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Spatial Disorientation Demonstration in The Netherlands

Eric Groen, Bernd de Graaf, Willem Bles, Jelte Bos, Frank Kooi
TNO Human Factors
P.O. Box 23, 3769 ZG Soesterberg
The Netherlands

Phone +31 346 356 372
Fax +31 346 353977
E-mail groen@tm.tno.nl

SUMMARY

In this paper we give an outline of the ground course on spatial disorientation that TNO Human Factor provides for military student aviators of the Royal Netherlands Airforce. During this one-day course a variety of laboratory equipment is used to let students experience and understand different disorienting phenomena and to make them aware of the peculiarities and limits of their sensory systems. With these demonstrations students learn in what situations disorientation, and possibly also symptoms of motion sickness, can be expected and when not. The course also includes an introductory session on the consequences of night vision for situational awareness, which we will describe here. We pay special attention to the motivation and form of the course. Finally we briefly discuss how the flight simulated demonstrator (DISO) of the RNLAF will be employed for demonstrating some flight-related visual illusions and how we upgraded the cockpit with night vision compatibility for practising the use of night vision goggles (NVG).

INTRODUCTION

In the early '90s, the Royal Netherlands Airforce (RNLAF) formulated a master plan to countermeasure spatial disorientation (SD) as a cause for flight accidents. Until then, some general theory on SD problems was presented in the Aviation Physiology class, but there was no actual familiarisation program. The RNLAF asked the Equilibrium & Orientation group of TNO Human Factors in Soesterberg to organise a program for demonstrating SD phenomena using their vestibular research facilities. This was to be realised on a short term. The goal was to have a ground course at the beginning of the elementary flying training in which student pilots would learn the limits of their sensory systems and the dangers of disorientation. On a longer term, the RNLAF asked to develop an advanced course with exercises for the more experienced pilots ("refresher course") in which the pilot practices his priorities during man-in-the-loop scenario's.

The advanced course does not exist yet, although with the development of the Desdemona concept our thoughts begin to crystallise. In the present paper we will give an outline of the basic demonstration program, designated "Demo Basic", which started in 1994 (De Graaf et al. 2000). Since then, more than 300 student aviators participated. Students invariably evaluate the course as very informative and useful. We will describe both the form and its contents, and will identify the – to our opinion – essential elements. At the end of this paper we will describe how we the Demo Basic can be extended with the flight simulated SD demonstrator of the RNLAF (DISO). Recently we investigated the added value of this device, and this year we will incorporate the DISO into a new edition of the Demo Basic.

Paper presented at the RTO HFM Symposium on "Spatial Disorientation in Military Vehicles: Causes, Consequences and Cures", held in La Coruña, Spain, 15-17 April 2002, and published in RTO-MP-086.

OUR APPROACH

Currently, about 65-70 student aviators are being trained on Woensdrecht AFB each year, future pilots on fixed-wing and rotary-wing platforms still together. Each of them participates in the Demo Basic after preferably 10-15 hours of flying experience. Students attend the course in small groups of three persons at a time. This allows for an open, interactive atmosphere with sufficient room for questions and discussion. More importantly, still, the small groups make it possible for each student to experience the demonstration him- or herself, and also to observe the stimulus and the response of their fellow students. This way they realise that, despite some inter-individual difference, their sensory systems show comparable idiosyncrasies that cause disorientation.

It is considered very important that students observe their own reactions ("from the inside out") and compare these with what they see and hear from their colleagues as a bystander ("from the outside in").

Furthermore, we believe that – for familiarisation purposes – demonstrations should be straightforward and understandable. What actually happens should be clear and unambiguous. The student will find it hard enough to match his or her sensation with what he observes that is going on. For this reason, we strongly recommend not to incorporate too complex situations and especially not to use so-called "cheated illusions". Although cheated illusions may give students some idea of how certain disorienting sensations feel, they are produced in a "faked" way and do not make clear the mechanism that causes the illusion. For example, one can "suggest" a tilt sensation during a dark takeoff by actually tilting the device (see Figure 1), but for observant students this is rather trivial. We therefore believe that the use of correct stimuli gives students true understanding of the disorienting mechanisms, which is to be preferred over the mere demonstration of a variety of sensations that may occur during certain manoeuvres.

Illusions should be demonstrated by the same mechanisms as occur in-flight.

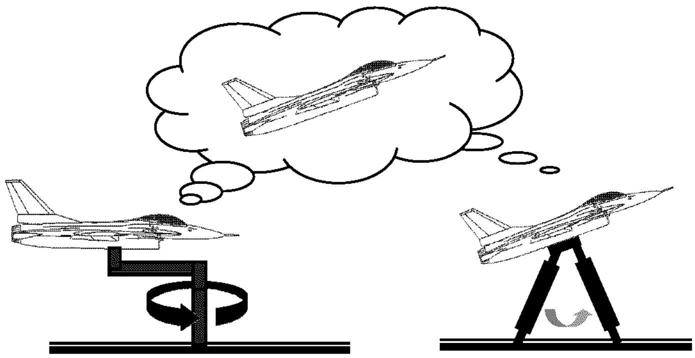

Fig. 1 Demonstration of pitch-up sensation (eg. during a dark takeoff) with a "true" illusion (left), or with a "cheated" illusion by actually tilting the device

In this respect, one does not necessarily require a high-tech demonstrator device with a realistic cockpit, since the fundamentals of SD phenomena can be adequately demonstrated using research facilities of a vestibular laboratory (see also AGARD-625)

DEMO BASIC CONTENTS

The Demo Basic is a one-day course and takes place at TNO-HF. The course includes the following topics:

- Basic theory on SD and physiology
- Demonstrations of (mainly vestibular) illusions
- Night Vision

Theory

During a 45 minutes introduction at the beginning of the day some basic physiology is reviewed. Since the students already followed a tutorial on aviation physiology earlier in their education, we can focus on the sensory systems and their characteristics tailored to the demonstrations later that day: the visual and vestibular system and the somatosensory system. The optimal operational range of each sensory system is explained as well as the close interaction between them. It is made clear how the sensory systems malfunction in transport situations. At this point it is stated that in each transport situation a person is, *by definition*, type 1 disoriented, and that one has to use his mind to interpret the situation, for example by using his instruments. It is stressed that SD is a creeping killer, which may emerge when one is the least expecting it. An anecdote is told of a SD incident, in which a pilot suffered from a persistent (visually induced) inversion illusion. This anecdote should strike students with disbelief first, and should become more acceptable throughout the course when they experience several persistent illusions themselves.

Demonstrations

The emphasis of the Demo Basic is on demonstrating the elementary disorientation effects, mostly related to the vestibular system. The organisation of the course is such that it starts with the most simple illusions and builds up to the more complex and sensational ones. In this paper, however, the presentation of elements is ordered according to the various pieces of equipment. Understandably, in our laboratory this mainly consists of vestibular devices. We do have some possibilities to induce visual illusions, be it with rather abstract stimuli that are not directly related to flight (e.g. random dot patterns). Still, the sensations induced by these displays are quite solid and useful to illustrate some basic visual-vestibular interactions. We have planned to extend the course with more flight-related visual illusions in the DISO cockpit (see later).

3-D rotating chair, yaw mode

The demonstrations start with a session in our servo-controlled 3-D rotating chair (Figure 2). The response of the horizontal semicircular canals is experienced during rotation on a vertical yaw axis. We use a velocity step of 90°/s that is sustained for 90s, while a hooded aviator verbally reports the perceived angular motion and also indicates the change in position in time by pointing a joystick in a fixed heading (like a compass needle).

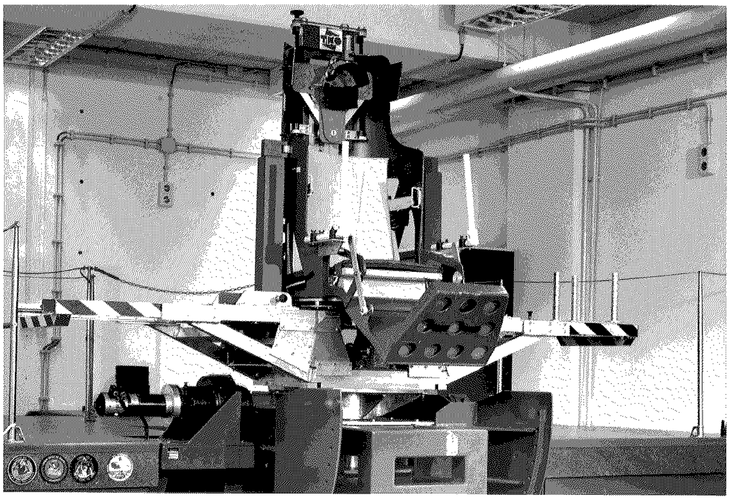

Fig. 2 The 3-D rotating chair in normal yaw mode (rotating on vertcial yaw axis). Demonstration of somagyral effect and the adverse effects of nystagmus on reading.

For the two student aviators watching along the sideline this clearly shows that the turning sensation fades away (somatogyral effect) during constant velocity and starts again, but now in the opposite direction, when the chair stops. It is explained that this concerns type 1 disorientation. After the first student has experienced this sensation successfully, the other two take turns. If a subject student is confused or does not exactly experience the intended sensation (for instance because (s)he has difficulties in ignoring the airflow that results from rotation), the instructions are explained again and it is given another try until it does work out. The time schedule of the course easily allows for repetitions.

The adverse effects of (horizontal) nystagmus on instrument reading are shown using a sinusoidal acceleration profile with a frequency of 0.033Hz and maximum speed of 180°/s. The hooded student is asked to read a matrix of numbers on a display straight-ahead. Here the relation with the flying situation is made and type 2b disorientation is discussed (one knows to be disoriented, but is unable to overcome it because of incapacitating eye movements).

3-D rotating chair, excentric yaw mode

The somatogravic effect is generated with the 3-D rotating chair positioned at about 0.5m off-centre (see Figure 3). The angular velocity is increased in a stepwise manner from 0-180°/s producing a lateral acceleration of about $0.8 m/s^2$. A dome is mounted on the chair onto which a random dot pattern is projected that rotates on the pilot's roll axis. This demonstrates a nice visual-vestibular interaction. Centrifugation in the dark typically produces a sensation of 30° static outward tilt (somatogravic illusion), whereas the rotating visual pattern on a stationary chair generally gives 15° of illusory body tilt. The combination of centrifugation and visual roll motion, however, effectively produces a sensation of full head-over-heels rotation as in an aileron roll (de Graaf et al. 1998).

This element is considered an essential part of the course because it convincingly shows the aviators that sensations that are completely different from the actual stimulus are easy to obtain. Moreover, comparison of the individual time histories and magnitudes of the response of the three aviators shows that different people may assign different relative weightings to the visual and vestibular signals, but that in general the response is the same.

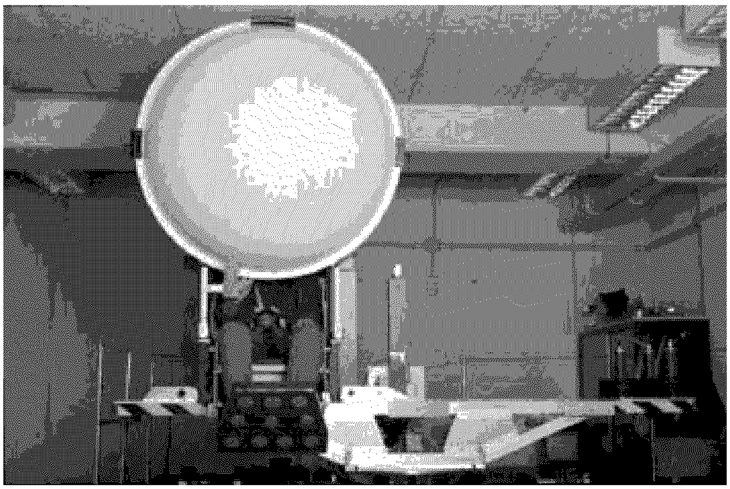

Fig. 3 Excentric mode of 3-D rotating chair. Demonstration of somatogravic effect and interaction with visual stimuli.

<u>3-D rotating chair, roll mode</u>

With the 3-D rotating chair in the roll mode (Figure 4), we demonstrate two effects. First, students estimate the angle of perceived body tilt (attitude) while the chair is put in different static orientations. This shows how people overestimate their body tilt in the dark and how inaccurate the biological attitude indicators are. Typically, in our chair subjects overestimate their tilt angle with a factor two, and it is not uncommon that subjects feel almost inverted at 90° of tilt to one side. The inability to estimate tilt angles correctly is very surprising to the aviators, who are supposed to fly with a precision within degrees. This way they learn that the correct sensor for this precision is outside the body, i.e. the flight instruments. When the chair is positioned upright again after several minutes of body tilt to the same side, there remains a feeling of 5-10° tilt in the opposite direction. This is an example of the "leans".

The second effect demonstrated in this mode is the "ferriswheel illusion" (Mayne 1974). Constant rotation about the horizontal roll axis leads to a series of sensations, where the aviator at the end no longer feels rotation but, instead, an alternating horizontal and vertical translation. This illusion nicely contrasts with the sensation during excentric yaw motion where aviators perceived continuous roll motion during linear acceleration, while during this actual roll motion they perceive linear acceleration. Since this condition is considered quite exciting, we have scheduled it towards the end of the day.

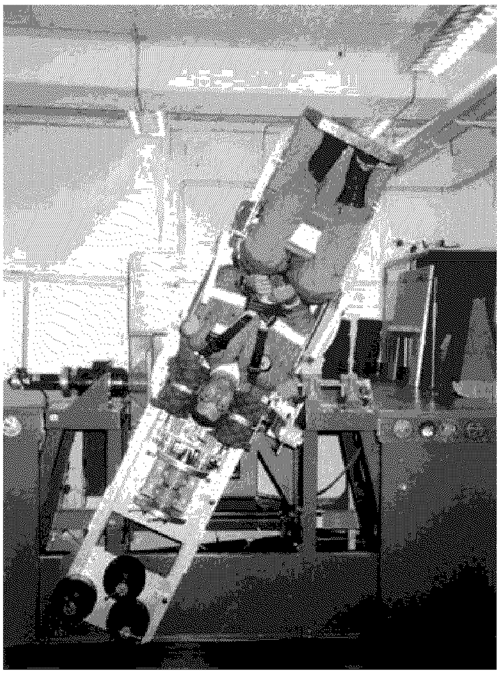

Fig. 4 The 3-D chair in roll mode. Demonstration of leans and ferriswheel illusion.

<u>Barany chair</u>

On our simple rotating chair shown in Figure 5 we demonstrate Coriolis effects. By comparing the effects with eyes open and eyes closed, students experience that angular motion is accurately perceived with a clear view on stable surroundings, but that the sensations may soon become disorienting, or even discomforting, when there is no clear out-the-window view. At this point the causal mechanisms of motion sickness are discussed in more detail, based on our spatial orientation model (Bles et al. 1998). Of course we keep the angular speed during the demonstration low in order to avoid real problems with motion sickness.

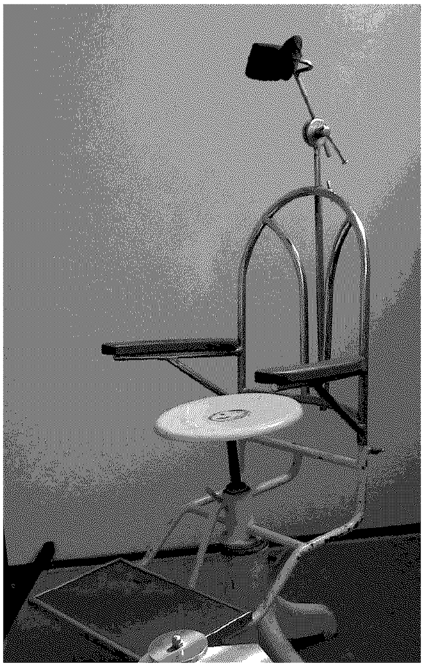

Fig. 5 Classic rotating chair. Demonstration of Coriolis effects.

<u>Tilting room</u>

In our tilting room (Figure 6) we demonstrate the effect of a tilting visual surround on posture and the percept of verticality (visual leans). One pilot is standing on a fixed platform inside the room, trying to keep upright stance, while the room is tilted statically (10°) or dynamically (frequency < 0.2Hz). The subject verbally reports on the apparent deviation of the subjective vertical. His or her postural behaviour is visualised for the other pilots by displaying the forces measured in the platform under the feet. The message of this exercise is that, despite the fact that you know that you are mislead by the sensory information, it is impossible to choose the correct information. Thus again: depend on your flight instruments.

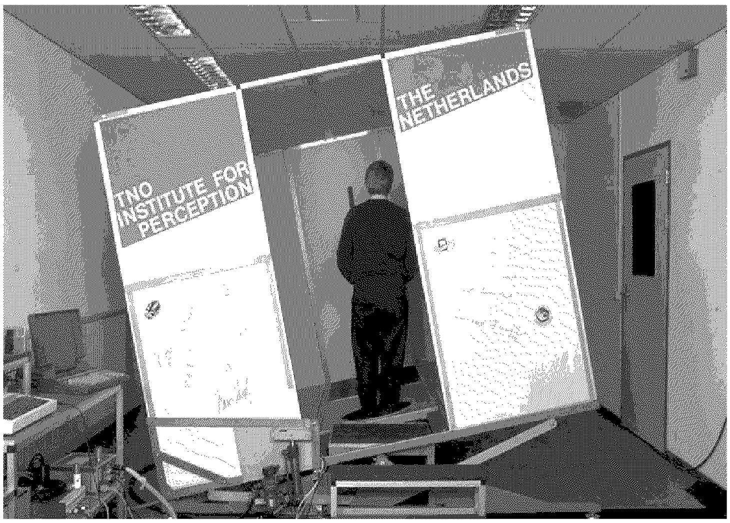

Fig. 6 TNO Tilting room. Demonstration of visual leans.

Night Vision

The course includes a special block on night vision sensors. Night vision goggles (NVGs) and thermal imagers (FLIR) make it possible to look outside at night, be it in a severely degraded fashion compared to natural vision during the day. The degradation of the visual image makes it more difficult to adequately maintain accurate situational awareness (SA). In a session of one hour, students learn to appreciate the various visual limitations by hands-on experience (Figure 7). Thus, similar to the demonstration of vestibular illusions, great importance is attached to an understandable and interactive demonstration of night vision apparatus.

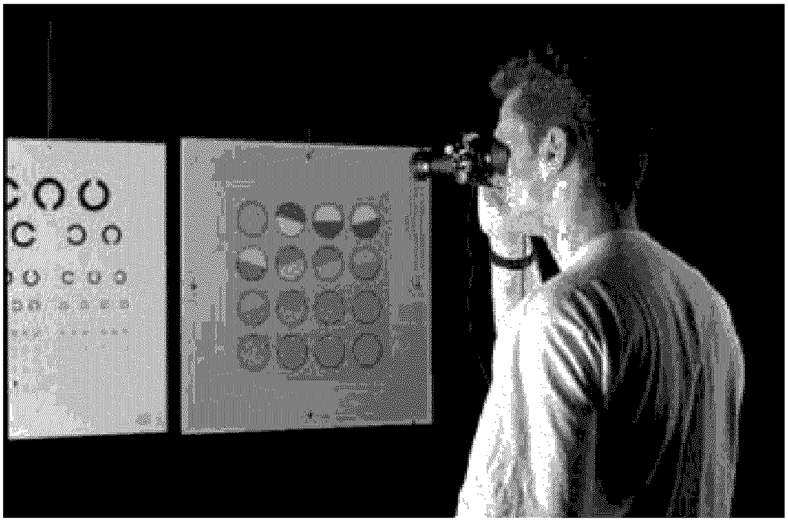

Fig. 7 Demonstration the degradation of vision by the use of NVGs.

The principles of image intensification (night vision goggles, NVGs) and thermal imagers are explained, and their (dis)advantages are compared. The five main visual limitations of NVGs are illustrated with five simple and representative tests mentioned in table I.

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

	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	near-acuity chart	8x
5	colour perception	false colour NVG images	∞

Next it is explained why depth and distance cues are of special importance to SA, and how these cues are degraded, absent or misleading in night vision sensors. The mechanisms of depth perception are reviewed (stereopsis, motion parallax, monocular depth cues), including the concept of visual illusions. The motivation for this exercise is to show students that a good understanding of vision and visual illusions is important because it is possibly the best way to identify false or incomplete visual sensations.

Recently we have upgraded the cockpit of the DISO so that it is night vision friendly. As described in the next section, we will use this feature to extend the night vision training of the Demo Basic with some NVG practice in a cockpit.

SD Demonstrator DISO

Since a few years the RNLAF owns an "Airfox DISO" (AMST Systemtechnik, Austria). This so-called "flight simulated disorientation demonstrator" is located at the neighbouring Aeromedical Institute in Soesterberg (Figure 8), which makes it convenient to combine the device with the Demo Basic. The DISO consists of a generic cockpit with a one-channel collimated out-the-window (OTW) display. The cockpit is mounted on a synergistic motion platform with six degrees-of-freedom (6-DoF). Between the motion base and the cockpit, an extra yaw axis allows for unlimited yaw rotation. The motion characteristics are specified in Table 2.

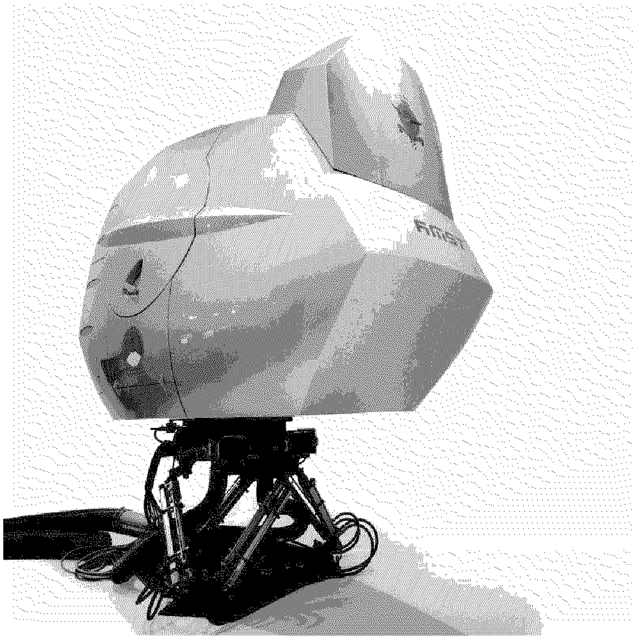

Fig. 8 SD Demonstrator DISO (AMST Systemtechnik).

Table 2 Specifications of DISO motion platform.

	Displacement	Velocity	Acceleration
Pitch	± 30 °	20 °/s	150 °/s^2
Roll	± 30 °	20 °/s	150 °/s^2
Yaw	± 60 °	20 °/s	150 °/s^2
Additional yaw	360 °	150 °/s	15 °/s^2
Heave	± 0.14 m	0.4 m/s	8 m/s^2
Surge	+0.32/-0.27 m	0.4 m/s	8 m/s^2
Sway	± 0.28 m	0.4 m/s	8 m/s^2

Recently we investigated how the Demo Basic can obtain added value from the DISO. Here we will describe the elements that were selected to be included in the program, in addition to the elements described in the previous sections. Several SD illusions are standard implemented in the DISO (see Table 3, the visual illusions marked with *), although the RNLAF instructor modified the parameters of some of the illusions to make them more convincing and effective. With respect to the elementary vestibular effects (Coriolis, somatogyral, somatogravic, Dark takeoff, etc.) we preferred to continue the demonstration of these effects in our laboratory. As argued above, laboratory equipment allows for more open and observable demonstrations than a cockpit where the student pilot is physically separated from the instructor and colleagues. We therefore had the "luxury" to disregard (most of) the vestibular illusions of the DISO, and to look primarily at the visual illusions and night vision possibilities. Still, it was considered useful to include the "Leans active", which simulates the leans after recovery from a co-ordinated turn. Although the illusion is cheated by disabling roll motion in the direction of the turn, the demonstration may be educational since it allows the students to make a connection between the sensation in the tilting chair with that in the cockpit. For this reason, it is relevant that the DISO session will be schedules at the end of the day after the TNO sessions.

The following *visual illusions* were considered appropriate in the context of the Demo Basic: autokinesis, false horizon, black hole approach, variations of runway perspective, and some illusions created by the DISO instructor, such as cloud leans, and confusing star-ground light (for a description of illusions, see e.g. Benson 1988).

Table 3 List of standard illusions in the DISO.

	Illusion
1	Coriolis (Barany chair)
2	Nystagmus
3	Oculogyral
4	Autokinese*
5	Somatogyral
6	Coriolis active
7	Graveyard spin
8	Leans (active)
9	Leans (turbulence)
10	Blackhole approach*
11	Dark take off
12	False horizon*
13	Variation of runway width*
14	Variation of runway slope*

With respect to the *night vision capabilities* of the DISO, we concluded that with minor modifications the cockpit could be made "NVG compatible", or perhaps more correctly "NVG friendly". The collimating display of the DISO is sufficiently uniform to allow for the use of F4949 NVGs. This is relevant, since the depth of focus of NVGs is only about 0.04 diopters (compared to 0.15 diopters of the eye), and optical aberrations would easily lead to blurred parts of the image. Thus the collimator's optical quality itself is suitable for the use NVGs. Ideally, a NVG compatible cockpit should meet the following requirements:

1. Canopy reflections due to instrument and cockpit lighting should be eliminated
2. OTW display should be invisible for the unaided eye
3. OTW display should give realistic NVG images

Regarding the first point, instrument reflections are normally eliminated by filters that let through visible light (400-600nm) but that block the (near) infrared part of the spectrum (600-1000nm). Instead of placing filters in front of each instrument, however, we opted for a less expensive solution and placed 2ND (neutral density) filters in front of the NVGs' lenses (Figure 9). These filters attenuate the available light (both visible and infrared) by a factor 100. The F4949 NVGs used by the RNLAF contain an ANVIS class-b filter that already blocks the visible part of the spectrum, so that the net effect of our filters is to attenuate the (near) infrared part of the spectrum. This seems adequate to make the instruments indiscernible through the NVGs, while the OTW display is sufficiently bright to remain visible through the NVGs. In fact, seen through NVGs with a 2ND filter the OTW image has the appearance of a night scene without moonlight. Using a 3ND (factor 1000) the OTW looks like a moonlit night scene. Because of its brightness, however, the OTW is also visible for the unaided eye looking under the NVGs. Thus, to meet the second requirement mentioned above, we placed a gelatinous filter in front of the OTW display, reducing the visible light with a factor 1000. The combination of both filter types (2ND and gelatinous) results in an OTW image that is dark for the unaided eye but clearly visible through NVGs, and instruments that do not disturb the NVGs image but that can be inspected under the NVGs with the unaided eye.

Regarding the third requirement, a NVG compatible simulator should contain a special "night visual database", so that the image generator can render the contrast and colours that are typical for NVGs images. However, at this moment, no such night database exists for the DISO. As a result no meteorological or geographical effects can be shown yet.

Fig. 9 F4949 night vision goggles with 2ND filters. In combination with the gelatinous filter in front of the collimated display, the NVGs can be used for training in the DISO.

With our simple modifications, the DISO can already be used for some elementary NVG training:

- Adjusting and focusing NVGs
- Showing the consequences of NVG compatibility (with and without filters), for instance the need to alternate gaze direction between straight-ahead (OTW) and under NVG (instruments)
- Compare the differences between moonlight and starlight conditions (2ND and 3ND filter) and the effect of "speckle noise"
- Getting used to the altered centre of gravity of the head

The following aspects can not be demonstrated yet, but they will become possible with an upgrade of the DISO's visual database into a night vision database:

- Halos resulting from bright light sources
- Contrast ratios due to the different spectral sensitivity of NVGs
- Visual illusions resulting from meteorological and geographic effects
- HUD (currently, the HUD does not stand out against the background OTW scene as it should, since it is simulated as part of the OTW image. The visual database should be changed as to take this into account).

Due to the small field-of-view of the OTW display, it is principally impossible to train adequate scanning behaviour that helps to update one's situational awareness. Moreover, the spatial resolution of the DISO image is not sufficient to demonstrate the deteriorating effects of NVGs on contrast and resolution. Therefore, demonstration of these principles in the laboratory will still be useful.

CONCLUSIONS

The Demo Basic is a familiarisation program for all student pilots of the RNLAF at the beginning of their flying training. The course is highly appreciated by its participants. It is considered very important that demonstrations take place on laboratory devices, which provide the best way to impart fundamental insight to the students about the mechanisms of disorientation and the limitations of night vision sensors. The unambiguous and "open" stimulus apparatus allows for close interaction between the subject pilot on the one hand, and the instructor and other pilots on the other hand. The basic course will be extended with some flight-related demonstrations in the disorientation demonstrator DISO of the RNLAF. Some typical visual illusions will be illustrated, and we will practice the use of NVGs. For this purpose the cockpit was made NVG compatible. However, the demonstration of basic vestibular illusions will not be done in the DISO, as long as the vestibular laboratory is an alternative.

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