perceive aircraft was in a spin."

". . . while travelling to a ship, passed a lighthouse and experienced vertigo . . . turned the controls over to the other pilot."

"While flying over smooth water in a turn, the reflected stars in the lake could be seen . . . after looking inside the cockpit to outside, the appearance of stars when looking down into the turn produced severe vertigo."

"Smooth undisturbed water will reflect/duplicate star pattern in the sky, causing momentary disorientation."

"Following sorties of >2 hours, when degoggling in flight it is very easy to feel completely disoriented, even over what would otherwise be a familiar area".

"On 89th night without flying goggles I became spatially disoriented during turning maneuvers at altitude."

4. Faulty closure judgement

". . . very hard to determine another aircraft's course in relationship to our own. Aircraft position lights are of no use under goggles."

". . . very difficult to tell if another aircraft is approaching or going away [when wearing] goggles. The only way to know is to look under the goggles."

". . . closure rate could not be judged adequately. Approach was concluded with abrupt pull-up just prior to contact with ground."

"During unbriefed join-ups, rate of closure can be very difficult to judge. Usually happens when lead aircraft calls for join-up on goggles without giving airspeed, altitude, and/or angle of bank."

5. Whiteout/brownout

"While hovering over M198 for hookup, blowing sand and dust obscured my vision. I had picked up slingloads during the day with the same amount of blowing sand and dust but it does not cause a problem except with goggles."

"While performing a multiple ship sling load to a single tactical LZ, dust was picked up in the rotor system and all visual references lost. A rear drift started causing stabilator to fail."

"While hovering over freshly cut grass, with IR light on and extended, the rotor tip vortices cause the loose grass to be recirculated, causing white out and backscatter."

6. No sensation of movement

". . . water was mirror smooth--lost all sense I had of motion--felt like I was in the simulator."

7. Faulty airspeed judgment

"Tower cleared us to hover taxi to our ramp. As we approached the end of the runway, I had the impression we were going excessively fast, and that we would overrun our turnoff. We were not, in fact, travelling excessively fast, and made our turnoff easily."

"Lose sense of airspeed due to lack of perceived texture over snowy fields. Generally moving faster than I thought."

8. Illusory rearward flight

"Over water, in left turn approaching LZ . . . crew was looking into LZ. Pilot and copilot had sensation of aircraft flying backwards."

9. Illusions of pitch

"While sitting in LZ discussing the last approach, another aircraft flew by overhead with pink light illuminated. The shadows moved across the ground causing the sensation that our A/C was moving or tilting."

10. Sensations of stars falling

". . . the sky/stars appeared to be falling and I could not maintain orientation on natural horizon."

11. Illusory sideward flight

"Aircraft felt as if it were flying sideways or 90 degrees to actual direction of flight."

D. Miscellaneous reports

1. Hardware-related problems

(a) Distortion

"With certain NVGs, when landing on a flat surface I get the illusion of landing in a hole or depression."

"Feel as if landing in a hole. The ground comes up around the aircraft, or level ground looks like a slope."

". . normal scanning head movement caused illusion of trees bending. . . . later determined that these goggles were not properly tested and should not have been accepted."

"Altitude perception changes with different pairs of ANVIS . . . must adjust perception for each flight where different goggles are used. All of our goggles have passed the distortion tests."

"A light viewed unaided from the corner of your eye displaces about 2 inches downward when your head is turned and the object is viewed with the goggles."

(b) Helmet too heavy

"As you fly, your helmet shifts (slides forward) on your head creating a distorted field-of-view. . . . counterweight helps but does not eliminate the problem. Reaching up with collective hand and straightening your helmet helps but is hazardous at nap-of-the-earth (NOE) altitude."

(c) Differences between tubes

". . . problem with depth perception will occur if one PVS-5 tube is "better" than the other. Usually the object viewed through the better tube will appear to be slightly closer than as viewed through the other tube."

". . . PVS-5 tubes are often mismatched in visual acuity. . . . causes headaches, hurting eyes, and poor vision for up to 3 hours after removing the goggles."

". . . when bright NVG tube is paired with a dimmer tube, objects close up appear to be in 3-D."

". . . differences in focus between PVS-5 tubes causes fisheye lens effect."

(d) NVG retention failure

". . . snap retaining the cut-away PVS-5 goggles to the rubber retention strap let go (became unsnapped). The aviator then had to fly with one hand. . . ."

"During high speed, low-level autorotation, pilot at controls lost his NVGs."

(e) Fogging of NVD

". . . the goggles themselves fogged up due to a temperature inversion. Bleed air heat was turned on and goggles cleared."

(f) Battery failure

"On numerous occasions I have had batteries cause the goggles to fade over a period of 30 minutes during a mission. . . .mistaken for diminishing weather condition."

2. Crew coordination problems

"I was wearing PVS-5, copilot was wearing ANVIS. I could not distinguish more than 1/8 mile visibility around aircraft nor could I determine a horizon. The copilot had no difficulty with the ANVIS."

3. Physiological effects

(a) Eyestrain

". . . eyes fatigue rapidly (20 minutes) unless precise focusing done."

(b) Headache

"I experience tension headaches after flying NVGs, and once I got sick when one lens failed."

(c) Color vision effects

"After completing flight, and removing the goggles, I could not distinguish between the colors green and white."

(d) Blurred vision post-NVD

"Just after removing goggles from "use" position to "store" (up) position I had blurry vision and no distant focus for about 2 seconds. Happens every time I degoggle in high ambient light environment."

(e) Conjunctival foreign bodies

"Numerous sand particles get lodged in loadmaster's eyes in dusty pads, etc. A small pair of goggles under the NVGs would help immensely."

Part II: PNVS/IHADSS anecdotes

A. Reports of degraded visual cues

1. Degraded resolution/insufficient detail

"I had one near miss while using the PNVS (less than one rotor disk separation), so now I use my unaided eye more frequently to check for other aircraft."

B. Reports of static illusions

1. Faulty height judgement

"Flights over water make height evaluation impossible--you must use radar altimeter."

2. Faulty attitude judgement

". . . maladjusted image rotation collar leading to tilted image, false horizon illusion, and 'leans.'"

C. Reports of dynamic illusions

1. Undetected aircraft drift

"In blowing snow, pilot did not notice vertical drift even though required symbology was functioning. The dazzle effect of snowflakes blowing through the FLIR field-of-view caused pilot to disregard symbology."

"Hovering over blowing tall grass without symbology--relative motion is induced and a stationary hover is difficulty."

2. Illusory aircraft drift

"...there is very often a strong illusion of movement at a hover created by head movement, misinterpreted as aircraft movement making the aviator correct for aircraft movement unnecessarily."

3. Disorientation ("vertigo")

"I was looking at pilot's PNVS but flying from the front seat . . . pilot turned his head left and down, slewing the PNVS sensor. The illusion I experienced was vertigo because I was no longer able to see in the direction of flight."

D. Miscellaneous reports

1. Hardware-related problem

"When relying on symbology, you can inadvertently start moving in adjustment to symbology movement."

2. Crew coordination problems

"While in the IP station of an AH-1 PNVS surrogate trainer with student for PNVS training, I was using ANVIS and he was using FLIR. . . with fog present at stagefield, I could only see approx. 400 m with IR searchlight, while student could see 5 km. Training was canceled."

3. Physiological effects

". . . takes 10 minutes to 1 hour after flying for my dark adapted left eye to get back in sync with my right (PNVS) eye."

". . . unaided eye frequently controlled vision so display was blanked until I blinked rapidly."

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