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HELICOPTER NVG COMPATIBLE COCKPIT ILLUMINATION ASSESSMENTS

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by

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Abstract

During the last 12 years EUROCOPTER Deutschland GmbH (ECD) has worked on night vision aids including helicopter **NVG** (Night Vision Goggles) compatible illuminations. Different illumination have been studied and realized.

The requirements of **MIL-L-85762A specification** are very high and have to be checked with spectral photoradiometers. The level of **NVIS radiance** (NR < 1.7x10-10 at 0.34cd/m²) has to be fulfilled for many instruments with **NVIS** (Night Vision Imaging System) "Green A" color in the CIE chromaticity diagram. Master caution and warnings have different chromaticity and radiance requirements. Military Helicopter (**HC**) missions with dark ambient light levels (night level 5 according to FINABEL report with <0.7mLux) especially need a NVIS-radiance performance value which avoids interference between the illumination and the response of Image Intensifier Tubes (**IIT**). Sunlight readability of all instruments with good contrast at 100 000 Lux is additionally required.

ECD has a night **VIS**ion Laboratory (**VISL**) with different resolution test pattern and instruments like the Spectro-Photoradiometers PR 713/PC and PR 1980C/NVG and several high-sensitivity Photometers (Luxmeter). Additional test devices are a Philips NVG 3. gen. (Type I, Class A/B: 645 nm cut-on filter), an Integrated Helmet Systems (IHS, Type II), an ANVIS 3.gen. tubes (Type I, ClassA: 625 nm) and a Monoscope (2. Gen. tube and with Class A and Class B filters).

Experience was made with the PR 713 and PR 1980C on linear or logarithmic radiance scale regarding different illumination technologies integrated into the HC cockpit:

- o filtered pure green LED-Panels
- o filtered incandescent light: e.g. green-filtered Bezels and postlights for 2" and 3" instruments,
- o filtered LCD-MFDs, filtered CRT-MFDs and filtered EL-Displays,
- o lighted switch or button technologies for status and warnings
- o floodlight techniques with green-filtered goose-necks or UV-lamps with fluorescence from saturn yellow or blanc emeraude painting.

The cockpit assessments on **BK117/AVT** and **TIGER** showed additional requirements for NVIS compatible illumination e.g. good legibility and readability, minimized masking effects (shadowing), high homogeneity of different lights, proper cockpit finish, reduced window reflections, installation aspects of floodlights, minimized HC detectability from outside, no auto kinesis effects (hard contrast) etc. for a good NVG cockpit layout. These parameters were assessed by engineers and pilots with a questionnaire using a type of Cooper-Harper-Rating procedure.

The paper presents the problems, improvements after assessments on Primary Integration Rig (**PIR**) and results of measuring NVG radiance, luminance, chromaticity co-ordinates, colors and contrasts for different illumination techniques in HC cockpits.

1. Introduction

A pilot flying with a helmet-mounted NVG or Integrated Helmet System (**IHS**), compare chapter 2, must also be able to read the illuminated displays in the crewstations with his unaided, normal vision (naked eye). Displays must be visible to the unaided eye while emitting very low levels of IR. If a display emits small amounts of radiant energy within the response range of the IR-sensitive photo cathode, it may degrade the performance of the NVG and therefore the visual acuity (compare chapter 4. Fig. 4-2). The flight safety of a HC should not be impaired. **NVG compatible illuminated** displays/instruments **do not interfere** with NVG sensitivity range and remain readable by the naked eye. On the contrary during daytime with illumination level up to 100 000 Lux, a sunlight readability of all instruments is required.
The **detectability** of a HC cockpit illumination from outside view with IITs or the naked eyes should be minimized for an enemy.

There exist two solutions for making the HC cockpit lighting NVG compatible:

a) **retrofit** an existing cockpit or

b) **new design** of instrument illumination according to MIL-L-85762A.

At the beginning of the 1980's a cost effective retrofit solution with floodlight electroluminescent (EL) and EL-Bezel technique (ref. 1) was selected which had bad uniformity and which was not completely NVG compatible according to MIL.

Remark: *MIL-L-85762A was at that time not* available.

The paper describes in chapter 2 the visual aids incl. night levels and the characteristics of MIL. Chapter 3 presents the VISionic Laboratory **(VISL)**, chapter 4 measurements of NVIS resolution and chapter 5 HC cockpit illumination technologies incl. measurements. Cockpit assessments on BK117/AVT and TIGER are mentioned in chapter 6.

Remark: HC exterior illuminations are not described in this paper.

2. Helicopter night flight requirements

2.1 Visual aids and night levels

In contrast to fixed wing aircraft, a HC flies lower. The so-called Nap of the Earth **(NOE)** flying is performed at heights between 3 and 50 feet above ground at a speed of approx. 0 to 40 knots at night and 0 to 70 knots in daytime. In the early days of aviation, information was restricted mainly to that directly coming to the natural sense organs like eye, ear and sense of balance. More and more artificial sensors are now being used, detecting signals of various wavelength which are translated into the area of natural perception. The pilot perceives most information with his two eyes.

Detailed descriptions of fundamental radiometric and photometric *characteristics*, NVGs, *physiology*, how the human eye works in photopic, mesopic and scotopic vision can be found in standard articles (e.g. ref.1,10,15,16) or books (ref.4). **Visual aids**, in the form of **multispectral electro-optic sensors** for helicopter night flight application can be divided into three main categories:

- o **Image Intensifier Tubes** (IIT, NVIS) near infrared (approx.0.6-0.93μm)
- o **Thermal Imager** (TI) thermal infrared approx. 3-5 and 8-13μm)
- o **Imaging Micro-Wave Radar's** micro-wave (approx. 35, 94 and 140GHz) (last sensor group will be installed in future HC's only)

The development of helmet-mounted **NVG with 3rd generation IIT** for helicopter applications allows the pilot to look around the goggles into the cockpit and onto the instrument panels in front of him with his "naked eye". He sees through the goggles into the outside world. *With the 3rd gen.* IIT it is possible to better amplify ambient light from the night sky and foliage or a defoliated tree reflectivity (Fig. 2-2).

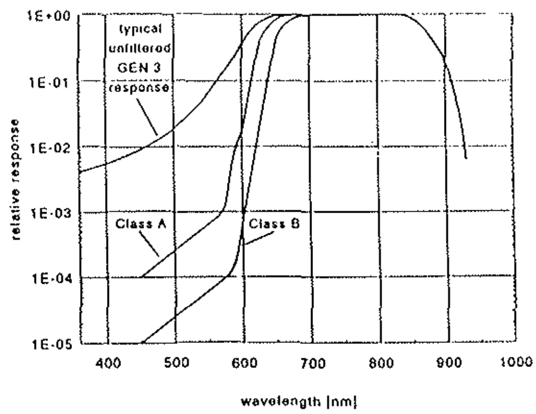


Fig. 2-1: Spectral response of 3rd generation IIT (unfiltered) and with Class A and Class B minus-blue filters in log.- lin. scale, compare chapt. 2.2.

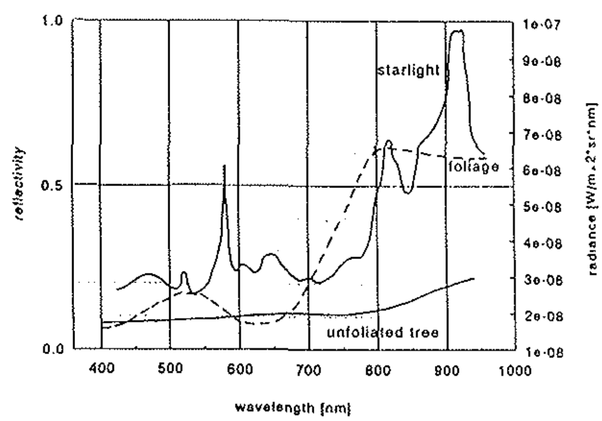


Fig. 2-2: Reflectivity for foliage or a defoliated tree and natural night-sky spectral irradiance in lin.-lin. scale (according to ref. 15)

The 3rd gen. IIT uses an objective with an input window, a high sensitive GaAs/AlGaAs Photo cathode, a Micro Channel Plate **(MCP)**, a P20 phosphor screen, an optical twister and an ocular with approx. 5cd/m² output luminance, controlled by an Automatic Gain Control **(AGC)** according to STANAG 4341. Observing the NVG screen, the observer receives a luminance level between photopic and mesopic vision, which means he *detects the monochrome radiation with the cones* (color) and rods (black and white) of his eyes.

Level of obscurity	night conditions	% per year, south France	illumination mLux *)	Level of obscurity	% per year northern Germany	illumination mLux *)
1	very clear	**14.0**	40-200	**1a**	**3**	135-400
				1b	**10**	40-135
2	clear	**24.0**	10-40	**2**	**27**	5-40
3	normal	**7.0**	2-10	**3**	**9**	2-5
4	dark	**27.5**	0.-2	**4**	**19**	1-2
5	very dark	**27.5**	0.1-0.7	**5a**	**22**	0.5-1
				5b	**10**	<0.5

Table 1: The table contains the distribution of the average ambient illumination and **levels of obscurity** (night) from a Finabel Study (1978) and measurements in northern Germany.
Remark: *) The night sky is observed by IIT's and not by human eyes. The precise value should be measured in irradiance (W/m²) instead of illumination (Lux)

The values from table I were measured over a period of one year in Southwest France and in north Germany respectively. The results indicate that for approx. 27.5% of the year very dark nights occur where illumination lies below 0.7 mLux, so-called night **level 5**. 3rd gen. IIT can amplify ambient light below 0.5 mLux.
Limits for image intensifier sensors in the **German Army Aviation Branch** are determined by
- o **ambient light** and
- o **transparency of the atmosphere.**

Image intensifier vision of at **least 1.5 km** is calculated from those two parameters and the light value must not be less then **0.5 mLux.**
On the contrary, a **TI sensor** detects the emitted radiation of each body. The TI introduces enhanced night vision capabilities for HC day and night flight together with new problems associated with the interpretation of visual information based on spectral and spatial characteristics differing from those provided by unaided vision. During a 24 hour mission the TI sensor alone can have a great disadvantage. The absolute temperature characteristic or the emissivity of natural materials varies as a function of a 24 hour period. Thermal zero contrast (wash out effect) is observed especially during and immediately after rainfall, while the so-called cross-over effect is apparent at dawn and twilight. Then the foreground is not detectable against the background.
Therefore the combination of the two visual aids: IIT and TI, which are based on different physical principles, is better suited to fulfil the increased requirements of adverse weather conditions during day and night time. An advanced **Integrated Helmet System (IHS)** with binocular vision incl. see-through capability (two CRTs, two IIT's and two combiners with optical path on the helmet) can display head up images of the intensifier and thermal images superimposed with flight symbology. The peripheral vision of an IHS is higher than in NVG, ref. 10 and 17.

Fig. 2-3: An IHS with see-through capability from GEC Avionics.

2.2 NVG compatibility requirements according to MIL-L-85762A

In order to fly night time missions with NVG or IHS, a helicopter cockpit has to fulfil some requirements concerning the cockpit lighting. These requirements and verification methods are specified in the Military Specification MIL-L-85762A. The different possible techniques of cockpit lighting are freely selectable and are not described in MIL.
MIL-L-85762A classifies Gen 3 NVG compatible lighting according to Night Vision Imaging System (**NVIS**) type and class:

Type I (NVG) Direct View Image:
The view through the goggle eyepiece includes only the NVG phosphor-screen image. The pilot must glance down to see his instruments.

Type II (IHS, Cat´s Eyes) Projected Image: A combiner lens allows the pilot a see-through capability with a simultaneously projected NVG image

Class A: Addition of a **625 nm** minus-blue cut-on filter to the objective lens (filter or dielectric coating) produces the response shown in Fig. 2-1. The one-percent (1%) relative response is at 595nm, which allows cockpit illumination **in blue, green (advisory) and yellow (caution, master caution, warning).** To avoid interference from orange and red displays, MIL-L-85762A excludes them from Class A cockpits.

Class B: Addition of a **665 nm** minus-blue cut-on filter to the objective lens produces the response shown in Fig.2-1. Here, the one-percent (1%) relative response is at 625 nm, which excludes most of red from the IIT response to allow cockpit illumination in **blue, green (advisory), yellow (caution), and red (master caution, warning).**
The German Army NVG (BM8043) uses a cut-on at **645 nm** between Class A and Class B.

Chromaticity co-ordinates, total contrast and uniformity:
Sunlight consists of different wavelengths. A small part of these wavelengths is so-called **visible light** detected by the three types of cones in the human eyes. White light is a mixture of the visible wavelengths (max.380-780nm). The different colors neutralize each other. If a certain wavelength is filtered one obtains a **dominant wavelength**, the so-called color. The color **purity** is determined by means of the Commission Internationale de l´Eclairage (**CIE**, 1931) diagram with an improvement of the 1976 Uniform Color Scale (**UCS**, Fig.2-5). The purity is given in percentage and is defined by the connecting line between the white point and the periphery of the CIE diagram. The third dimension of color is added to the CIE chromaticity diagram by adding the luminance-factor axis (intensity, **grey scale**) which determines the **color contrast**. NVIS colors (Green A, Green B, Yellow and Red) are not standard aviation colors, but are particular to NVIS because of the limits on NVIS radiance (NR). For NVIS Class A goggles the red color is not allowed because red falls within the Class A NVIS response and would cause unacceptable NR. The measured UCS co-ordinates (u´, v´) are required to be within a color circle defined as

$$(r)^2 \geq (u' - u_1')^2 + (v' - v_1')^2$$

The Index of Discrimination (**ID**) is calculated by means of the Pythagorean Theorem in a three dimensional space with the luminance contrast (**IDL**) *and the color contrast* (**IDC**).

$$ID = \sqrt{(IDL^2 + IDC^2)}$$

for sunlight and NVIS readability

$$IDL = \frac{\log\frac{L1}{L2}}{\log\sqrt{2}}$$

L_1, L_2 = luminance values of compared colors; L1 > L2

$$IDC = \sqrt{\frac{\Delta u'^2 + \Delta v'^2}{0.027}}$$

Δu and Δv = 1960 CIE-UCS chromaticity co-ordinates of compared colors

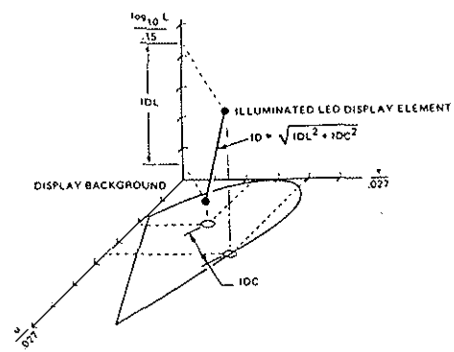


Fig. 2-4: Total achieved contrast

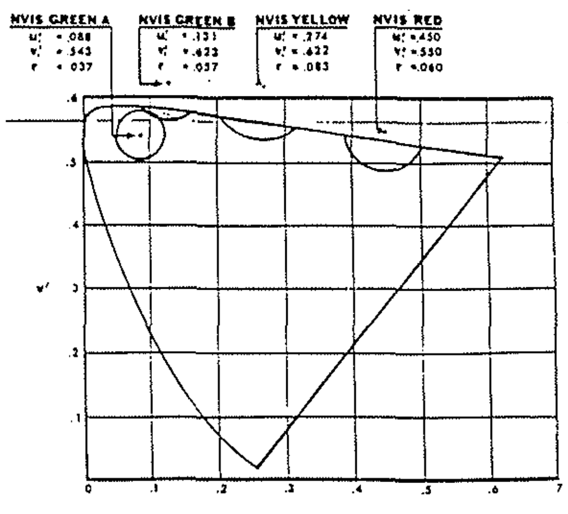


Fig. 2-5: Chromaticity coordinates (u´, v´) UCS 1976 with MIL-L-85762A color levels

The **uniformity** of the HC cockpit markings shall be in a illuminance range of either 3:1 according to MIL-P-7788E or 2:1 according to MIL-L-85762A.

NVIS radiance (NR):
NR is a figure of merit to measure the degree of NVIS interference of illumination at a specified luminance. NR can be used to compare the relative **NVIS compatibility of illuminations**.

NR is calculated from the measured spectral radiance (W/sr m² nm) of a light source.
If the image of the cockpit lighting, when viewed through the NVG, is not brighter than the outside scene then that lighting could be considered as being compatible.

The most difficult terrain feature to see at night is a defoliated tree. The NVIS radiance of a **defoliated tree in starlight** is derived by multiplying the spectral radiance of starlight by the spectral reflectivity of tree bark and using this curve for **N(λ)** in the equation, compare Figs. 2-1 and 2-2:

$$NR_X = G(\lambda)_{max} \int_{450}^{930} G_A(\lambda) * S * N_t(\lambda) * d\lambda \quad \text{where}$$

NR_X = NVIS radiance **threshold** value of tree bark in starlight illumination (-); NR_A for Class A, NR_B for Class B response

$G(\lambda)_{max}$ = standardization factor (1 mA/W), to obtain correct dimensions

$G_A(\lambda)$ = relative spectral response for NVIS Class A (-)

S = scaling factor (-); (increase of device S/N ratio by taking higher luminance values as 0.34 cd/m²; here 1)

$N_t(\lambda)$ = spectral radiance of tree bark in starlight (W/m² sr nm)

dλ = wavelength in 5nm increments

resulting in the radiance threshold value:

$$NR_t = 1.7 \times 10^{-10} \ (-)$$

for NVIS with Class A cut-on filter.

Since the total amount of NVIS radiance emitted by a lighting component varies with the brightness setting, a luminance level had to be defined at which the NVIS radiance is to be measured. When using NVIS a pilot views his cockpit lighting with his unaided eye. US Air Force tests showed that pilots using NVIS set their cockpit lighting to less than 0.1 foot-Lamberts (0.34cd/m²). The requirements for NR_B only, incl. colors and luminances are shown in Table 2. The equation for NR_A and NR_B in the MIL includes a scaling factor S with $S = L_r / L_m$

where:

L_r = required luminance for NVIS radiance and

L_m = luminance measured by the spectro-radiometer, to avoid S/N problems of the measuring device.

MIL-L-85762A describes further the following items: controls, secondary instrument lighting, compartment lighting, utility lighting, emergency exit lighting, caution and advisory signals, jump lights, work and inspection lights, CRTs, EL, LCD's etc. and also quality assurance provisions: first article and quality conformance inspections.

Color	1976 UCS Chromaticity Coordinates			NR_B
	u′	v′	radius	
Green A	0.088	0.543	0.037	$< 1.7 \times 10^{-10}$ at 0.1fL
Green B	0.131	0.623	0.057	$< 1.7 \times 10^{-10}$ at 0.1fL
Yellow	0.274	0.622	0.083	$< 1.5 \times 10^{-7}$ at 15 fL
Red	0.450	0.550	0.060	$< 1.4 \times 10^{-7}$ at 15 fL

Table 2: Chromaticity Coordinates and NR_B levels (extract from MIL-L-85762A, Tables VIII/IX)

3. ECD Night VISion Laboratory (VISL)

In the ECD Night Vision Laboratory it is possible to conduct two kinds of measurements:

a) **Resolution measurements** of Image Intensifier Systems

b) **NVG compatibility** measurements according to MIL-L-85762A (radiance, luminance, chromaticity coordinates, contrast etc.)

For both kinds of measurements a total darkroom is necessary. Total dark means not only a room without windows; the walls and the furniture are dim black, while the door is hidden behind a black curtain to keep out light coming in through the slits between door and floor. Every single light source e.g. light bulbs and LED's in the measuring-equipment or the computer is covered by black tape. To find all the disturbing light sources (or leaks) it is advisable to use a NVG.

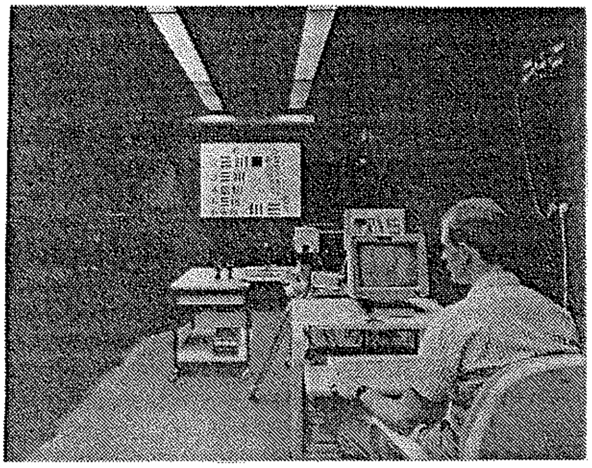


Fig. 3-1a: The ECD Night Vision Laboratory (VISL)

For the Image Intensifier System measurements there is a defined and reproducible illumination/irradiance source required.

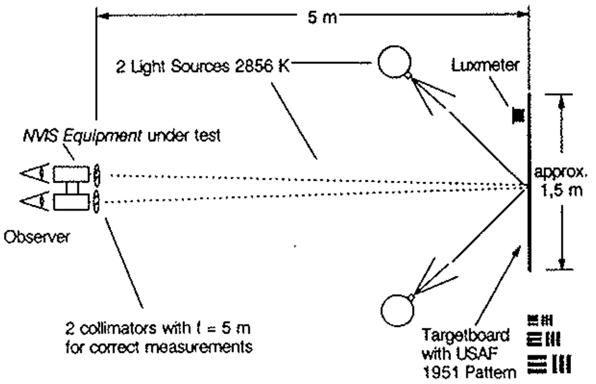


Fig. 3-1b: Top view of the test set with two controllable integrated spheres in VISL to measure resolution and sensitivity of NVIS

Therefore two integrated spheres are in the laboratory installed which illuminate one end of the laboratory incl. target at an angle of 45° from the left and the right side (Fig. 3-1b). It is therefore possible to achieve a very homogeneous illumination of the end of the laboratory, where the vision test boards e.g. the USAF 1951 high contrast targets (100% or 70%) are located. The light sources in the integrated spheres are halogen spots (12 volts) operated in current-stabilization, to keep a constant color temperature.

For NVG and IHS tests the MIL-A-49425(CR) requires norm light **A** , which has a color temperature of 2856 K (+/- 50K allowed). To simulate different night vision levels without changing the color temperature, there is an adjustable Iris aperture in front of the halogen spot in the integrated sphere. Illumination levels between 0.01 mLux and 3.6 Lux can thus be reproduced. In the future starlight simulation experiments with a slide-projector are planned.

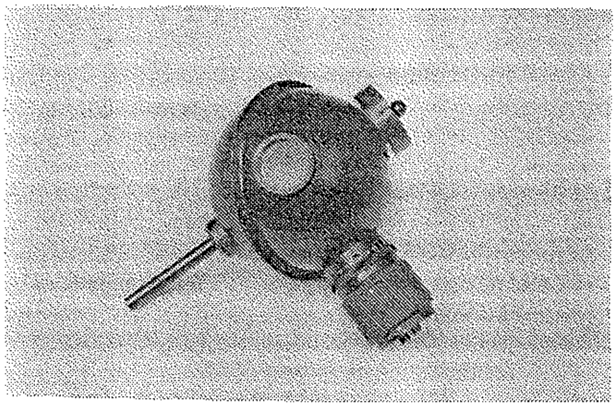


Fig. 3-2a: Integrated sphere

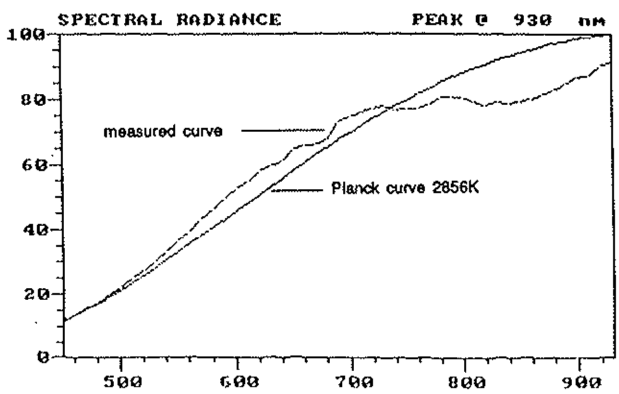
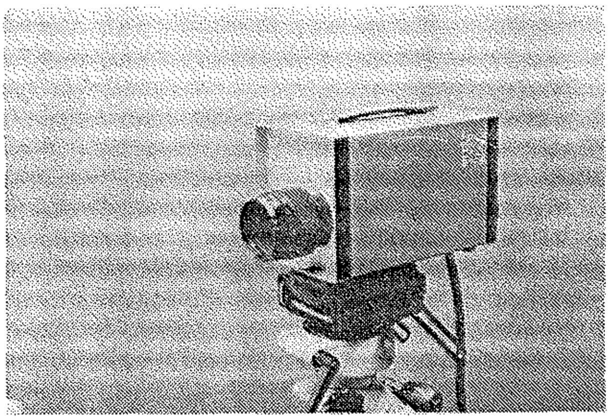


Fig. 3-2b: Spectral radiance measurement of norm light A and theoretical Planck-curve for 2856K temperature

To measure sensitive illumination levels, the laboratory is equipped with several high sensitivity photometers from LMT and EG&G. The LMT S1000 has a measuring range from 600 kLux down to 0.01 mLux (10^{-5} Lux).
Two Spectral Photoradiometers from Photo Research (PR713PC and PR1980C/NVG) and a Monoscope from Hoffman Engineering Company are used for the NVIS radiance and chromaticity measurements.



Figs. 3-3a: PR713PC fast spectro-photo radiometer mounted on a tripod

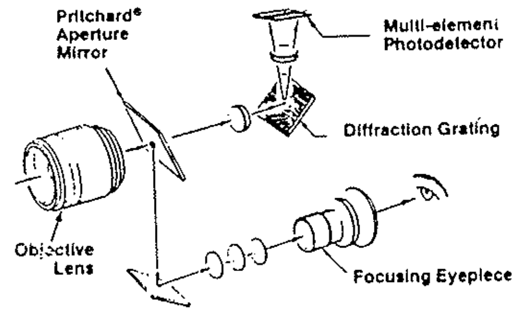
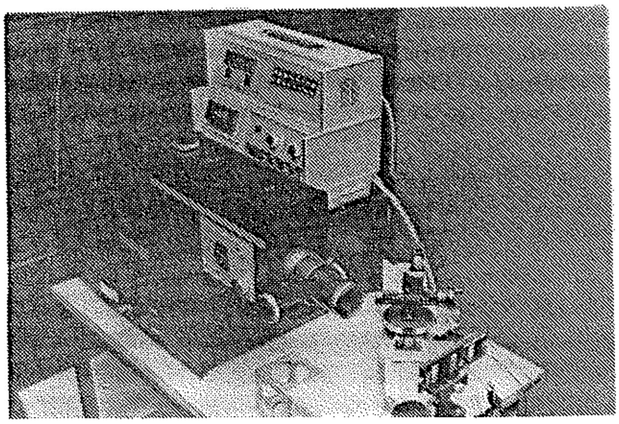
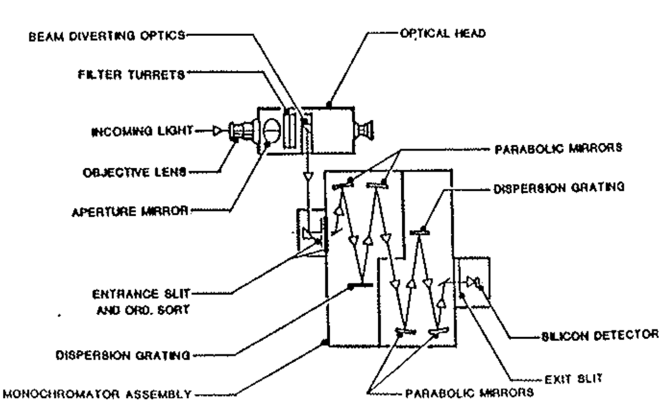


Fig. 3-3b: Optical path from the Pritchard Aperture Mirror spectro-photoradiometer.

The PR713PC spectro-photoradiometer measuring-head functions by the **Pritchard Aperture Mirror** Principle:
The light passing through the objective lenses falls on a mirror, which is positioned at an angle of 45° to the line of sight. In the center of this Pritchard Aperture Mirror there is a small aperture. Only the light finding its way through this aperture falls on a diffraction grating. The spectrally diffracted light is analysed by a 256-element photo detector-array. Light, which strikes the Pritchard Aperture Mirror, falls on a second mirror and then through the eyepiece. The image in the eyepiece shows the test object. The Pritchard Aperture is visible as a little black spot in the center of the image and characterises the measuring area. A software programme run on a Personal Computer, calculates the sensor signals and shows the spectral scan, the CIE chromaticity coordinates and the luminance (approx. 1 - 23 000 cd/m²). See Figs. 3-3a and 3b).
The advantages of the PR713 are the mobility inside the laboratory or cockpit, the short measuring cycles of a few seconds to approx. 1 minute (maximum), but sources with low luminance level (< 1cd/m²) cannot be measured. The spectral range is 390 nm to 1070 nm. The rapid decreasing sensitivity over 1000 nm of the sensor leads to noise, which is visible in the measuring plot.

The PR1980C/NVG spectro-photoradiometer (Figs. 3-4a and 4b) consist of an optical head with a Pritchard Aperture Mirror Disc System for luminance measurements, a monochromator assembly for the spectral scans and a control and display unit. In contrast to the Pritchard Aperture Mirror System of the PR713PC the mirror is constructed here as a revolving disc with several apertures between 3° and 2'. The luminance measuring range from 0.01e-5 to 10.00e7 cd/m² is much more sensitive than the range of the PR713PC. A typical ANVIS scan takes about one hour with 10 nm steps.





Figs. 3-4a and b: The PR1980C/NVG spectro-photoradiometer and the optical path

For spectral scans the light leaves the optical head and, guided by two mirrors, enters the *monochromator assembly, where it is dispersed* by a double dispersion grating system. During a scan the gratings are turning simultaneously step by step. The steps are adjustable between 1 to 10 nm. One scanning cycle lasts about 1 hour, depending on the measured radiance levels of the source. The scan range lies between 380 and 930 nm for NVIS measurements. The software has additional features to the software of the PR713PC. For example, it is possible to choose a **linear** or a **logarithmic** scale on the abscissa, which is very important to show the near IR parts of a cockpit illumination. A further
remarkable feature is the so-called '**NVIS-Scan**'. This is a spectral scan mode, in which the NVIS-radiance NR_A or NR_B according to MIL-L85762A is computed by the software. If NVIS-radiance and NVIS-color is in the allowed range, there appears a '**pass**' in the measuring-plot (see Fig. 5-1c).
The monoscope (Figs 3-5a and 5b) is a special measuring equipment for the direct determination of the NVIS-radiance NR_A and NR_B.

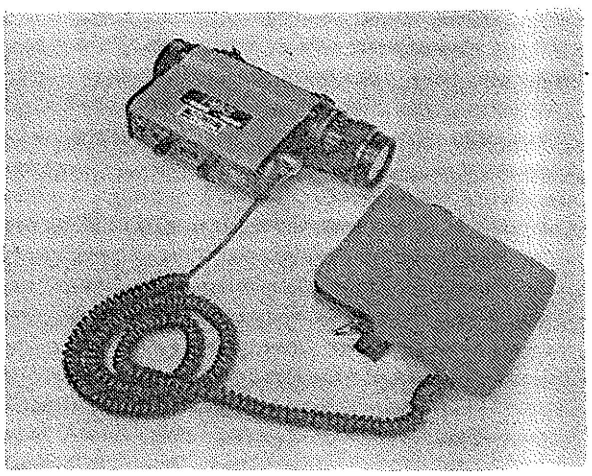


Fig. 3-5a: Monoscope NVG 103 from Hoffman Engineering Company

Essentially the monoscope consists of a second generation image intensifier tube with a phosphor screen. The gain is adjustable in four positions between 500 and 2000-times. Directly in front of the photo cathode there is a dimable LED. To measure the NVIS radiance of a cockpit light it is necessary to look through the monoscope. Then the LED, which is also visible on the phosphor screen, is dimmed to the same brightness as the cockpit light. A display shows the NVIS radiance, computed by the electronics according to the sensitivity of a 3. generation tube. The accuracy reached in tests is in +/-10% range, compared to the PR1980C. It is possible to mount a camera on the monoscope instead of an ocular lenses .

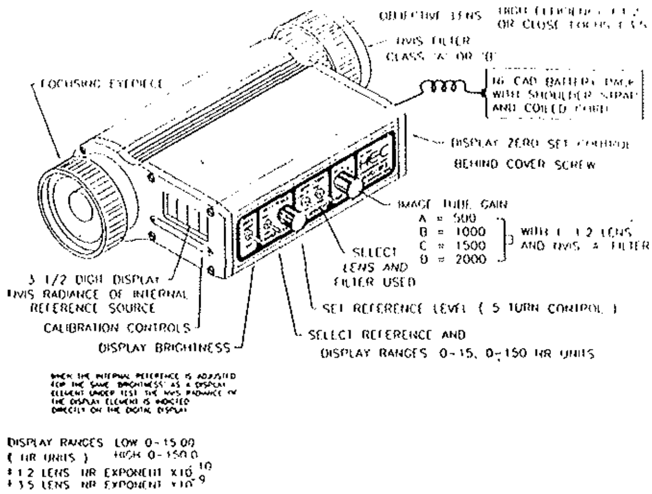


Fig. 3-5b: Drawing and techn. data from monoscope

4. Resolution measurements of Image Intensifier Tubes (NVGs and IHS)

Three types of NVIS devices were tested. The Philips NVG (BM8043) is the benchmark for the NVIS: These goggles comprise two identical straight-through monoculars with fixed objective focus (approx. 10 m to infinity) and adjustable eyepiece focus. The objective is a 26 mm focal length, F-number 1.2 lens which gives a circular field of 42° and a magnification of 1:1. The two monoculars are held together at the front on a tilting hinge for adjustment of Inter Pupillary Distance (**IPD**) at the rear. Adjustment of IPD will vary the FOV overlap. The resolution measurement with several test persons (average values) is shown in Fig. 4-1. This NVG uses a cut-on filter at 645nm, that means between Class A and Class B.

The tested **IHS** from GEC Avionics (see Fig. 2-3) has a fixed objective and eyepiece focus. The field of view (FOV) of this prototype version is 35°. Both combiners are adjustable in three directions: IPD, distance to the eyes and in height.

In contrast to the german NVG and the IHS the *French NVG with 42° FOV from SOPELEM* has adjustable objectives and oculars but no cut-on filters.

The **resolution tests** were made with a USAF 1951 bar pattern target. Several persons with a good visus (over 100%) had to determine at 9 illumination levels which bar group they can resolve easily and which hardly. The mean of these both figures was averaged with values of the other persons. The curves in Fig. 4-1 are fitted to the average values of 6 persons.

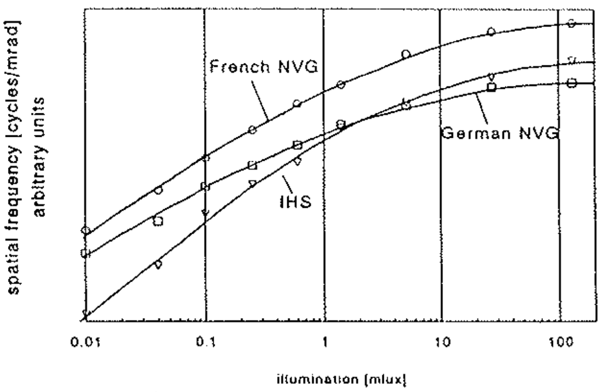


Fig. 4-1: Measurements of German NVG (42°, with cut-on filter at 645nm), French NVG (41°, without cut-on filter) and IHS (35°, with cut-on filter) with four or six test persons

In order to demonstrate the **degradation of spatial resolution** of a NVG with non-compatible

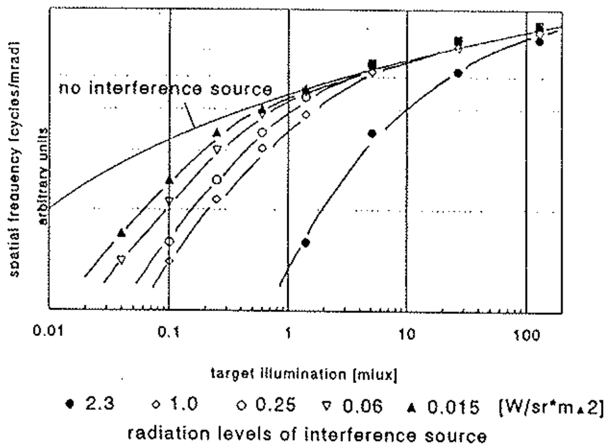


Fig. 4-2: Interference of a NVG with different levels of non-NVG compatible light. The radiation reached the NVG outside of the FOV and caused a remarkable degradation in the resolution

cockpit lighting, a resolution test was made in the presence of an interference light source (integrated sphere). Radiation from 600 to 950 nm was emitted and reached the NVG outside of the FOV. The results in Fig. 4-2 show clearly the impact of stray light as the source was placed outside of the FOV.

5. HC cockpit illumination technologies including measurements

5.1. NVG-compatibility measurements

5.1.1 Measuring problems and experiences with a Spectro-Photoradiometer

Some problems may be encountered while making NVIS compatibility measurements:

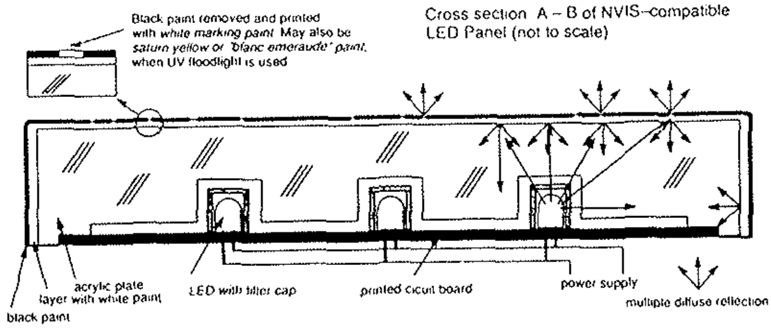
- o small areas (letters or pointers) cause a bad S/N ratio for the PR and subsequently identify an NVIS compatible item as **not compatible**, because the noise floor is integrated and seen as NR radiance. As much light as possible must be trapped (larger aperture or illumination level higher than the 0.1 fL, see ref.15, for more detailed discussion of PR problems)
- o it should be measured that the spectral behaviour of the component remains unchanged at higher levels
- o light/radiation sources or stray light in the darkroom should be prevented
- o the interpretation of a scan is difficult when plotted in log ordinates
- o pass or fail statements should be carefully examined (calculation of NR_A or NR_B, NR limits, noise floor from the machine etc.)

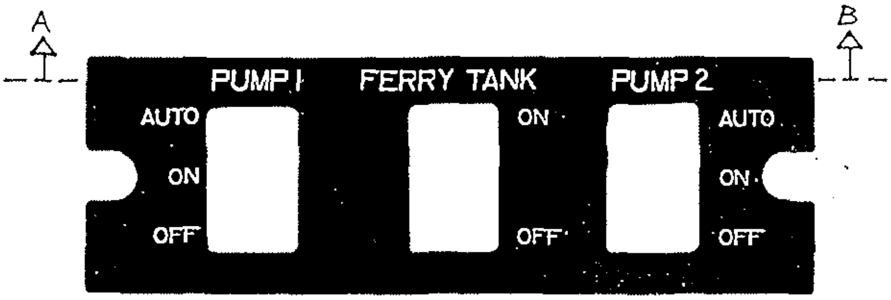
There are NVG on the market without a clear definition of their response. The NVIS class A or B rules only lead to the desired compatibility together with a properly filtered NVIS device.

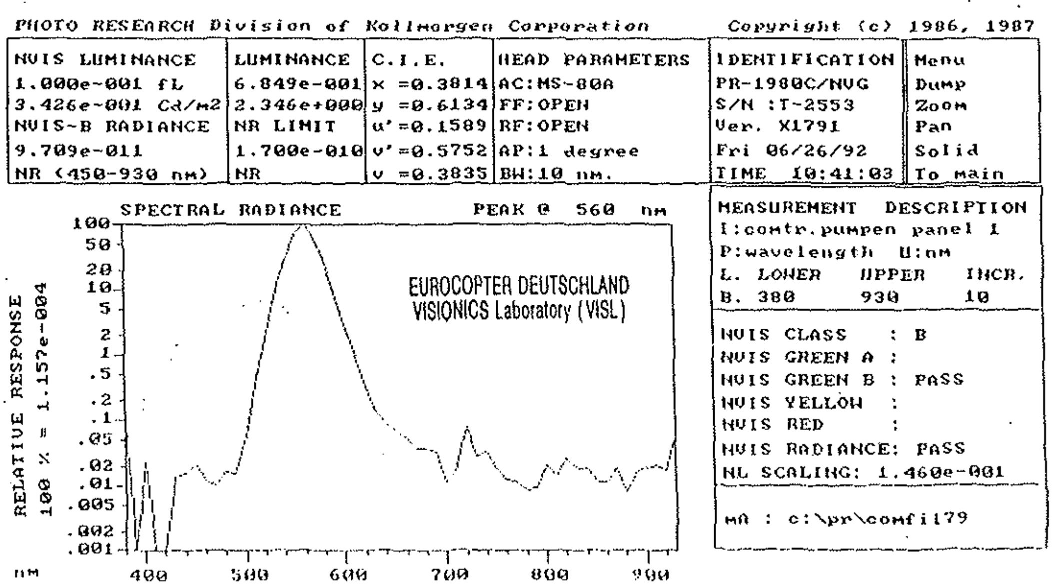
5.1.2 Measurements on NVG compatible equipment

Some major components of a NVG compatible crew station are shown. The results from NVIS tests are accompanied by a short description of the item.

Internal illuminated panel (Class B compatible): Made from an acrylic plate and **filtered pure green LED's,** as shown for a real TIGER sample in Fig. 5-1a. The dimming curve is comparable to those of incandescent lamps. The supply voltage range is 14 to 28VDC and the nominal illuminance is 1fL (3.4 cd/m²) at 28VDC. The NR_B value is well under the limit, the color is at the border of the NVIS Green B *area because* of the color shift by the saturn yellow paint. This fluorescent paint allows a second mode by night: illumination with UV floodlight.







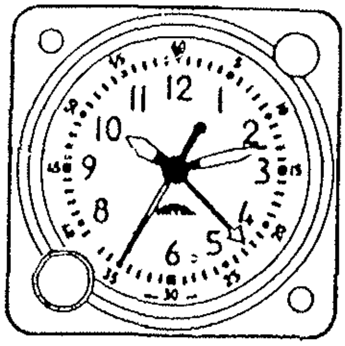
Figs. 5-1a, b, c: **Internal illuminated panel** (primary HC illumination)

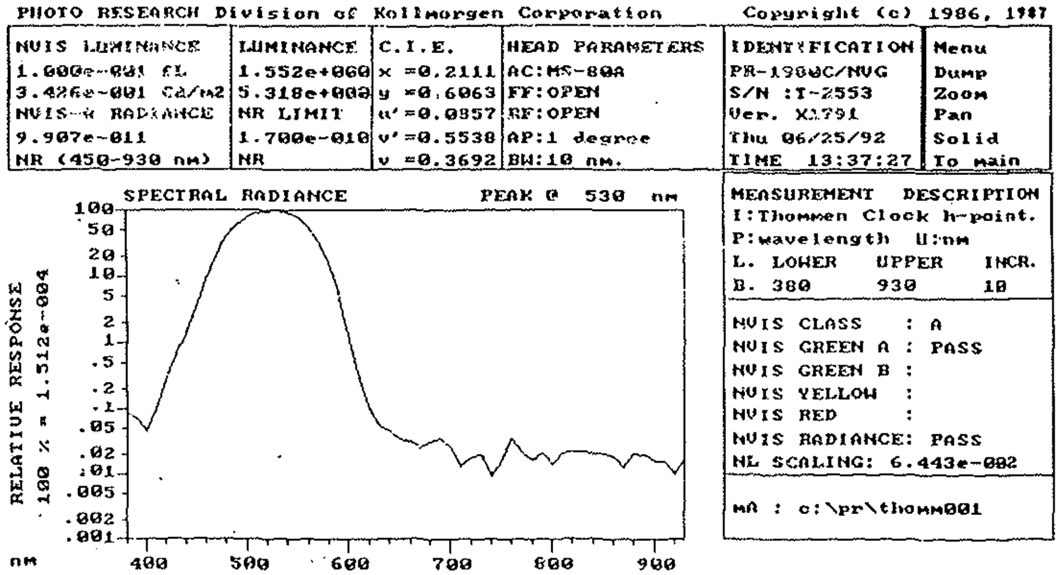
a) *Cross section of filtered* LED *panel, comp.* Fig.5-1b (according to ref.15)

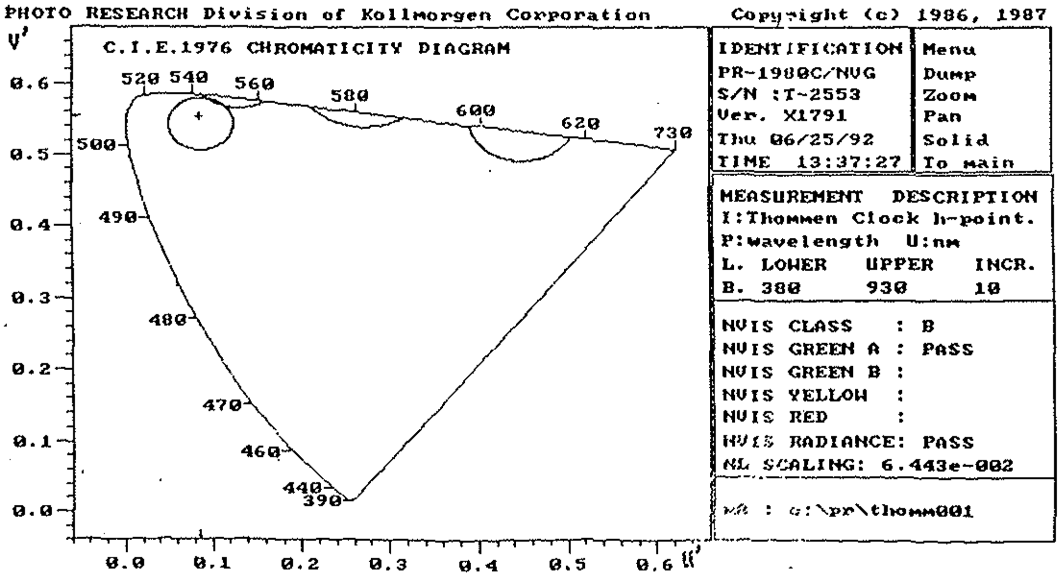
b) Sample of a panel with filtered LED (560nm,from COMTRONIC); UV-floodlight fluorescence is possible on saturn yellow paint

c) Logarithmic spectral radiance scan of such a LED panel radiating through the saturn yellow paint

Internally illuminated aircraft clock (Class A compatible):
This is a conventional instrument with an **internal filtered incandescent lighting** and a wedged cover glass. NR_A is quite low, the color is right in the center of NVIS Green A. This clock may be used in a class B cockpit also but with a slight color shift if desired. At rated voltage the luminance is at the upper limit (1.5 fL).

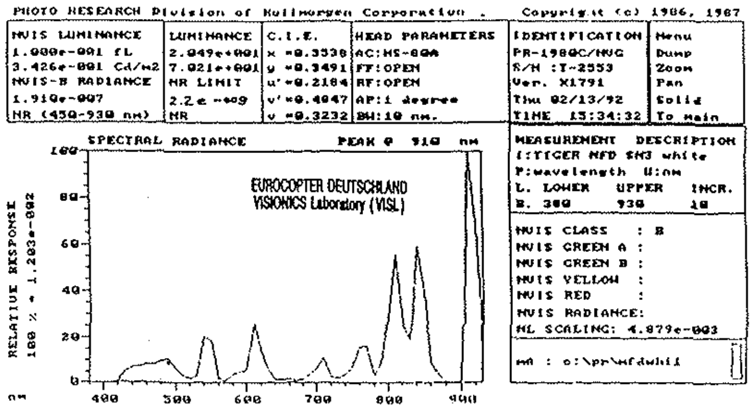


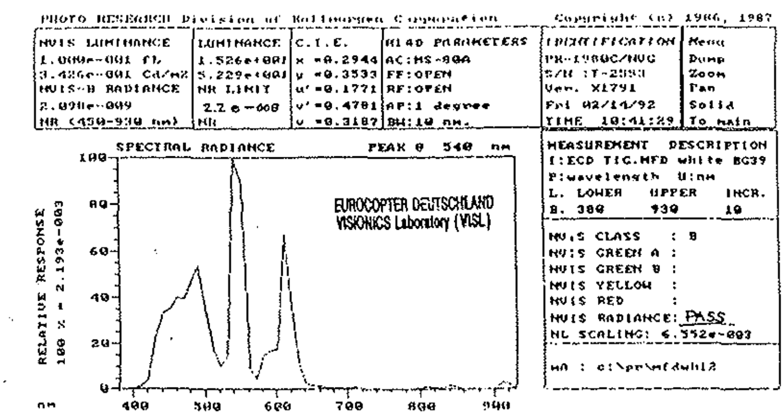


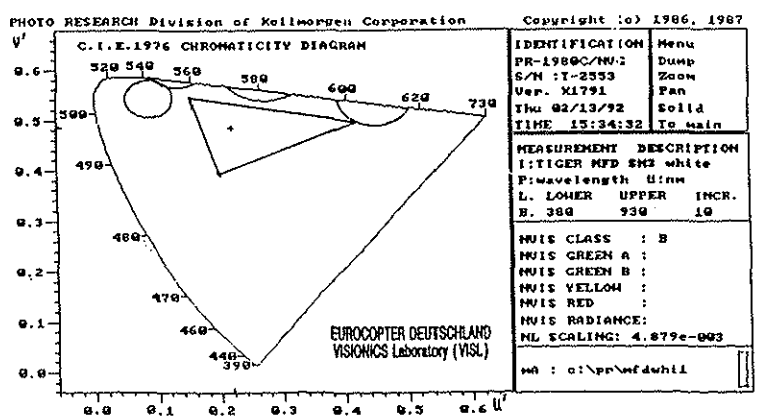


Figs. 5-2a, b, c: **Incandescent green filtered light technique** (Revue Thommen Clock)
a) drawing of an 3"-instrument with Bezel
b) spectral radiance measurement of the light with a logarithmic NR presentation
c) USC 1976 chromaticity diagram

Color MFD with LCD: Two color MFDs with LCD technology are installed in each TIGER cockpit. They have 512 by 512 quadruples with 2 green, 1 blue and 1 red pixels for color generation. Fig. 5-3a shows the spectral radiance scan for white color without a special NVG filter. The amount of NR is unacceptable. By adding a Schott BG39 filter the NVIS compatibility is obtained according to MIL with $NR_B < 2.2 \times 10^{-9}$ for white, compare Fig. 5-3b and $NR_B < 1.1 \times 10^{-8}$ for red. The MFD has not yet been tested by the pilots during a night flight mission to confirm acceptance compatibility. The chromaticity diagram, Fig. 5-3c, shows the white point (little cross) and the three pure colors red, green and blue which are extracted by three scans. The blue color should be enhanced.







Figs.: 5-3a, b, c: **Color MFD with LCD** from SEXTANT/VDO

a) spectral radiance scan of an unfiltered LCD-MFD (linear presentation)

b) spectral radiance scan of a filtered LCD-MFD with BG39 Schott filter with linear presentation)

c) USC 1976 chromaticity diagram of a LCD-MFD

UV illumination as secondary lighting

In the TIGER there is a group of standby instruments in the pilot's cockpit which has an independent UV illumination. Their dials are painted with saturn yellow. The measurement set-up as well as the test results for this lighting method is shown in Fig. 5-4

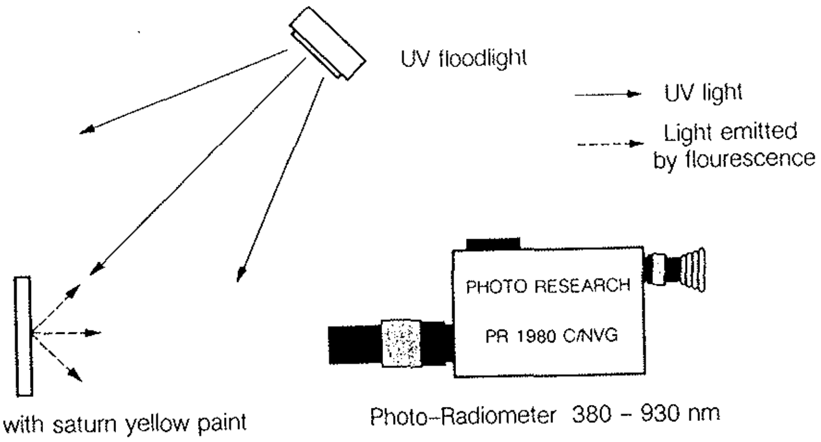


Fig. 5-4a: Measuring set-up

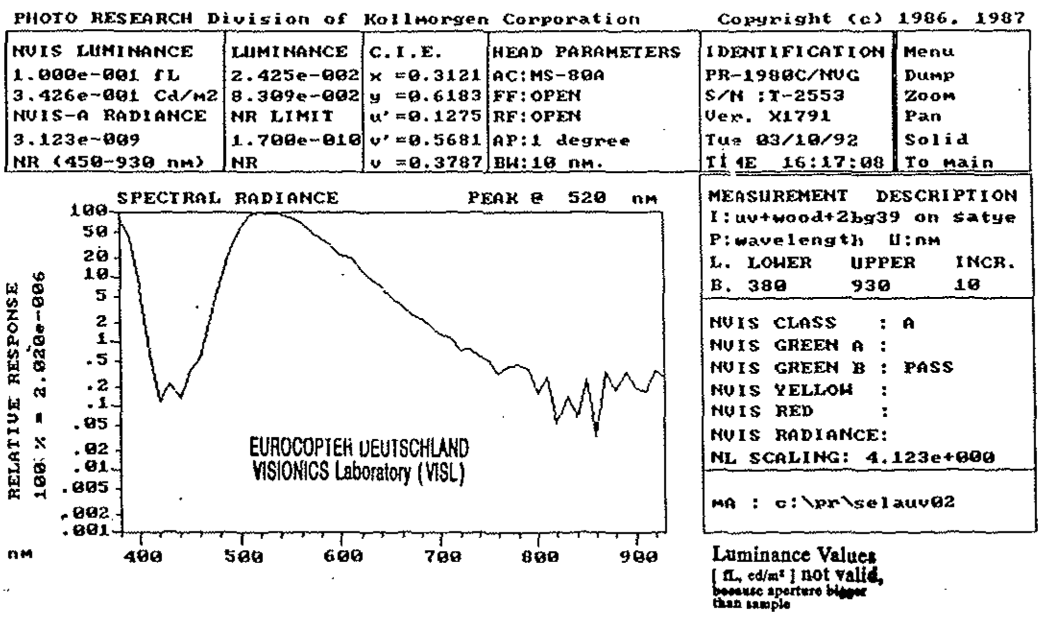


Fig. 5-4b: Spectral radiance scan of the fluorescence of saturn yellow paint induced by UV (log. presentation); the peak at 380 nm comes from the UV source. Besides the desired light for the eyes, the fluorescence shows an unwanted component above 600 nm.

Secondary instrument and backup floodlighting

The secondary instrument and display floodlighting system of the TIGER cockpit is made with pure green LED's and filter glass. The color is NVIS Green B, the NR has a pass for Class A and Class B. The measurements were made against a white standard.

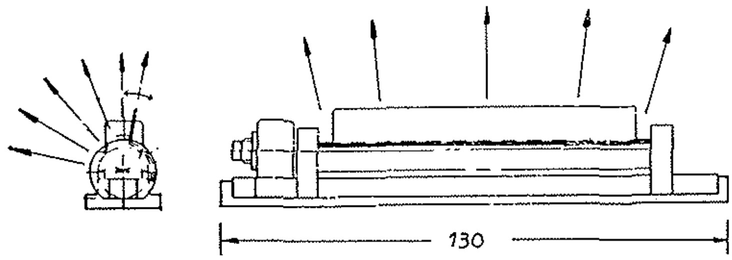
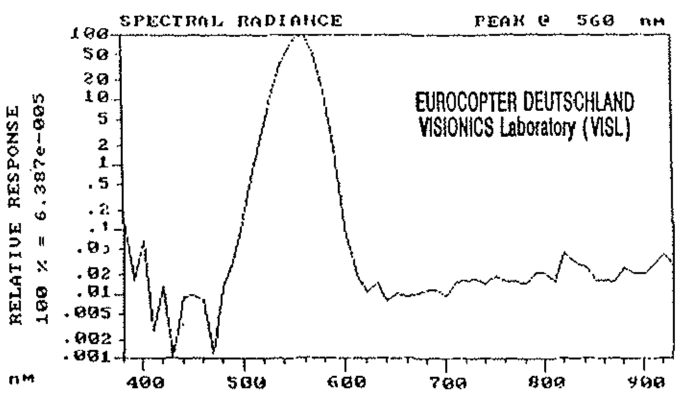


Fig. 5-5a: **Secondary instrument and backup floodlighting** of TIGER cockpit with pure green LED and filter glass (from COMTRONIC)

PHOTO RESEARCH Division of Kollmorgen Corporation Copyright (c) 1986, 1987

NVIS LUMINANCE	LUMINANCE	C.I.E.	HEAD PARAMETERS	IDENTIFICATION	Menu
1.000e-001 fL		x =0.3510	AC:MS-80A	PR-1980C/NVG	Dump
3.426e-001 Cd/m2		y =0.6419	FF:OPEN	S/N :T-2553	Zoom
NVIS-B RADIANCE	NR LIMIT	u'=0.1404	RF:OPEN	Ver. X1791	Pan
7.174e-011		v'=0.5777	AP:1 degree	Tue 10/15/91	Solid
NR (450-930 nm)	NR	v =0.3851	BW:10 nm.	TIME 08:46:53	To main



MEASUREMENT DESCRIPTION
I:LED_Grn+Weiszstandard
P:wavelength U:nm
L. LOWER UPPER INCR.
B. 380 930 10

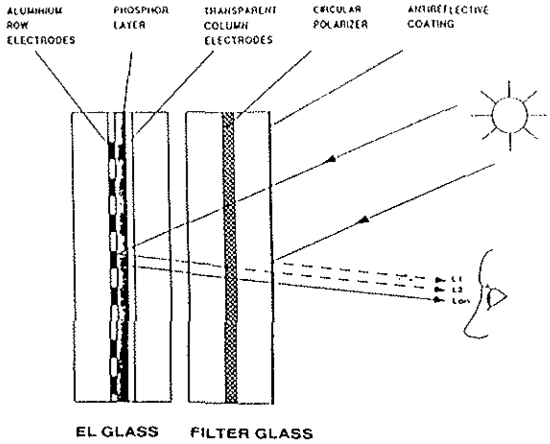
NVIS CLASS : B
NVIS GREEN A :
NVIS GREEN B : PASS
NVIS YELLOW :
NVIS RED :
NVIS RADIANCE: PASS
NL SCALING: 2.657e-001

MA : c:\pr\ledbkupw

Fig. 5-5b: Spectral radiance scan achieved against a white standard (log. presentation)

EL-Display from TIGER CDU

The principle of the electroluminescence display is shown beside. Unwanted radiation components from the phosphorescence are cut off by a Schott IR suppression filter.



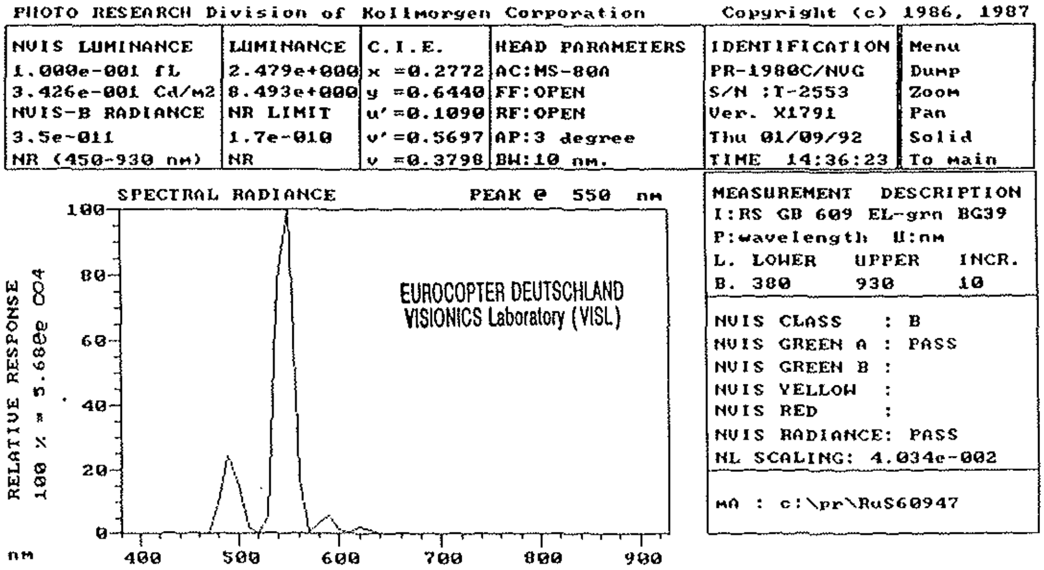


Fig. 5-6a: Spectral NR scan of EL-CDU display with an additional BG39 filter (Schott)

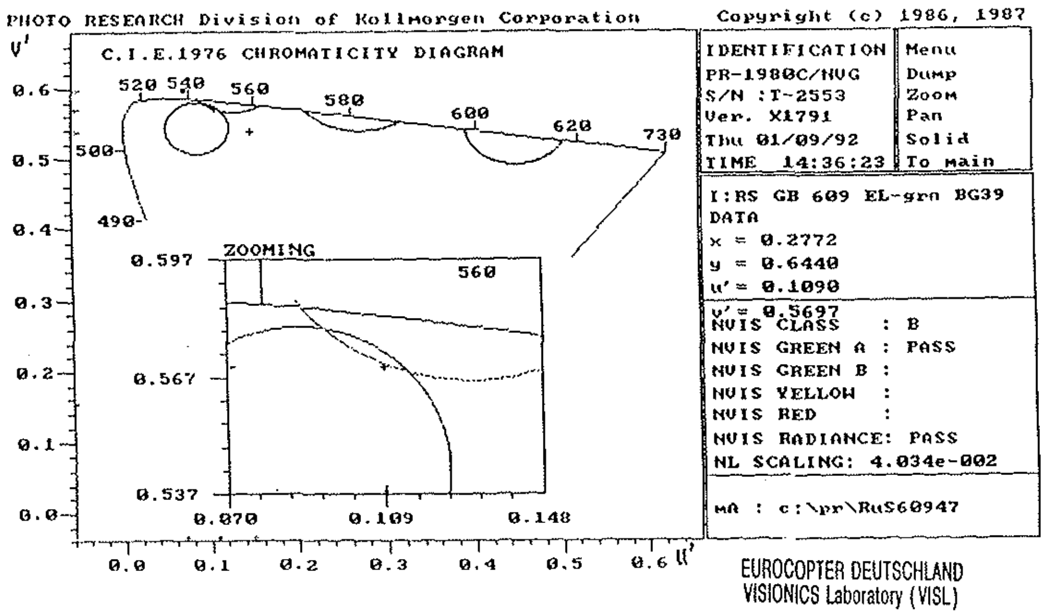


Fig. 5-6b: Chromaticity diagram of EL-CDU display

5.2 Open areas in NVG cockpit illumination

- Red flags and red range markings on dials must be painted with fluorescing red paint in order to be seen under NVIS compatible green light. Otherwise they are invisible. There is only a black space, see Fig. 5-7a. Lit with light, e.g. ANVIS Green B, free of IR this generate an IR radiation seen by the NVG. The allowed amount of NR of this type is not covered by the above mentioned spec.

- For a flag, which appears only for the appropriate event, we could assume an NR as defined for NVIS Red. According to FAA rules for the standby instruments (e.g. torque, RPM, Temp.) however all range markings emit NR.

There is a very simple and effective solution for this problem by changing from the **color coded range markings** to **form coded range markings**. This problem is considered in STANAG 2324 but there is a long way to go in order to obtain FAA civil certification. For military aircraft there is more freedom and Fig. 5-7b shows our proposal for a form coding.

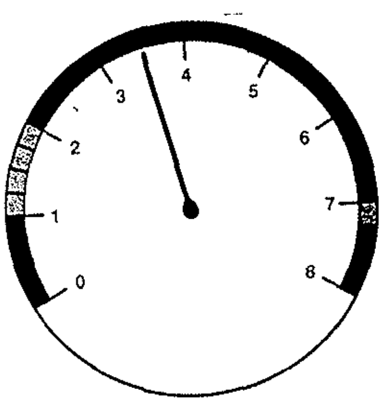


Fig. 5-7a: Range markings with color coding: under green light there are no more clear cues visible,

- Flashlights are also not covered by the above mentioned spec. It is desirable to have an NR limit for flashlights with an amount of white light which is used for map reading.

- There should be a recommendation for a maximum of totally illuminated yellow and red surfaces from indicators, push buttons, warnings etc. APACHE, an American supplier, proposes an area of about one square inch as the upper limit. This is also valid for yellow, red and white symbols on MFD's - many symbols drawn with those colors will disturb the NVG.

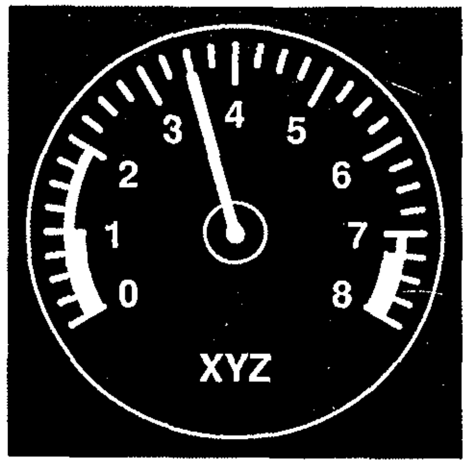


Fig. 5-7b: Rang markings with form coding (instead of color coding)

6. Cockpit assessments on BK117/AVT and TIGER

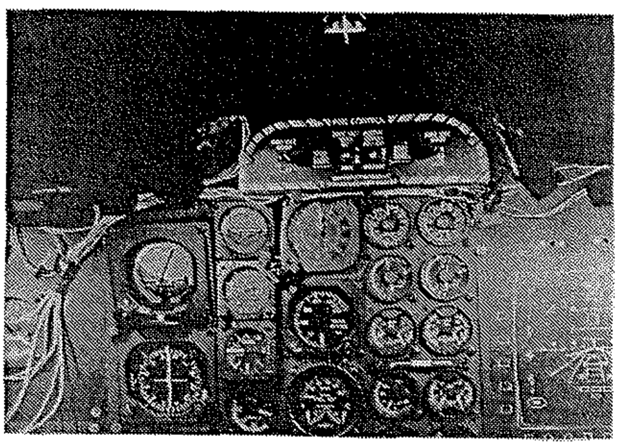
ECD has been working on NVG compatible cockpit illuminations since 1984. At that time precise requirements of luminance/radiance in the response range of the IIT's were not established.
A lot of work was done by retrofitting conventional instruments in existing HC cockpits, e.g. BO105 and BK117. The 3. gen. NVG type incl. their exact filter characteristics are prerequisites for the right illumination techniques design.

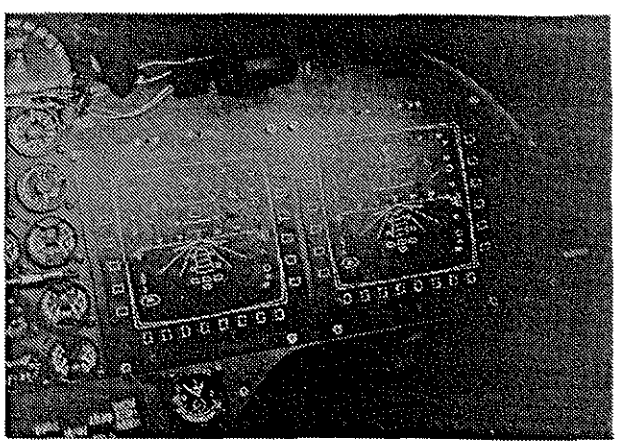
6.1 BK117/AVT Cockpit lighting (retrofit)

AVT (Avionik Versuchsausrüstungs Träger) is a flying test bed helicopter, based on BK117, to obtain experience with some TIGER avionic systems and missions. Trials are planned with NVG, IHS, FLIR, DMG, CDU, MFD, Data transmission, GPS etc. MMI aspects will be studied additionally. NVG compatibility of the AVT cockpit is a prerequisite for trials with NVGs or IHS. The goal was to achieve, by retrofitting, a quality according to MIL-L-85762A, Class B.
The philosophy applied was:

a) to keep the standard internal white lighting system alive (for conventional civil certification and flight rules)
b) for a NVIS flight: switch off the white lighting and switch on green floodlights, put filter glasses over the annunciator panel and the 2 master caution warnings
c) to change the internal illuminated panels into pure green LED panels
d) to filter the colored beam index CRT-MFDs

The following components are integrated into AVT:
green filtered incandescent (GFI) floodlight, GFI goose necks, GFI post lights, GFI utility lamp, indicators from Staco, filters from Wamco and Schott, CRT-MFD, EL-Display and LED keys of CDU.
There are exceptions like the compass, some illuminated push buttons etc. which have been replaced by new ones. They are now NVG compatible even in a normal civil night flight.
Examinations of the single components according to MIL-spec. have shown good results in the VISL and the pilots gave a positive assessment.
There are some effects like fluorescent paint on flags or range markings which may be seen with the NVG but there is no NR limit defined in the MIL-spec. (see also chapter 5.2).
The most difficult items to replace are small round indicators (around 10mm diam.) with yellow or red caps. There is no supplier which guarantees on one hand sunlight readability and on the other hand NVG compatibility. Large size indicators from, for example Eaton or Korry, should be installed, but a given I-panel cannot accommodate such large items.





Figs. 6-1a and 1b: NVG compatible floodlight illumination on BK117/AVT

6.2 TIGER Cockpit illumination assessments; new design

The TIGER has a tandem cockpit for the pilot and the gunner/copilot with few conventional instruments. New instruments are: Pilots and gunner visionic and armament panels, EL-CDU, LCD-MFD, RFI, etc. The primary illumination of the TIGER cockpit design took into account **UV floodlighting technique** with fluorescence from saturn yellow paint and **integrated LED panel** lights. Floodlight techniques, especially in a narrow cockpit, lead to shadowing and installation problems. The amount of lights using each technique and other lighting aspects have to be assessed.
Therefore in the last three years several TIGER Cockpit illumination assessments were made in the **VISL**, on the **Class II Mock-up** and on the Primary Integration Rig (**PIR**). The following parameters were assessed by engineers and pilots using a questionnaire in a Cooper-Harper-Rating procedure for the pilot and the gunner cockpit:

- o NVIS compatibility of illumination,
- o good legibility and readability with adapted illumination brightness (dimming range),
- o minimized masking effects (shadowing),
- o installation/mounting aspects of lamps on glare shields and side consoles
- o high uniformity/homogeneity (2:1) of different illuminations,
- o proper cockpit finish,
- o reduced window reflections,
- o minimized HC-detectability from outside with naked eyes and with NVG's
- o no auto kinesis effects (hard contrast) for a good NVG-cockpit layout, etc.

Following **improvements** from the previous visual assessments have been taken into account for final solution:
- o Glare shields extended to prevent mirror effects and reflections in the front, roof and side windows especially from illumination from the side consoles
- o LED panels in both cockpits upgraded for homogeneity and NVG-compatibility (MIL-L-85762A)
- o Location of UV lamps and upgrading for uniformity/homogeneity and NVG-compatibility
- o Position areas of green lights and high intensity to allow back-up function on legend legibility
- o Handlight available with Green and UV light
- o Optimization of brightness (dimming curves) setting range for the different illuminations
- o Brightness and color optimization on status and warning lights
- o NVG compatibility of EL- and filtered LCD-Displays

	Phase	Integr. LED light	UV flood-light	Green flood light	Approx. light levels under tent (mLux)
0	Familiarization with the equipment	x	x	x	100
1	Examination of discrete components "one after the other"	x	 x	 x	100
2	Operational modes without NVG	x	 x	x x	50 - 1000
3	Operational modes with **German NVG** incl. NVG compatibility 1) (discrete and mixture with green light)	x	 x	x x	0.5 - 50
4	Operational modes with **French NVG** incl. NVG compatibility 1) (discrete and mixture with green light)	x	 x	x x	0.5 - 50
5	Detectability from outside Integr.+ Green UV + Green	x	 x	x x	0.5 - 50

German NVG: Philips BM8043, French NVG: Sopelem OB56A

1) subjective and qualitative tests

Table 3: Procedure of (visual) cockpit lighting assessment; there are 2 assessments: one for the pilots and one for the gunners cockpit

The result of the TIGER illumination assessments is the a **mixed solution**:

- o The **main primary illumination** on all side consoles, inter pedestal consoles and the instrument panel will be with **integrated LED panels.**
- o Excepted areas will be illuminated via indirect **UV lighting** under glare shields with fluorescence effect coming from saturn-yellow (or blanc emeraude) painting (Fig. 5-1a). These areas are, for example the back-up-instruments, the clock, etc. on the front instrument panels, and for the government furnished equipment (e.g. IFF) on the gunner right hand console, compare Figs.6-2a and 2b.
- o A **secondary green floodlight** will be installed additionally under glare shields and side consoles to reduce hard contrast and for back-up purpose.
- o A moveable **hand lamp** with green and UV light and with a rechargeable battery is stowed in a box (for each cockpit).

The helicopter's front windows are in the optical path of the NVG. Therefore we have carefully looked at the transmittance of the material. Fig. 6-1 shows the basic transmittance measuring set-up and the results obtained.

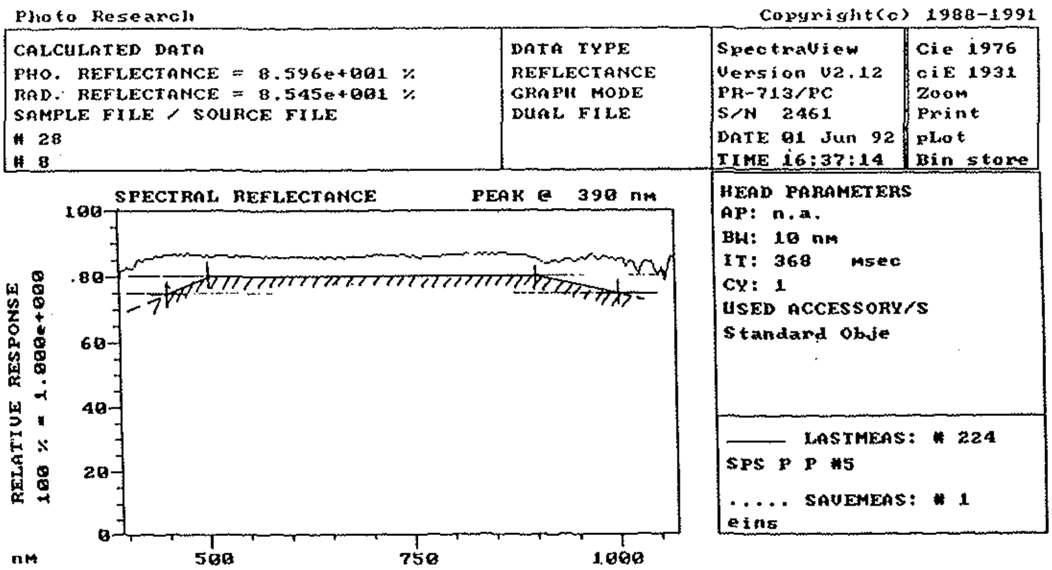


Fig. 6-1a: The transmittance of the TIGER front windows is better than 80% in the visible and IIT response spectrum

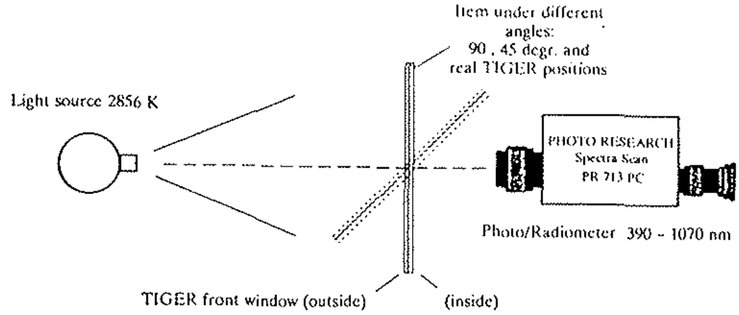


Fig. 6-1b: Principle of transmittance measurement of a TIGER front window

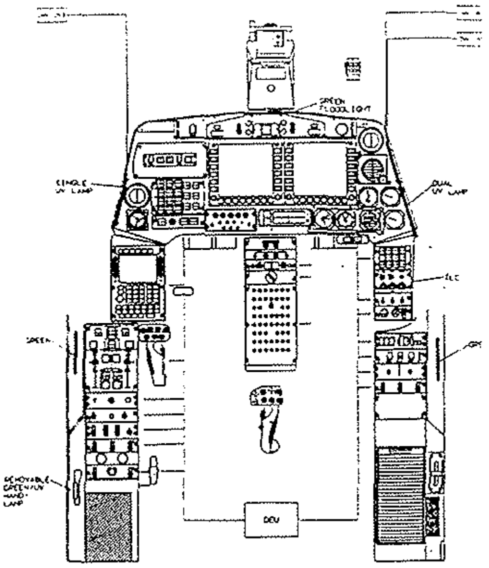


Fig. 6-2a: TIGER Pilot-Cockpit, design drawing

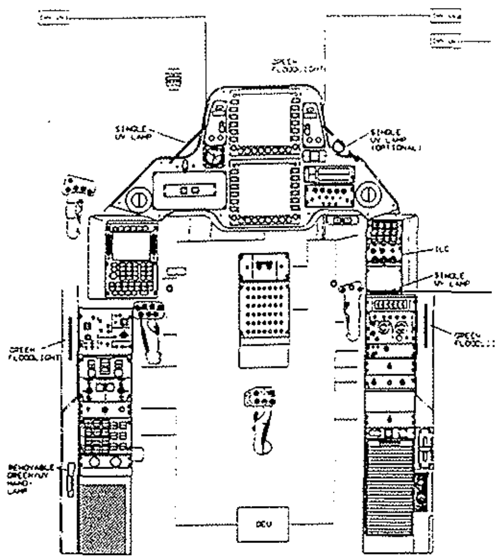


Fig. 6-2b: TIGER Gunner-Cockpit, design drwg.

Fig. 6-3a: TIGER Pilot-Cockpit

Fig. 6-3b: TIGER Gunner-Cockpit

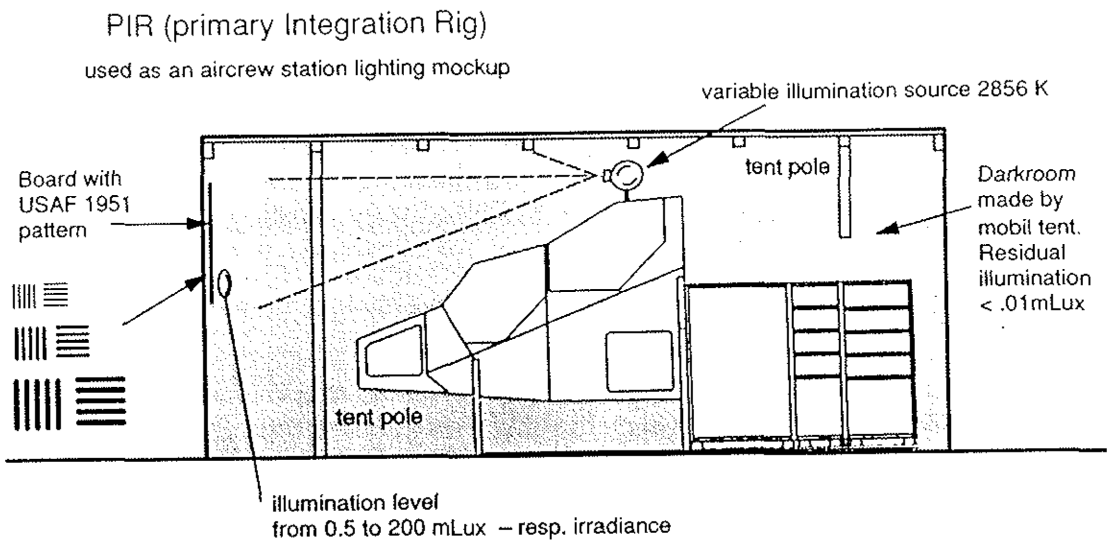


Fig. 6-4a: Dark tent over TIGER-PIR with target (bar chart) and integrated sphere for lighting assessment

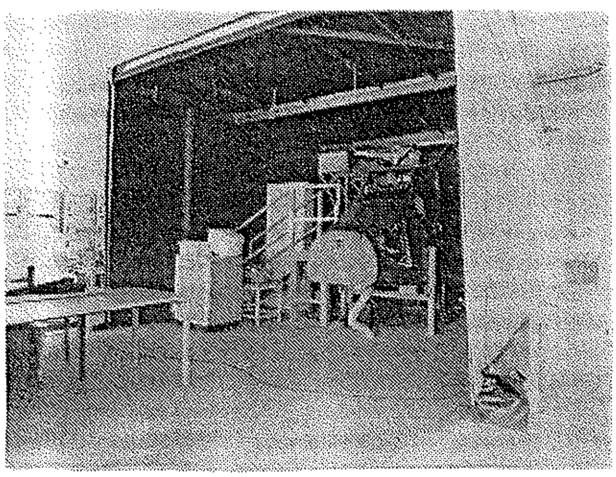


Fig. 6-4b: Black tent over cockpit section (PIR)

7. Conclusion

The VISL has proven to be an excellent, well-equipped facility providing an ideally suited environment for the assessment of, in particular, HC cockpit lighting. It can equally be used for customer service to make tests and verification procedures according to MIL-L-85762A.
The primary cockpit lighting for a modern night mission HC with filtered pure green LED technology is a very good and cost effective solution.
The results of various tests of NVG compatible components show the possibility of making a really NVG compatible HC crewstation complying with MIL-L-85762A requirements.

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