NVG Training Developments in The Netherlands

Dr. F.L. Kooi
TNO Human Factors
PO Box 23, 3769ZG Soesterberg
The Netherlands

Frank.Kooi@tno.nl

LtCol. Ted Meeuwsen, Lt. Marjon de Graaff
Center for Human Factors in Aviation
PO Box 22, 3769ZG Soesterberg
The Netherlands

ABSTRACT

Night Vision Goggle (NVG) imagery differs from the naked-eye view which makes it difficult to interpret. For time critical tasks – like flying an airplane – training is an essential element to ensure safe operation. The Netherlands has been devoting effort to further enhance and streamline the NVG training. The primary effect of the impoverished nature of NVG imagery is to reduce visual performance. The secondary effect is to cause visual illusions: the viewer misinterprets the scene without realizing it. Existing NVG training tools like terrain boards and flight simulators do a good job to demonstrate the reduced image quality of NVG's, but only partially cover the more deceptive illusions. TNO has developed a series of interactive demonstrators designed to be representative of NVG visual illusions, and therefore complementary to a terrain board and simulator. The training value is powerful because experiencing a visual illusion first-hand makes a big impact ("apparently I can't trust my eyes!"). The course participants next learn the techniques to prevent and/or resolve the illusion. Student pilot responses so far have been very positive. Hands-on demonstrations are now being incorporated in the RNLAF NVG Lab, integrated with the treatment of night vision theory. To further accommodate NVG training, the F-16 Mission Simulation Center (MSC) has been adapted to quickly and effortlessly provide medium-quality NVG stimulation. The various NVG training tools need to be carefully coordinated in order to achieve effective repetition where needed and avoid unnecessary repetition where possible.

1.0 INTRODUCTION

The Royal Netherlands Air Force (RNLAF) increasingly makes use of night vision devices, such as night vision goggles (NVGs) and thermal imagers, to enable night-time operations. However, the quality of intensified imagery is much reduced compared to normal viewing during the day. Moreover, NVG's cause visual effects that do not occur during the day [1]. There is a clear need for an entry-level NVG training program to familiarize inexperienced personnel with these fundamental and surprising NVG issues [2]. Ruffner's report that "Findings from field experience and mishap and accident analyses suggest that problems experienced by NVG users can often be attributed to a limited understanding of NVG capabilities and limitations, and to perceptual problems" [3] is in line with the Dutch findings. When asked, Dutch pilots indicate to be fully content with the NVG training they receive [4]. At the same time the RNLAF Center for Human Factors in Aviation, responsible for the NVG training in The Netherlands, regularly encounters military personnel with a training deficiency, particularly outside the pilot community. Sometimes the personnel is aware of it, and sometimes not. In-flight NVG training in the

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Netherlands is severely limited due to regulatory restrictions and the limited number of dark hours in summer time. The value of ground-based NVG training is therefore high. For these reasons the Netherlands invests to expand the NVG training facilities and upgrade the training procedures. In recent years TNO has expanded its hands-on NVG demonstrations which make up part of the "Spatial Disorientation Demonstration" program [5]. This paper summarizes these hands-on demonstrations [6] and the planned transition to the Dutch NVG training course.

Complementary developments elsewhere include computer-based training oriented towards practice of NVG perceptual skills prior to operational deployment [7]. The authors argue that continued exposure to a broad variety of NVG environments is imperative to maintain operational readiness. The US Navy "NITE LAB" plans the incorporation of atmospheric and weather effects with partial see-through mirrors ("HUD's") [8]. The technological complexity of HUD's poses the challenge to make the demonstrations fast and effortless. It will be of interest to compare and combine these NATO efforts on NVG training regarding their effectiveness and ease of implementation.

2.0 STRUCTURE OF NVG INTRODUCTORY TRAINING

"NVG introductory training" is conducted prior to operational training in the aircraft or vehicle. The Dutch introductory training is a condensed version of the USAF and US Army courses and consists of some classroom instruction centred around photo and video recordings, hands-on experience, and simulator training [3]. Like elsewhere, the bulk of the NVG training takes place on-the-job. The framework of NVG training can be described in terms of three integrated but not necessarily consecutive stages:

1. Knowledge
2. Experience
3. Behavior

Purpose of the NVG introductory training is to convey basic *knowledge*, have the course participants personally *experience* the fundamental NVG visual problems, and thirdly to train basic NVG *behaviour* (flight manoeuvres, visual scanning, etc) before entering the operational NVG world. The USAF "Night vision goggle training course" [9] provides a good basis for the first stage, the academic instruction. Stage 2 in the Netherlands at present revolves around actual NVG's, eye charts, and the AMST terrain board (Figure 1). The terrain board helps to bridge the gap between theory and application. It is suitable to demonstrate a variety of visual effects from a helicopter point of view and allows the students to become involved in the miniature world by changing viewing position and/or by changing the lighting conditions. In this sense the terrain board is "hands-on", providing a more active experience than passively watching someone else's experience through videos or photos. Though powerful, these demonstrations are limited in two ways. Firstly they primarily concern the reduced visibility of objects and structures through the NVG rather than "visual illusions" as defined below. Secondly, the course participant is still more a spectator than a true participant. The spacious RNLAF NVG Lab at the Center for Human Factors in Aviation provides ample opportunity to enrich the experience in the future. In Stage 3 NVG training and spatial disorientation (SD) training come together in the DISO flight simulator [10]. The DISO training involves active participation and a sense of competition among the course participants [5].

Figure 1: Stage 2 of the current NVG training. On the LEFT demonstration of the reduced visual acuity and contrast sensitivity with F4949 NVG's. On the right the AMST terrain board, demonstrating a variety of NVG effects like halo's, inability to look into shadows, confusion of colored lights, etc. These demonstrations focus on the reduced NVG visibility of objects more than NVG illusions. The DISO simulator shown in the left image is the primary tool for SD training, requiring active participation of the course participants.

3.0 NVG DEMONSTRATIONS AT TNO

TNO Human Factors provides the "Spatial Disorientation Demonstration" program to RNLAF student pilots using TNO's vestibular research facilities [5]. The purpose is to make the student pilots aware of the limits of their sensory systems and the dangers of disorientation at the beginning of the elementary flying training. The course includes a 1 ½ hour block on night vision sensors which through the years has been expanded to include an increasing variety of hands-on demonstrations. Students learn to appreciate the various visual limitations by personal experience. This chapter describes the complementary value of the TNO interactive demo's to NVG training. While the NVG block contains elements of all three didactic stages outlined above, most time is allotted to the demonstrations. The theoretical knowledge as captured by Tables 1 and 2 supports the demonstrations and vice versa. The goal is to enrich the learning experience by actively involving the course participants (making it *hands-on*), adding personal confrontations with visual *illusions*, and increasing the scope of the *operational conditions*.

3.1 Hands-on

The NVG training session at TNO starts off with a contest. The group is split in two teams with the mission to detect the other team first, one team with thermal imager(s) the other with NVG's. During the "mission debrief" many of the thermal and NVG characteristics are discussed and directly linked to the fresh personal experiences. The sense of competition fires up the ambition to learn. After experiencing two examples of the hands-on NVG demonstrations described later in this Chapter, the principles of image intensification (NVG's) and thermal imagers are explained and their (dis)advantages compared. The visual limitations of NVG's are experienced first hand with the tests listed in table I. During the thermal session the instructor explains the basics of thermal signatures & camouflage while exploring the thermal facial features of the course participants.

The added value of hands-on experience also expresses itself with respect to simulator training. The experience with the former is real, while the latter remains faked. A personal confrontation with a visual illusion can make a big, even emotional impression. When the world is not as it appears to the eyes, this shakes one's confidence. For example, physically stepping on an invisible obstacle in an apparently welllit room is plain weird. Not being able to detect real smoke is an entirely different experience than the inability to see fog in a simulator image. Analogous to a simulator, the terrain board also has a fake-world-feel to it. It's impressive, but still not real, it still represents another world. We therefore argue that hands-on experiences with real substances come closest to the real world *experience* where timely recognition of illusory scenarios, appropriate handling, and the stress of actual risks ultimately come together. Hands-on demonstrations enhance the impact of the NVG training program.

	Limitation	Test	"Loss factor"
1	resolution	visual acuity chart	3-5x
2	image contrast	contrast sensitivity chart	4-8x
3	Field-of-view	perimetry	10x
4	ability to read	reading chart	8x
5	Color perception	False color NVG images	infinite

Table I. The five main limitations of NVG's. The right-most column gives an approximate indication of the difference between day vision and night vision through a NVG.

3.2 Visual illusions

While on the surface NVG imagery appears to have a structure similar to daylight imagery, in actuality its characteristics differ significantly. As a result, visual illusions - the phenomenon that the world is not as it appears to be - rarely occur in the real world during the day but are common with NVG's at night. They are primarily caused by cultural lighting (halo's), and are aggravated by shadows, weather, and very low light levels. It is particularly important for military personnel to be acquainted with NVG characteristics and environmental conditions that cause visual illusions. It is for this reason that the Netherlands has made visual illusions a focus of the NVG training development. Misinterpreting a scene is particularly important for pilots.

In this section we review the two main mechanisms that lead to NVG visual illusions. Next we describe a set of demonstrations that were developed with the express purpose to train the course participants to recognize visual illusions and the circumstances when they tend to occur. The motivation is to show students that an understanding of vision and visual illusions is the basis to identify false or incomplete visual sensations.

Figure 2: A classic example of a geometric illusion by Esher, making smart use of the perspective depth cue. The water perpetually runs down the water mill. The majority of visual illusions in the arts consist at least in part of "depth illusions".

3.2.1 Misperceiving depth

Depth and distance cues are of special importance to spatial disorientation because these cues are easily degraded, absent, or misleading in night vision sensors. The two eyes in essence make two-dimensional images of the world, like photographs. The 3-D structure of the world around us therefore needs to be interpreted with the two-dimensional left eye and right eye images as the starting point. The sense of distance and depth is therefore not automatically available to our visual system but must be *interpreted* from a set of "cues" provided by the environment. Table 2 lists these cues. This interpretation process is subject to error if too many cues are missing or available cues are contradictory. The *monocular depth cues* provide the depth perception when viewing the world with one eye closed and the other stationary. The depth in photographs is based exclusively on these cues, also called *pictorial depth cues*. That pictures can convey a strong sense of depth is shown in Figure 2 which gives a compelling example of the power to mislead the viewer. Table 2 also provides an overview of those depth cues that can still be relied on under NVG conditions. A good understanding of these depth cues allows a pilot to discriminate environments that may cause visual illusions from environments that are visually reliable.

	Depth cue	**Effect of NVGs (compared to daylight view)**	
1	*Stereopsis*	*REDUCED ACCURACY*	*due to lowered resolution & contrast*
2	*Motion parallax*	*HANDICAPPED*	*due to limited FOV*
3	*Accommodation*	*ABSENT*	*NVG's are fixed focus*
Pictorial ("monocular") depth cues			
4	Occlusion	RELIABLE	when vertical features are present
5	Perspective	RELIABLE	when parallel features are present
6	Object familiarity	RELIABLE	when man-made features are present
7	Relative height / horizon	RELIABLE	when the horizon is visible
8	*Shading*	*IMPOVERISHED*	*due to lowered contrast*
9	*Texture*	*IMPOVERISHED*	*due to limited resolution*
10	*Atmospheric contrast reduction*	*BIASED*	*due to lowered contrast*
11	*Color*	*ABSENT*	

Table 2. Eleven depth-cues and the limitations imposed by NVG's. Some of the depth cues do (blue) and others *do not* (*red cursive*) remain intact with NVG's. The four reliable cues are particularly useful for piloting.

3.2.2 Perceptual filling-in

When a cat walks behind a half-open fence we experience the motion as continuous, the missing half is being filled-in. The visual system assumes the most likely solution when the image is occluded or otherwise not interpretable. Figure 4c instead gives an example where filling-in is misleading and therefore dangerous. The rooftop is clearly visible behind the tree foliage in the day-view image, including the window. In the NVG image on the right, the rooftop is "filled-in" as part of the tree foliage, and escapes detection. Why does this happen in the NVG image but not during the day? During the day the rooftop distinguishes itself from the tree foliage in its color, luminance, and texture. Through the NVG the rooftop no longer distinguishes itself from the foliage because 1) color is absent, 2) the luminance is virtually identical due to the high chlorophyll reflection, and 3) the texture is too subtle to be picked up by the NVG. As a result the visual system makes a best guess and interprets the rooftop region as belonging to the trees. Perceptual filling-in therefore is a useful visual phenomenon under normal circumstances but tricky while using NVG's.

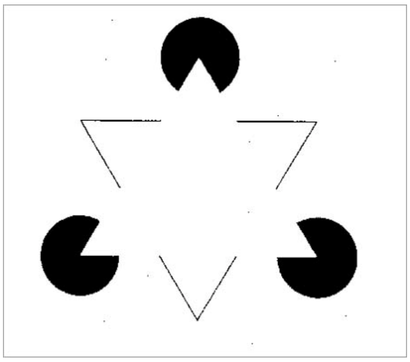


Figure 3: A classic example of "filling-in" by Kanizsa. Two triangles appear, while neither are present.

3.3 Expanding the operational scope: meteorological effects

Our third goal is to expand the scope of operational conditions to include atmospheric conditions. The terrain board is less suited to Dutch F-16 pilots who typically fly at medium to high altitudes. The primary visual effects that occur in the air are the unpredictable perception of other aircraft and the horizon through meteorological conditions like haze and clouds. We have developed demonstrations that show visual effects relevant to the F-16 environment, as in Figures 4c, 6, and 7; as such they supplement the current terrain board.

3.4 Example demonstrations

As stated above, our goal is to enrich the learning experience by making it more *hands-on*, adding visual *illusions*, and including a wider scope of *operational conditions*. Figures 4 and 6 present examples of our approach that are fit for public release. The four demonstrations of Figure 4 are part of the "Disorientation Demonstration" course TNO provides as part of the initial military pilot training in the Netherlands [5], [6]. These photographs serve to illustrate the type of illusions and do not represent the final demo. The actual 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 images in the left column of Figure 4 show the daytime views and the right column show the corresponding night time views as seen through an NVG. The demonstrations have in common that the NVG percept deviates dramatically from the daytime view. A questionnaire distributed among Chinook flight personnel confirms the link to visual illusions experienced in flight, in particular the lack of visibility in shadows, the lack of color, and the halos [11].

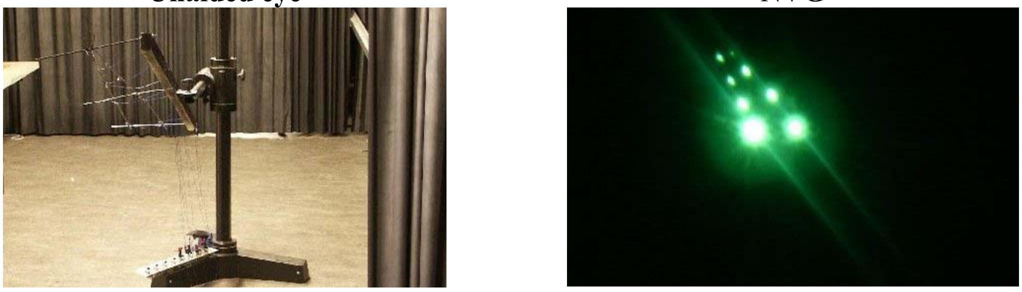
Figure 4a illustrates how *halo's and the dominance of light sources* can cause a reversed depth perception with NVG's. The true geometry is from left in front to right in back, but with the NVG the perceived geometry reverses back-to-front. When the observer moves sideways it appears as if the construction becomes fluid: the geometry distorts. This demonstration is particularly powerful because the viewer cannot overcome the illusion even when (s)he is aware of the correct geometry.

Figure 4b demonstrates the lack *of NVG image quality in shadows*. This 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 invisible when viewed with NVG's at night. The difference between black and dark grey disappears as a result of the poor contrast transfer of NVG's [12].

Figure 4c illustrates the *high reflectivity of chlorophyll* in the near-IR. The scene shows two piles of bricks in the foreground, with trees and grass in the background. Behind the trees there is a house. At places the roof of the house can be seen shining through the leaves of the trees. During the day the dark branches provide a strong contrast with the roof reflecting the light of the sky and the sky itself. This obvious visual distinction disappears in the NVG image because the trees and roof lack luminance as well as color as well as texture contrast.

Figure 4d demonstrates the good visibility of fog with the naked eye and the *poor visibility of fog* with an NVG. Notice the distinction between the visibility of the fog and the visibility through fog; both are effectively degraded with NVG's. The fog is produced with a compact fog generator. Several NVG characteristics contribute to the effect. The monochrome green color of NVG's makes the color of sky and ground identical. The high reflectivity of chlorophyll masks the distinction between vegetation and atmosphere in the NVG. The visual system tends to group objects of similar color and brightness together, hampering the segmentation of atmosphere and ground. Thirdly, the reduced NVG resolution and contrast further degrade the ability to discriminate the typically textured ground from the typically un-textured sky. We believe this provides the basis for observation that subtle atmospheric effects easily go unnoticed with NVG's whereas they are immediately apparent during the day [1].

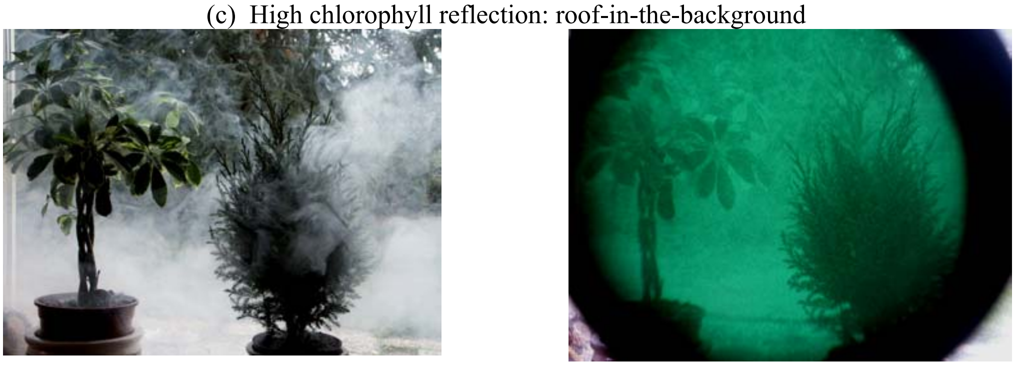
Unaided eye **NVG**



(a) Halo's: Geometric illusion

(b) Poor contrast sensitivity: soldier standing in the door entrance

(c) High chlorophyll reflection: roof-in-the-background



(d) Fog/ cloudiness is much less visible with NVG's

Figure 4: Illustration of different illusions occurring when viewing through NVG's.

4.0 TRANSFER OF THE TNO DEMONSTRATIONS TO THE NVG COURSE

As mentioned before, the terrain board demonstrates the lack of NVG image quality but does not convincingly demonstrate visual illusions. We are in the process of filling this gap by incorporating the TNO visual illusions described above in the RNLAF NVG Lab. To be of practical value, the hands-on demonstrations must be time efficient to fit in the tight schedule of the NVG courses and the attention span of the participants, which especially in the dark tends to be limited. This means no setup and storage time, demonstration completed quickly, with an easy-to-remember take home message. The four demonstrations shown in Figure 4 are being adapted to become part of the terrain board. The inability to look into shadows is also available in an “Army version”. The course participant walks from one end of the NVG lab to the other. The lighting is setup such that the room is clearly visible but the floor is shaded. Randomly placed rubber mats are invisible with the straylight sensitive NVG, making every step of the traverse an adventure. By comparison, when the light geometry is kept constant and the light level turned up to a daylight level, the rubber mats *are* visible to the naked eye.

4.1 Case study: F-16 visual scanning

Another hands-on demonstration is being developed based on F-16 pilot reports on the difference between NVG flight and day flight. The limited NVG field-of-view seriously hampers the jet pilot’s ability to quickly locate his wingmen. The demonstration repeats across the three training levels with an increasing level of operational relevance, providing an example of effective repetition.

4.1.1 Level 1: Knowledge

The rather narrow NVG field-of-view is immediately apparent when looking through an NVG and requires little explanation. The image shown in Figure 5 compares the field-of-view of a standard NVG with two image intensification tubes to that of a panoramic NVG, containing four image intensification tubes.

Figure 5: Comparison of the rather narrow NVG field-of-view to the much roomier Panoramic NVG field-of-view.

4.1.2 Level 2: Hands-on experience

While the limited NVG field-of-view requires little explanation, its implications do. Student pilots generally are surprised by the dramatic effect of the 40deg field-of-view on basic skills like visual search and postural stability. The hands-on demonstration shown schematically in Figure 6 highlights the challenge of locating one’s wingmen with NVG’s.

Procedure

- One of the students stands in the middle of the NVG lab, looking straight ahead.
- At the signal of the instructor, the student looks right then left to spot the two wingmen (F-16 cut-outs on the wall), and then back to the straight ahead viewing direction.
- The instructor measures the time to completion with a stop-watch
- The student repeats the task wearing the NVG

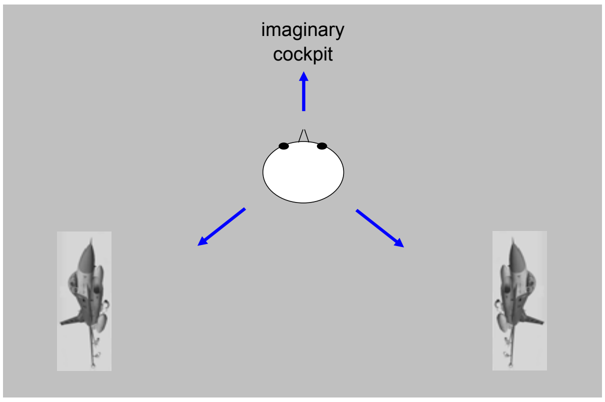


Figure 6: Schematic representation of a "wingmen search task" in the NVG lab.

Especially if the position of the F-16 cut-outs is varied the time required to complete the task increases dramatically with the NVG, from a fraction of a second to several seconds. The hands-on demonstration is very quick to do because no setup time and virtually no explanation are required.

4.1.3 Level 3: Behaviour in (simulated) flight

The analogous task can be experienced and trained in the flight simulator. The longer the pilot looks away from the horizon and cockpit, the greater the risk of unnoticed changes in aircraft attitude and spatial disorientation (SD). The pilot's task can be made more challenging by changing the conditions, for example by flying in thin clouds that obscure the horizon.

To summarize, F-16 scanning behaviour with NVG's can be demonstrated and experienced in a systematic and time-efficient manner.

5.0 NVG-STIMULATION IN THE MSC SIMULATOR

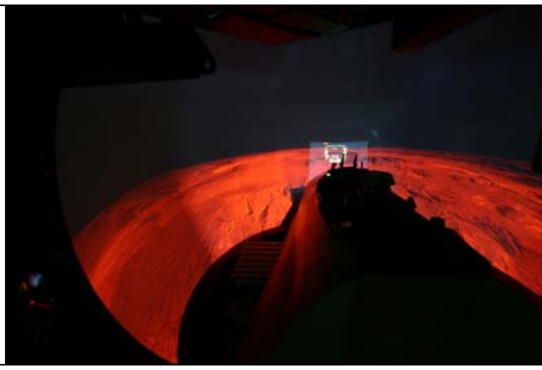
The TNO/RNLAF F-16 Mission Simulation Center (MSC) is a research and pilot training environment. In the near future it will include a HMD+head-tracker combination, enabling NVG simulation. For the NVG training curriculum we have devised an adaptation that requires virtually no set-up time and therefore can easily be combined with other simulator users. It is based on the "NVG stimulation" technique, the pilot viewing the simulator through an actual NVG. In the MSC the wide field-of-view Barco-dome [13] projects the day-view image in red at the regular luminance levels (Figure 7). This saves setup time because the numerous lights in the MSC do not need to be dimmed. The image is barely visible to the pilot who wears close-fitting minus-red bicycle glasses that cover the entire field-of-view. The NVG's are fitted with a neutral density filter + artificial pupil combination, reducing the red to the appropriate night time luminance level. The green NVG image does pass through the minus-red glasses.

The artefacts associated with *NVG-stimulation* are most notably the absence of halo's in the NVG image (halo generation requires a very high image dynamic range) and an incorrect NVG view of the cockpit which in the MSC is not NVG compatible. The scenario, 10km above terrain without cultural lighting, is chosen such that these artefacts do not play a role.

In effect we have expanded the MSC facility to include on-demand medium-quality NVG-stimulation. The advantage over the high-quality NVG-simulation (head-tracker with HMD) therefore is the flexibility provided by the minimal setup time. Other simulators in use by the RNLAF include the Cougar Helisim at Eurocopter near Bordeaux, the Chinook simulator at Ft Benson, and the AMST Diso in Soesterberg. The

Cougar and Chinook simulators provide excellent NVG compatible cockpits, but the outside world contains the characteristic NVG-stimulation artefacts.

Day image



NVG stimulus

Day view

→

→ Filtered NVG →

NVG view

Figure 7: The TNO Mission Simulation Center expanded with NVG stimulation. Because the lights do not need to be dimmed, the conversion from other simulator uses is virtually instantaneous.

6.0 CONCLUSION

Training is required to correctly interpret NVG imagery. Although the images look natural, their characteristics differ from those of daylight images and regularly induce visual illusions. Some characteristics of image intensification can be trained efficiently by deploying photo- and video-simulation techniques, others with a terrain board, and others yet with hands-on demonstrations. The *experience* with hands-on demonstrations is particularly powerful, providing an additional training resource in addition to terrain board, lecture materials, and NVG simulator. The RNLAF is in the process of expanding the NVG introductory training with additional hands-on demonstrations.

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