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An Assessment of Luminance Imbalance with ANVIS at an Army Helicopter Training Airfield

By

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Aircrew Health and Performance Division

May 1997

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U.S. Army Aeromedical Research Laboratory
Fort Rucker, Alabama 36362-0577

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One of the causal factors listed in a 1996 mid-air collision between two Australian Army helicopters in formation was a speculation of possible luminance imbalance between the right and left channels of the night vision goggles (NVGs) at the airfield of origin for the two helicopters involved in the accident. This study describes a field method of measuring and determining luminance output and imbalance for 20 pair of NVGs at a U.S. Army airfield. The luminance source to activate the aviator night vision imaging system (ANVIS) was a calibrated NVG test set (TS-3895 U/V). The photopic sensor of an illuminance radiometer was placed on the eyepieces of the ANVIS and relative illuminance values were taken for each channel at light levels above and below the automatic brightness control (ABC) level in the ANVIS power supply. The light level above the ABC limits the upper luminance output and the level below the ABC is a function of the ANVIS gain. In the laboratory, the illuminance values from the radiometer were calibrated to luminance values using the same NVG test set for the light source and a Pritchard 1980A photometer. The results showed a significant correlation between the luminance values from the right and left eyepieces above or below the ABC level, but the correlation

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below levels for the same tube was not significant. It was also found that 80 percent of the surveyed ANVIS that had been routinely used for several years did not meet the suggested 10 percent luminance imbalance criteria for either above or below the ABC level. The implication from this study is that the 10 percent imbalance criteria is not realistic from a measuring or user acceptable standpoint.

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Objective

The objective of this study was to determine the luminance differences between the right and left oculars of typical fielded aviator's night vision imaging system (ANVIS) at Fort Rucker, Alabama.

Military significance

Luminance imbalance between oculars of night vision goggles (NVGs) was listed as a causal factor in an Australian mid-air collision between two Blackhawk helicopters in June 1996. The possible luminance imbalance was hypothesized by Dr. B.A.J. Clark, Research Leader, Human Factors, Defence Science and Technology Organisation, Australia, as potentially inducing the "Pulfrich" phenomenon, which theoretically could affect distance estimations. Dr. Clark found that 45 percent of 20 pair of ANVIS units had more than 10 percent luminance differences between oculars, or significant differences in contrast, as a basis for the assumption of induced visual illusions.

After the mid-air accident, Australian Army Aviation was restricted from formation flight with NVGs until this tube imbalance issue could be resolved. A request for the U.S. Army Aeromedical Research Laboratory (USAARL) assistance from Brigadier W.J.A. Mellor, Commander, Aviation Support Group, Army Aviation Centre, OAKEY QLD 4401 (Australia), was received 20 January 1997 (see appendix A). In this letter, four specific requests for information were listed concerning tube imbalance and testing methods and equipment used by the U.S. Army Aviation Center.

However, in response to Brigadier Mellor (see appendix A, Executive Summary), USAARL could not state what NVG luminance imbalances occur for typical fielded ANVIS, which are subjectively checked by U.S. Army pilots before each flight, in addition to the 90 and 180 day tests for high and low light resolution. This study measured the luminance imbalance between ANVIS oculars at a Fort Rucker training airfield.

Background

In June 1996, the Australian Special Air Services Regiment (SASR) was conducting a training mission using Blackhawk helicopters and ANVIS. Just prior to arriving at the point for the soldiers to rappel down to their objective from the helicopters, two of the helicopters collided. This accident was very similar to the daytime accident in 1995 that occurred at Fort Campbell, Kentucky during a rehearsal, except this one occurred at night using NVGs.

During the accident investigation, Dr. Barry Clark from the Aeronautical and Maritime Research Laboratory, Australia, measured the contrast and luminance output from 20 sets of

ANVIS at the airfield from which the fatal accident originated. He found that 45 percent of the ANVIS had luminance imbalances or reduced contrast of more than 10 percent. The maximum luminance imbalance reported was -26.7 percent using the equation: 100 x (right-left luminance)/right luminance. If the right and left contrast values are reversed in the equation, the imbalance calculates to be +21 percent. Dr. Clark hypothesized that this luminance or contrast imbalance could be a causal factor in the accident by altering depth perception due to the "Pulfrich" phenomenon. The Pulfrich effect is defined as "the apparently ellipsoid or circular excursion of a pendulum actually swinging in a plane perpendicular to the direction of view when a light-absorbing filter is placed in front of one eye" (Schapero, et al., 1960).

This short study was generated to augment our response to one of the requests for information in the Australian letter, which requested "advice on the likelihood of tube imbalances of less than 30% causing visual illusions of depth perception and distance estimation that would be considered a flight safety problem for NVG formation flight." U.S. Army Aviation does not test NVG luminance imbalance after the goggles have been fielded, and there are no data on the average and range of imbalances for "flight worthy" ANVIS.

There are no specifications for luminance imbalance for ANVIS in MIL-A-49425(CR) (Department of Defense, 1992a) or the image intensifier tubes specification MIL-I-49428(CR) (Department of Defense, 1992b). However, the luminance output at high light level for each ocular should not be less than 0.7 footlambert (fL), or more than 2.1 fL. This three to one ratio is also specified for the minimum and maximum gain at low light levels below the automatic brightness control (ABC) point in each ANVIS tube. This is 67 percent imbalance when calculated as: $100 \times (1 - L_{lower}/L_{higher})$, or -200 percent when calculated as: 100 x (right - left luminance)/ right luminance if the left channel is brighter.

After the ANVIS are received by the aviation units, the ANVIS are checked every 90 days for high and low resolution requirements using a test set, TS-3895/UV (Department of the Army, 1983). If the ANVIS user or an aviation life support equipment (ALSE) specialist determines that there is something wrong with the goggles, a request for maintenance (DA Form 2407) is completed describing the defect, and the ANVIS are sent to the Directorate of Logistics (DOL) for evaluation and repair. At Fort Rucker, the NVG repair is located on-post.

Every 180 days, the ANVIS are sent to the unit's depot level for more extensive tests and repair in addition to the high and low resolution checks. The tubes are "purged," where the gas is removed from each ocular and nitrogen inserted at a given pressure. The ANVIS are checked for collimation (alignment), accuracy of eyepiece diopter settings, and the objective lens adjustment to go past infinity focus.

The ANVIS used at Fort Rucker during helicopter training by students and NVG instructor pilots were originally purchased in the mid to late 1980s. Although a record of the total number of hours used is not kept for each goggle, a very conservative estimate of the number of operational hours for a typical ANVIS at the training fields would be in the hundreds of hours.

Measuring the luminance through the eyepieces of NVGs has been very challenging as noted during previous USAARL NVG studies (Kotulak and Rash, 1992; Kotulak and Morse, 1994). Alignment of the optical axis of the objective lens of the photometer and eyepiece optical axis is critical in obtaining repeatable values. The light source, an extended field of view (FOV) greater than the FOV of the NVGs, and uniformity of the illuminated surface for viewing are also critical and can cause considerable differences in maximum output values. It is also important that the procedures can be repeated by any other investigators to either verify the results or determine their ANVIS imbalance ranges at other locations. For a field study, the luminance imbalance procedures should be quick, but with sufficient repeatability and accuracy for relative type readings. The calibration and measuring procedures will validate the field method.

Since Fort Rucker is the home of Army aviation and recognized as the leader for helicopter NVG flight training, an analysis of the interocular luminance imbalance of our typical ANVIS would be of interest to the Australians and other U.S. and allied ANVIS users.

Method

Approval was obtained from the Aviation Training Brigade to measure the light output of 20 pair of ANVIS at one of the primary Army airfields at Fort Rucker on a noninterference basis. The ANVIS are stored at the ALSE building. The afternoon period after 1400 local time provided the least interference to the ALSE personnel for the measurements. The approach for this study was to use a simple, but sensitive, radiometer with a photopic sensor head to measure the relative light output of the sample ANVIS, using a readily available light source, and then calibrating the radiometer response to the photopic luminance measurements in the laboratory.

Apparatus: Photodyne radiometer, model XL88
NVG test set, model TS-3895A/UV
ANVIS, AN/AVS-6 (Omnibus II procurement)

Field procedures:

At the airfield, 20 pairs of ANVIS were selected from approximately 200 available pairs. A dark room was provided and NVG compatible flashlights and lip lights were used for recording the ANVIS illuminance output with the radiometer, but not during the measurements. In our first attempt, the ANVIS objective lenses were turned fully clockwise towards infinity focus and the eyepiece lenses were turned fully clockwise for maximum minus power, which minimized the distance from the eyepiece optics to the back of the intensifier tube. Later laboratory tests showed that setting the eyepiece diopter scales at zero diopters also provided a consistent value.

Measurements were taken on the first attempt using the high and the low light level setting of the NVG test set. After the first attempt to obtain relative luminance output from the ANVIS eyepieces at the airfield, it was learned that the low light level of the test set was too low for

reliable readings with the radiometer. On the test set, there are three rotary knob positions between the high light level (above the ABC level) and the low light level (approximately star-light). Placing the rotary knob one click above the low light level produces a light level below the ABC point and above the low light level. In this position, there is play (hysteresis) in the knob such that the readings are higher towards the high level and lower with the knob position towards the low light level. Therefore, during the medium light level measurements, the knob was held in the position that produced the higher of the two readings.

The sequence for measurements was alternated between the right and left oculars between ANVIS samples. The high measurements were measured first to ensure the ABC had been activated to stabilize the gain control for the low light level readings. At every fifth trial, as indicated with an asterisk (*) on the recording form (appendix B), the ANVIS used for the first trial was remeasured to determine stability of the measurements.

During both the initial trial and the actual repeated measurements of the same ANVIS during the testing, some drift was found in the measurements from the radiometer over time. These measurements were repeated in the laboratory with one ANVIS and a standard filtered light source, and are described in the calibration section (appendix C).

Laboratory calibration:

Additional apparatus:

Photo Research Pritchard photometer, model 1980A
Photo Research luminance standard lamp, 100 fL
Haag-Streit perimeter

Since the radiometer is actually an illuminance meter, certain procedures were necessary to calibrate the photodyne readings with the Pritchard 1980A luminance values. The 1980A model photometer measures luminance in 5 selectable angular cones from 3 degrees down to 2 arc minutes. The larger degree internal apertures increase low light level sensitivity. The Photodyne radiometer integrates the light over a 180-degree hemisphere with the luminous flux intensity varying as the cosine square function relative to the angle perpendicular to the sensor surface. The 1-degree internal aperture for the photometer provided sufficient response for measurements through the ANVIS above and below the ABC level.

An adapter was attached to the Photodyne radiometer sensor head to accurately align the sensor head with the housing on either the standard or 25-mm ANVIS eyepieces (see figure 1). The adapter piece is actually an objective lens cap for the AN/PVS-5 NVG with a hole in the center to expose the sensor head of the radiometer. The NVG test set and the Haag-Streit perimeter were used as light sources for the ANVIS and the regulated lamp standard for the objective lens aperture calibration and the radiometer drift assessment over time. Appendix C describes the calibration procedures in detail.

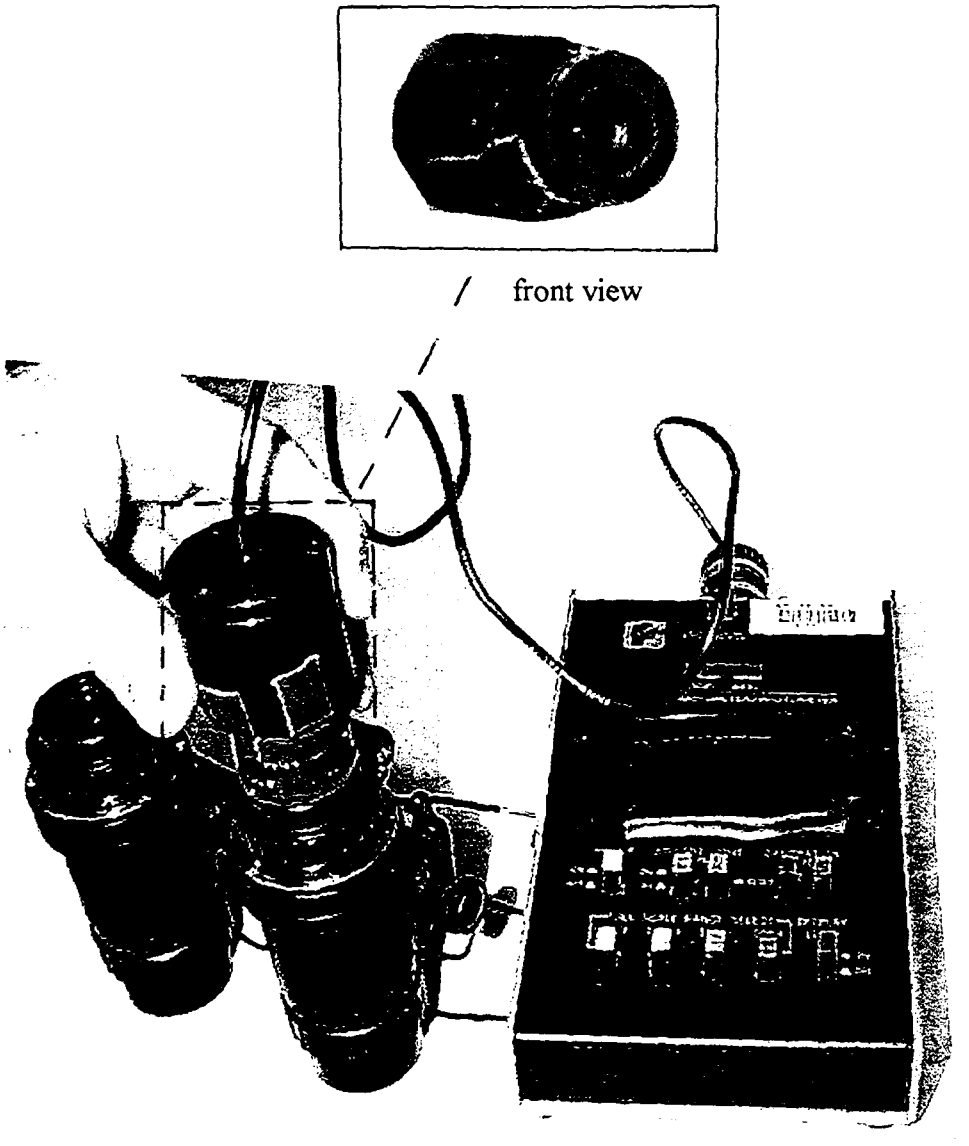

Figure 1. Radiometer with photopic sensor head and eyepiece adapter.

Results

Percent difference between tubes for a given light level was computed as: $100\ (1 - L_{lower}/L_{higher})$. For the 20 sets of ANVIS evaluated, the mean, standard deviation (SD), minimum (Min), maximum (Max), median and 95 percent (%) confidence interval (CI) of the relative illuminance and percent difference values are showed in table 1. The individual measurement values and computations are located in appendix B. To convert the measured ANVIS millifootcandles (mfc) to footlambert (fL) values in the central FOV, see calibration procedures in appendix C.

Table 1.
Descriptive statistics of
high and lower light levels with percent differences.

	RT High (mfc)	LT High (mfc)	High % Diff.	RT Low (mfc)	LT Low (mfc)	Low % Diff.
mean	217.1	218.9	7.85%	57.05	49.95	17.58%
SD	21.99	30.64	6.96%	16.94	11.02	11.76%
Min	192	185	0.00%	30	38	1.82%
Max	260	319	23.08%	110	79	47.78%
Median	208	204	5.51%	53	46.5	16.84%
95% CI ±	10.3	14.34	3.25%	7.93	5.17	5.50%

N = 20 pair of ANVIS

Table 2 shows the percent of ANVIS with luminance imbalance above 10, 20, and 30 percent above, below, and above or below the ABC level.

Table 2.
Percent of ANVIS with luminance imbalance.

Imbalance	>10 percent	>20 percent	>30 percent
Above ABC level	25%	10%	00%
Below ABC level (gain)	70%	35%	15%
Above or Below ABC level	80%	40%	15%

Parametric comparative statistics were used to determine if there were significant differences in luminance imbalance between high and low light levels. Using the paired "t" test, there were no significant differences at the 95 percent level of confidence between the right and left luminance outputs at light levels above the ABC level or below the ABC level.

Similarly, using regression analysis, the correlations between the right and left ANVIS channels above or below the ABC level were significant at the 95 percent level (DF = 18, r = 0.501 for above ABC and r = 0.554 below ABC). For a sample of 20, the 95 percent confidence level for the correlation coefficient is satisfied with values greater than 0.444. However, the correlation between the high and lower values for each channel was not significant at the 95 percent confidence level (DF = 38, r = 0.269). (For an N of 40, the 95 percent confidence level for the correlation coefficient is satisfied with values greater than 0.313.)

Figure 2 shows a scatter plot between the right and left tubes for the high light level and figure 3 plots the lower light levels with ± 20 percent dashed lines bracketing the equal line.

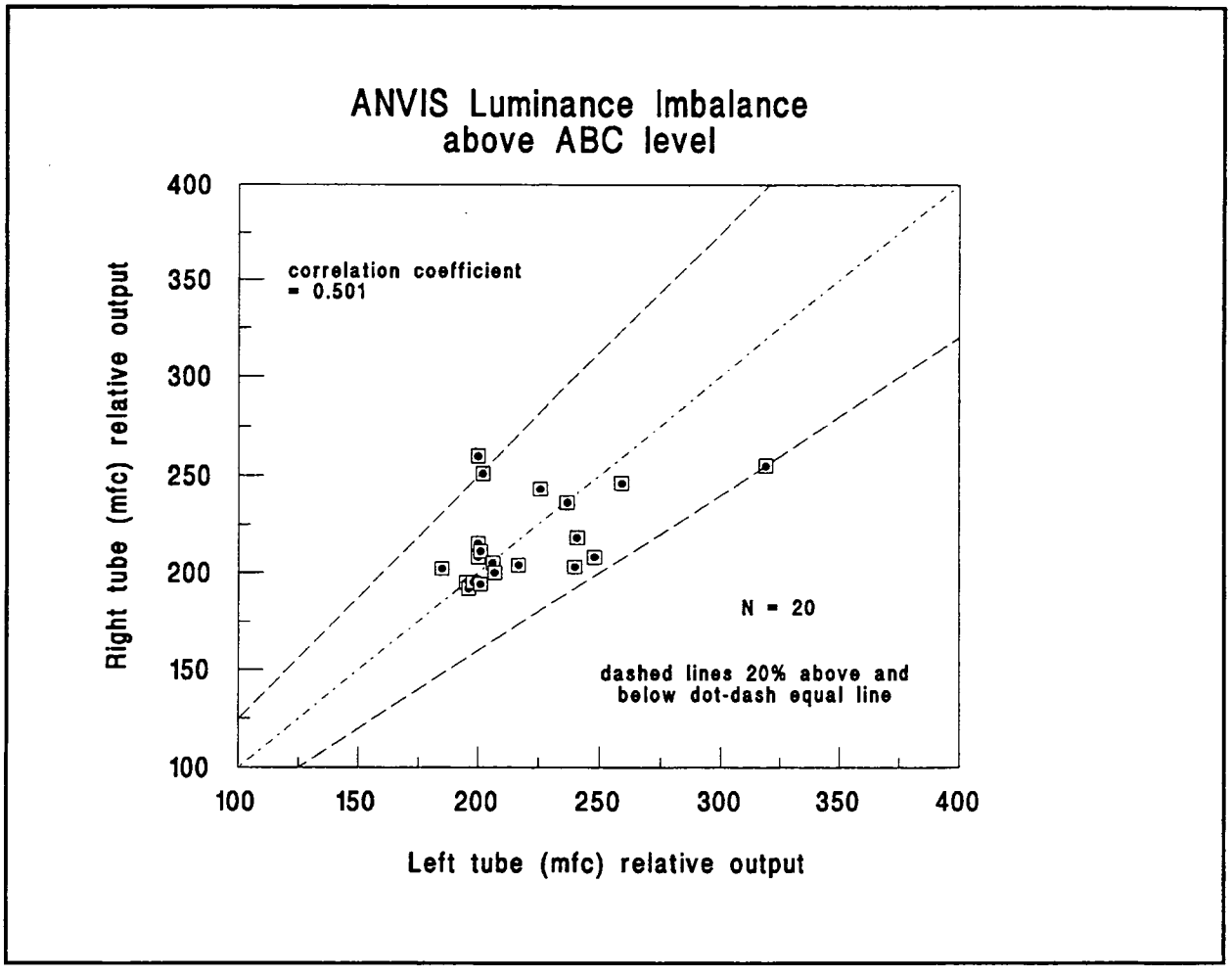

Figure 2. ANVIS luminance imbalance between right and left tubes above ABC level (high light condition).

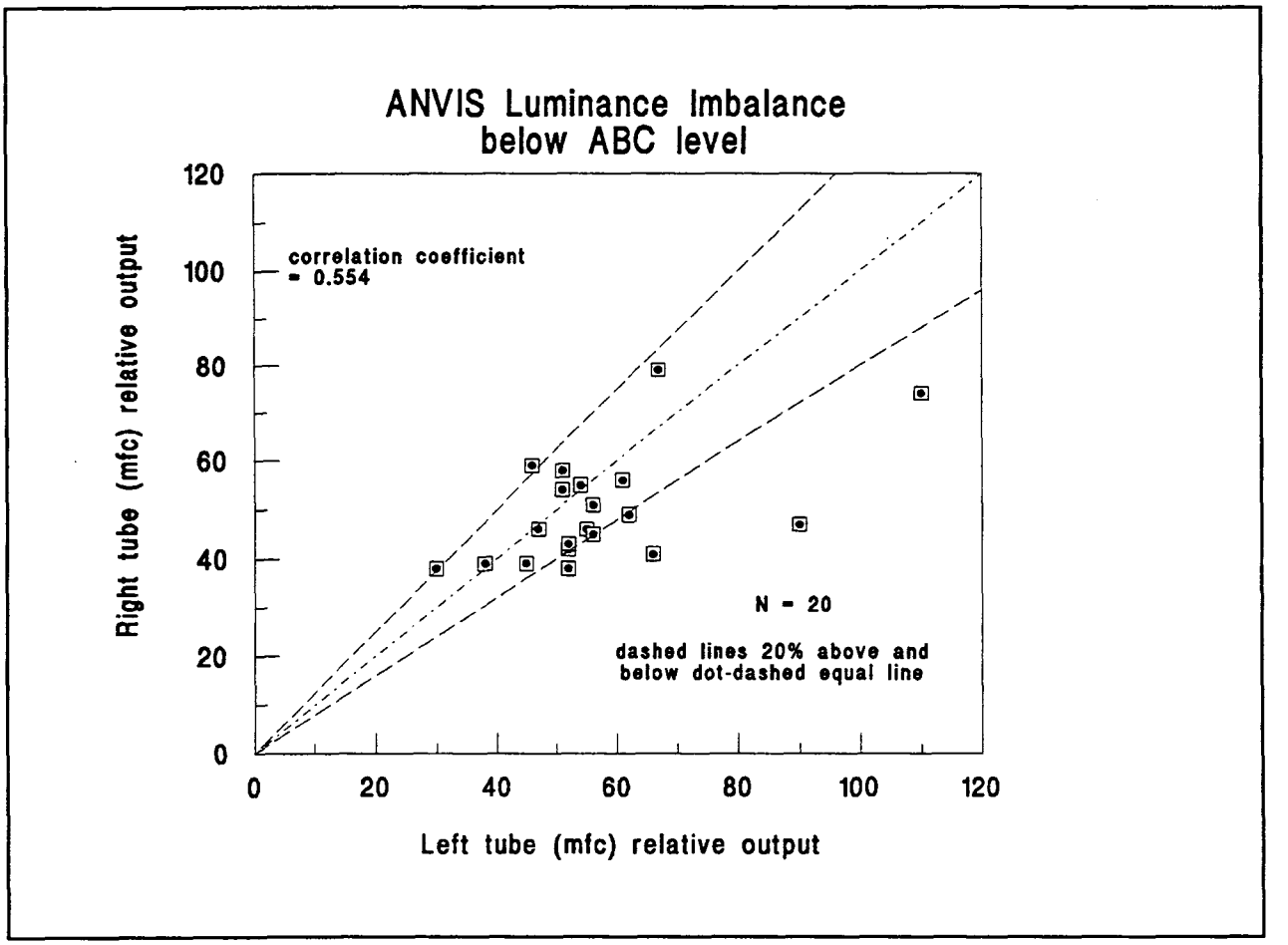

Figure 3. ANVIS luminance imbalance below ABC level
(lower light condition relative to tube gain).

Figure 4 is a scatter plot showing the relationship between the high luminance output above the ABC point and the lower light levels below the ABC point. The correlation coefficient is not significant at the 95 percent level.

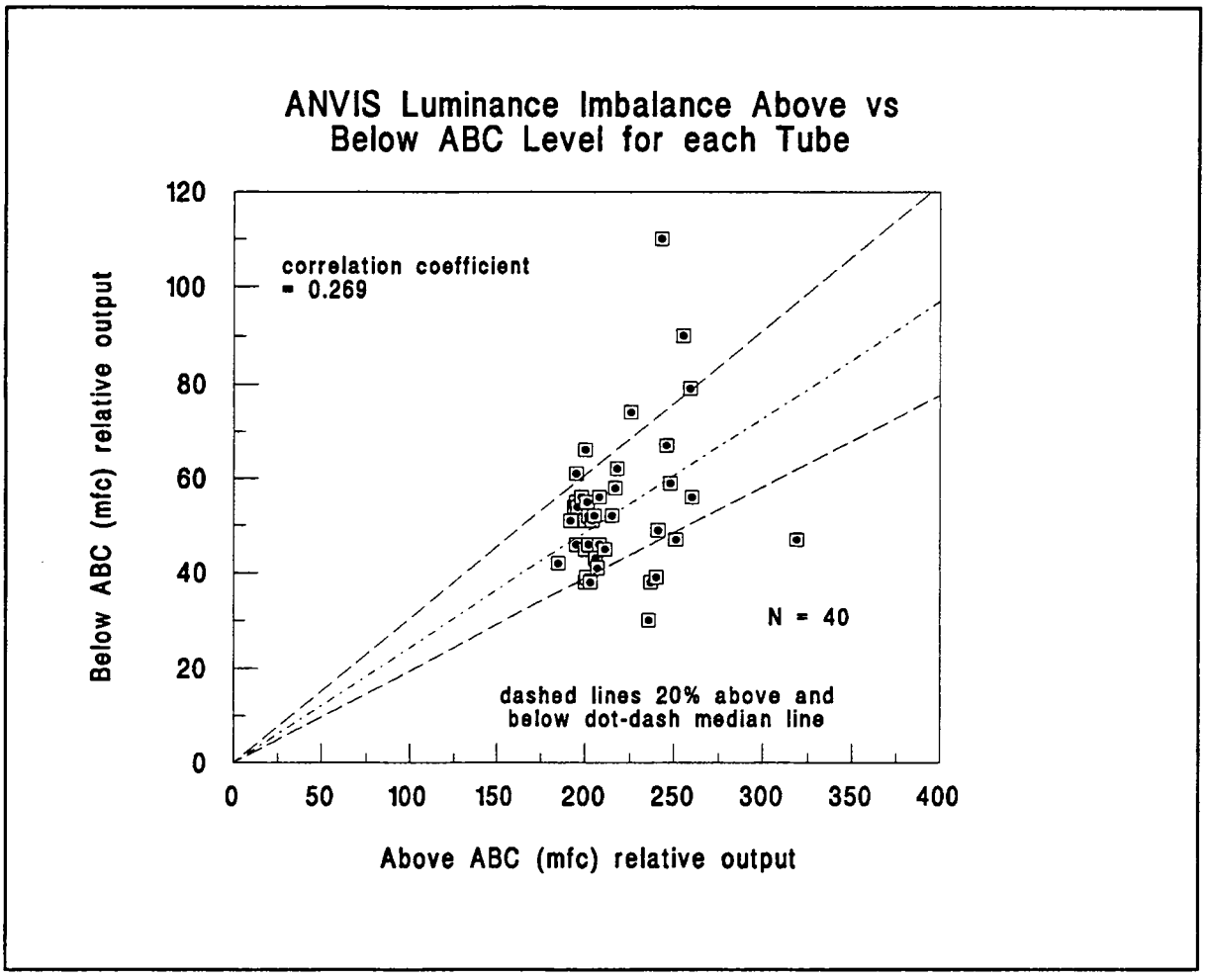

Figure 4. Comparison between relative luminance output above and below the ABC level for each tube.

Repeated measures of the same ANVIS over a 45 minute period were very stable until the last two low measures towards the end of the experiment (see appendix B). The decrease in the low values were approximately 20 percent. The relative difference between the tubes did not change, but the absolute values were lower for the last two readings. The question of whether the values of the radiometer changed with time for the lower values only or whether the actual output from the ANVIS changed on the lower input could not be determined at the airfield.

To test whether the ANVIS or the radiometer changed with time during the field evaluation, the high and lower values were repeated on a USAARL ANVIS and a filtered light standard in the Laboratory over a 2 1/2 hour period. The apparatus procedures were duplicated from the field measurements by leaving the NVG test set and radiometer <u>on</u> between measurements, but turning

the ANVIS off between measurements. The light standard was also turned off between measurements. Two different filters were used with the light standard to produce values towards the upper and lower range found for the measurements below the ABC level in the field experiment. The results indicated that the radiometer values rather than the ANVIS probably changed with time. However, the relative values were proportionally consistent in the laboratory test even after the low battery warning was activated and the display light had dimmed to where auxiliary lighting was required to read in the display. See appendix C for data values and calculations of percent differences.

Discussion

The NVG test set model TS-3895/UV provides a calibrated light source above and below the ABC level that is available to all government investigators for comparison purposes to this data or other NVG devices. However, the test set as a light source does have some unique features. The full ANVIS 40-degree FOV is not fully illuminated uniformly, dropping off towards the periphery. The lower FOV is brighter than the upper field, particularly at the medium light levels used for the measurements below the ABC level. If the NVGs are tilted, the readings with either light measuring instrument will vary. Therefore, at the light levels above the ABC level, the absolute luminance output from the ANVIS with the test set in the center of the FOV is above that obtained with a uniform background that fills the full 40-degree FOV (Bender, 1986). Aligning the photometer along the ANVIS eyepiece axis and at a given location in the white background of the test pattern of the test set will also reduce the amount of variability.

Psychophysical measurements or judgements of any noticeable differences in apparent output brightness between tubes for the twenty pair of ANVIS in this study were not solicitied. However, more than 100 NVG pilots, both students and instructors, used these ANVIS over the last 5 years or more, and none of these ANVIS had been reported as having unacceptable output between tubes.

During this study, one ANVIS was returned to DOL for repair with reported unacceptable brightness and color differences between tubes. Using both the standard NVG test set with the separate radiometer and a Hoffman ANV-126 NVG Test Set with a built-in gain capability, the brightness outputs for this ANVIS were measured. With the standard test set, the ouptput differences were 29 percent above the ABC level and 62 percent below the ABC level. With the Hoffman Test Set, the difference in gain between the two tubes (below ABC level) was 55 percent. The imbalance above the ABC level was not measured with the Hoffman NVG Test Set. Subjectively, the dimmer tube appeared more yellow than the brighter and greener tube.

Conclusion

Accurately measuring the luminance output from ANVIS in a field setting and in the laboratory is very challenging. The use of a simple illuminance radiometer on the ANVIS eyepieces with the NVG test set for the light source provides an economical and repeatable method to assess relative luminance imbalance both above and below the ABC in the ANVIS power supply. We found that 80 percent of the ANVIS surveyed that were routinely used for NVG training did not meet the suggested 10 percent luminance imbalance criteria either above or below the ABC level. The one set of ANVIS returned for unacceptable luminance and color differences between the tubes during this study measured 29 percent output difference above the ABC level and 62 percent below the ABC level. The results from this study imply that a maximum of 10 percent output imbalance between ANVIS oculars is unrealistic from a measuring standpoint and has not been reported by student and NVG instructor pilots as being unacceptable. The relative illuminance imbalance data from typical fielded ANVIS in this study provide a basis for future psychophysical assessments. The effects and the amount of display luminance imbalance on performance is unknown for any specific task.

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Abbreviations

ABC - automatic brightness control

ALSE - aviation life support equipment

ANVIS - aviator's night vision imaging system

CI - confidence interval

DA - Department of the Army

DOL - Directorate of Logistics

fL - footlambert

FOV - field of view

mfc - millifootcandle

Max - maximum value

MFG - manufacturer

Min - minimum value

NSN - national stock number

NVG - night vision goggle

% - percent

SASR - Special Air Services Regiment (Australian)

SD - standard deviation

TS - test set

USAARL - U.S. Army Aeromedical Laboratory

Appendix A.

Tasking letter and USAARL response (Executive summary)

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Army Airfield
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In reply please quote:

1/3/14

20 January 1997

Colonel D. Shanahan
Commander
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FORT RUCKER AL 36362-5292

REVIEW OF NVG TECHNICAL ASSESSMENT - BLACK HAWK S70A-9 MID-AIR ACCIDENT 12 JUN 96

References:

A. Draft AMRL report" Investigation of Visual Factors in the June 1996 Black Hawk Accident" by B.A.J. Clark (sent by e-mail to Dr McLean)

Dear Colonel,

1. On 12 June 1996, two Black Hawk helicopter collided in mid-air during the conduct of special recovery operations training. Both aircraft were destroyed and eighteen soldiers were fatally injured. The accident investigation resulted in a Board of Inquiry (BOI) which is being finalised at the moment.

2. The Accident Investigation Team sought the expert assistance of Dr Barry Clark from the Aeronautical and Maritime Research Laboratory, based in Melbourne to provide an analysis of the visual factors related to the accident. As a result of Dr Clark's initial findings and advice from our Aviation Psychologist, a restriction was placed on formation night vision goggle (NVG) flight until the results of the BOI were known.

3. The BOI findings cast some doubt on Dr Clark's report related to the effect of tube imbalances on depth perception and distance estimation. Specifically, the assessment that 9 of the 20 pairs of NVG assessed by Dr Clark were unsuitable for use due to either excessive inequality of the light output between pairs or low values of contrast rendition in individual barrels. The Air Standardisation Coordinating Committee (ASCC) Draft AIR STANDARD 61/116/P14 requires that the "Central field luminance values for left and right channels shall differ by no more than 30 percent (0.15 log units)." Although this AIR STANDARD is primarily concerned with "look through" Head Mounted Displays, it is also relevant to image intensification devices such as NVG.

4. The ASCC Draft Advisory Publication 61/113R/4 Visual Requirements of Head Mounted Display Systems identifies a maximum value of 10% luminance disparity. It would appear that Dr Clark has applied this value to his assessments, not the current AIR STANDARD.

5. In November 1996 LTCOL Rob Collyer visited your laboratory as part of his training for the position of Aviation Psychologist at this Headquarters and advises that he was warmly received for which I thank you. During his visit he was requested to liaise informally with your NVG researchers to determine what standards the US Army use for tube imbalances and whether the methodology used by Dr Clark was sufficiently rigorous for the findings to pass peer review. Dr McLean provided some initial advice which has allowed us to progress the review of our restrictions on NVG formation flight.

6. AMRL are in the process of reviewing Dr Clark's report but will not be able to release their findings until the end of March 1997. This does not accord with our operational requirements for the conduct of NVG formation flight on two of our major exercises in February 1997 and our need to release or modify the NVG formation restriction.

7. Headquarters, Aviation Support Group requests that USAARL provide the following information to allow a risk assessment of NVG formation flight to be undertaken by the end of January 1997:

a. a peer review of the portion of Dr Clark's report relating to luminance variation across the field of view to determine whether Clark's methodology was appropriate and his findings are justified;

b. advice on the likelihood of tube imbalances of less than 30% causing visual illusions of depth perception and distance estimation that would be considered a flight safety problem for NVG formation flight;

c. the current US Army approach to tube imbalances and what method of measurement and what criteria are used; and

d. what equipment is used by the USAAVNC for NVG adjustment in the field for first and second line maintenance adjustment.

8. I apologise for the short notice and the degree of urgency that are placed upon this request, but it is unavoidable if we are to review the NVG formation flight restrictions before the commencement of Exercise "Tandem Thrust" which is a US/AS combined exercise. The format of the comment by your researchers is not important, rather the ability to meet our deadlines is the critical factor.

9. The point of contact at this Headquarters is LTCOL Mike Bonner on telephone (+61-76-919041), facsimile (+61-76-919010) and e-mail HUMFAC@t130.aone.net.au.

10. Thank you for your assistance.

for W. J. A. HELLOR AOD
Brigadier
Commander

DEPARTMENT OF THE ARMY
U.S. ARMY AEROMEDICAL RESEARCH LABORATORY
FORT RUCKER, ALABAMA 36362-0577

REPLY TO
ATTENTION OF:

January 28, 1997

Office of the Commander

SUBJECT: Review of NVG Technical Assessment - Black Hawk S70A-9 Mid-Air Accident, 12 Jun 96--USAARL Technical Memorandum 97-17

Brigadier General W. J. A. Mellor
Commander
Aviation Support Group
Army Aviation Centre
Army Airfield
Oakey QLD 4401

Dear General Mellor:

In response to your January 20, 1997, request for technical assistance regarding the Black Hawk S70A-9 Mid-Air Accident, an executive summary and technical report are enclosed.

Our Laboratory points of contact for this report are Dr. William McLean, telephone number 334-255-6813, facsimile 334-255-6977, or e-mail mclean@ rucker-emh2.army.mil, and Lieutenant Colonel Jeff Rabin, telephone number 334-255-6868, facsimile 334-255-6977 or e-mail rabin@rucker-emh2.army.mil.

Sincerely,

Dennis F. Shanahan
Colonel, U.S. Army
Commander, U.S. Army Aeromedical
Research Laboratory

Enclosure

EXECUTIVE SUMMARY

On behalf of our Laboratory and the U.S. Army Medical Research and Materiel Command, we extend our sincerest condolences to the families, friends and all involved in the unfortunate mid-air Blackhawk helicopter collision on 12 June 1996. The report by Dr. B.A.J. Clark describes numerous plausible causative and contributory factors to this accident. Dr. Clark's comprehensive analysis exemplifies his keen insight, resourcefulness, and abilities as a leading visual scientist whose reputation certainly precedes him. The technical report which follows includes detailed comments on this report, as well as comprehensive responses to the four items in your official request. Responses to those items are summarized below.

In response to the item regarding the methodology used for measuring ANVIS display luminance (sections 6.2.3.2 and 6.2.3.3 of Dr. Clark's report), we acknowledge the difficulty of this measurement, particularly at low light levels in a makeshift, field environment. Accuracy and consistency of measurement depend critically on focus of both the photometer and ANVIS, optical alignment of all elements, and photometer sensitivity. Dr. Clark's report suggests that the test environment and methods did not allow adequate control of these factors, which could have resulted in considerable measurement variability. Measurement of contrast (difference between luminance of small target and background relative to background) is even more critically dependent on proper focus and alignment, and thus more prone to measurement error. No mention is made in Dr. Clark's report of whether the between channel differences in display luminance and contrast were verified subjectively by viewing each channel alternately with one eye. If there were significant differences in brightness and/or contrast between tubes, then this could have been verified by alternate monocular inspection using a small number of observers. This subjective confirmation would help substantiate what appear to be questionable objective measurements.

The requirement for tube imbalances of less than 10% is probably too stringent in terms of human visual performance, and too difficult to develop, maintain and measure accurately with existing equipment. A 10% luminance difference between tubes is only 0.046 log units; a value which is considerably less than the minimum luminance imbalance associated with erroneous depth effects, such as the Pulfrich phenomenon. Moreover, such a small difference is problematic to measure accurately given drift in display luminance and variability in photometer readings, particularly at low light levels. In contrast, a luminance difference no greater than 30% (0.15 log units) is more realistic in terms of the minimum difference known to produce illusory depth effects (0.1 to 0.2 log units), and with

what may be achieved and measured with existing equipment. It is also worth noting that Apache helicopter pilots use a monocular helmet mounted display with FLIR imagery during the night, but typically fly without imagery (see-through mode) during the day. Insofar as the daytime (see-through) luminance transmission of the display is only 20%, the pilot is effectively flying with an 80% difference in luminance between the two eyes. Despite this luminance disparity, none of the pilots we have questioned report illusory depth or distance percepts. This in no way denies the potential for occurrence of illusory percepts, but does exemplify the adaptive nature of the human visual system. This adaptive, compensatory nature was also revealed in an extensive study of the effects of hyperstereopsis (altered depth perception from increased separation between the eyes), which revealed little actual effect on flight performance.

In response to the third item, current standards for ANVIS are not specific for luminance imbalances between tubes, but do require certain maximum and minimum display luminances, depending on ambient light level. These values initially were based on what the developer could produce, and on what could be reliably maintained in operational environments. Although, in our experience, we rarely encounter channels in a single ANVIS which differ in output by more than 30%, Dr. Clark makes the important point that tolerances should be based not only on engineering and logistical constraints, but also on achieving safe and effective visual performance. With the advent of brighter, higher quality ANVIS tubes, we should modify our specifications to ensure that luminance imbalances do not exceed 30%. This is a realistic goal, although additional equipment may be necessary to implement this at post-production levels.

In response to the fourth item regarding equipment and maintenance, the detailed memorandum which follows specifies equipment and procedures for NVG maintenance and adjustment in the field.

In conclusion, accurate measurement of ANVIS display luminance and contrast is a challenging endeavor, with considerable potential for error. Luminance imbalances of 10% (0.05 log units) are possible, but are unlikely to pose a significant threat to safety or performance. With the advent of newer night vision goggles with higher gain and improved resolution, we must realistically modify existing specifications to minimize differences between tubes, and maximize safety and performance.

Appendix B.

ANVIS imbalance recording form

DATA RECORDING FORM

Date: 28 Feb 1997, Time: 1415-1500, Location: Lowe AAF

Trial #	NVG #	RT High	LT High	High % D	RT Low	LT Low	Low % D	90 day due
1*	186	208	200	3.9%	56	51	8.9%	5/11/97
2	187	260	200	23.1%	56	45	19.6%	4/15/97
3	189#	236	237	0.4%	30	38	21.1%	4/15/97
4	190	203	240	15.4%	38	39	2.6%	5/20/97
5*	192	218	241	9.5%	62	49	21.0%	5/11/97
6	193	195	195	0.0%	55	46	16.4%	3/17/97
7	196	202	185	8.4%	52	42	19.2%	4/21/97
8	197	204	217	6.0%	51	58	12.1%	5/21/97
9*	202	251	202	19.5%	47	46	2.1%	4/17/97
10	204	192	196	2.0%	51	54	5.6%	5/11/97
11	206	194	201	3.5%	54	55	1.8%	4/21/97
12	210	200	207	3.4%	66	41	37.9%	4/28/97
13*	211	215	200	7.0%	52	38	26.9%	5/09/97
14	214	205	206	0.5%	52	43	17.3%	4/22/97
15	215	195	198	1.5%	61	56	8.2%	4/28/97
16	217	243	226	7.0%	110	74	32.7%	3/15/97
17*	217	208	248	16.1%	46	59	22.0%	5/11/97
18	222	246	259	5.0%	67	79	15.2%	5/17/97
19	226	255	319	20.1%	90	47	47.8%	4/22/97
20*	227	211	201	4.7%	45	39	13.3%	4/26/97
	mean	217	219	7.9%	57.1	50	17.6%	
	SD	22	30.6	7.0%	16.9	11	11.8%	

* Indicates repeated measurement of the test goggle #186 (see next page).

\# Goggle # 189 had 25-mm eyepieces, which produce values 20% lower than standard eyepieces.

Data Recording Form Test Sample with Repeated Measures

Trial #	NVG #	RT High	LT High	High % D	RT Low	LT Low	Low % D
1	186	208	200	3.8%	56	51	8.9%
5	186	211	201	4.7%	54	47	13.0%
9	186	211	202	4.3%	51	44	13.7%
13	186	210	200	4.8%	56	48	14.3%
17	186	211	202	4.3%	46	42	8.7%
20	186	213	201	5.6%	45	40	11.1%
	mean	210.7	201	4.59 %	51.3	45.3	11.61%
	SD	1.49	0.82	0.56%	4.46	3.73	2.21%
	Min	208	200	3.8%	45	40	8.7%
	Max	213	202	5.6%	56	51	14.3%
	med	211	201	4.5%	53.5	45.5	12.1%

Appendix C.

Calibration procedures and results

Radiometer drift determination

The Laboratory test of the Photodyne radiometer stability versus time was conducted using the battery charger and display light until the low battery warning was activated. A Laboratory ANVIS, No. 17030B, with the same NVG test set TS-3945 U/V that was used in the field measurements were used for the laboratory drift assessment. A regulated standard light source, SPECTRA™, 100 footlamberts, Photo Research Corp., was filtered with two different filters to produce medium to low values from the radiometer. The sensor head of the radiometer was placed directly on the flat diffuse surface of the standard light source.

Table C-1.
Radiometer drift with time.
Illuminance values are millifootcandles (mfc).

Time (pm)	Minutes Duration	Right High	Left High	Right Medium	Left Medium	Standard Low	Standard Higher
2:09	0	221	204	97	56	26	70
2:20	11	218	202	102	58	25	69
2:32	23	220	203	100	55	26	68
2:48	39	219	202	99	57	25	70
2:54	45	220	202	100	58	25	69
3:06	57	218	201	102	59	25	70
3:27	78	219	202	102	56	25	70
3:46*	97	246	226	112	65	29	77
4:00	111	241	221	112	64	28	75
4:18	129	242	222	115	67	28	76
4:40	151	244	225	114	66	30	77
5:00**	171	300	277	142	82	36	97
first seven values, median		219	202	100	57	25	70

* Illuminance values increased by approximately 12 percent.
** low battery warning on and display light very dim.

Table C-2 lists the calculated percent differences between the right and left eyepiece outputs at the high and low light level, and between the median values determined for the first seven measurements in the previous table.

Table C-2.
Percent differences between right and left channels and median values.

Time minutes	RT vs LT (High)	RT vs LT (Lower)	RT vs Med. (High)	LT vs Med. (High)	RT vs Med. (Low)	Lt vs Med. (Low)
0	7.7%	42.0%	+0.9%	+1.0%	-3.0%	-1.8%
11	7.3%	43.1%	-0.4%	0.0%	+2.0%	+1.8%
23	7.7%	45.0%	+0.4%	+0.5%	0.0%	-3.5%
39	7.8%	42.4%	0.0%	0.0%	-1.0%	0.0%
45	8.2%	42.0%	+0.4%	0.0%	0.0%	+1.8%
57	7.8%	42.2%	-0.4%	-0.5%	+2.0%	+3.5%
78	7.8%	45.1%	0.0%	0.0%	+2.0%	-1.8%
97*	8.1%	42.0%	+12.3%	+11.9%	+12.0%	+14.0%
111	8.3%	42.9%	+10.0%	+9.4%	+12.0%	+12.3%
129	8.3%	41.7%	+10.5%	+9.9%	+15.0%	+17.5%
151	7.8%	42.1%	+11.4%	+11.4%	+14.0%	+15.8%
171**	7.7%	42.3%	+37.0%	+37.2%	+42.0%	+43.9%
		median (mfc)	219	202	100	57

* illuminance values increased approximately 12 percent.
** low battery warning on and display light very dim.

Some drift of the readings of the ANVIS output will also occur in the first few minutes. The radiometer and NVG test set were turned on at least 10 minutes prior to measurements to minimize instrument drift. The ANVIS luminance output drift is different at the above ABC level and below the ABC level and is shown in figure C-1.

Right versus left channel of NVG test set

The high and medium light levels with the NVG test set were used to assess the difference between the right and left channels of the test set. High and medium measurements with the radiometer were taken with the test ANVIS alternately positioned with the left and right objective

lenses placed in the corresponding right and left ports of the test set, and then the ANVIS was turned upside down, placing the left ANVIS objective in the right NVG test set port and right objective in the left port of the test set. For the high light level of the test set, the difference between the right and left channels was less than 1 percent. For the medium light level, the difference was less than 4 percent.

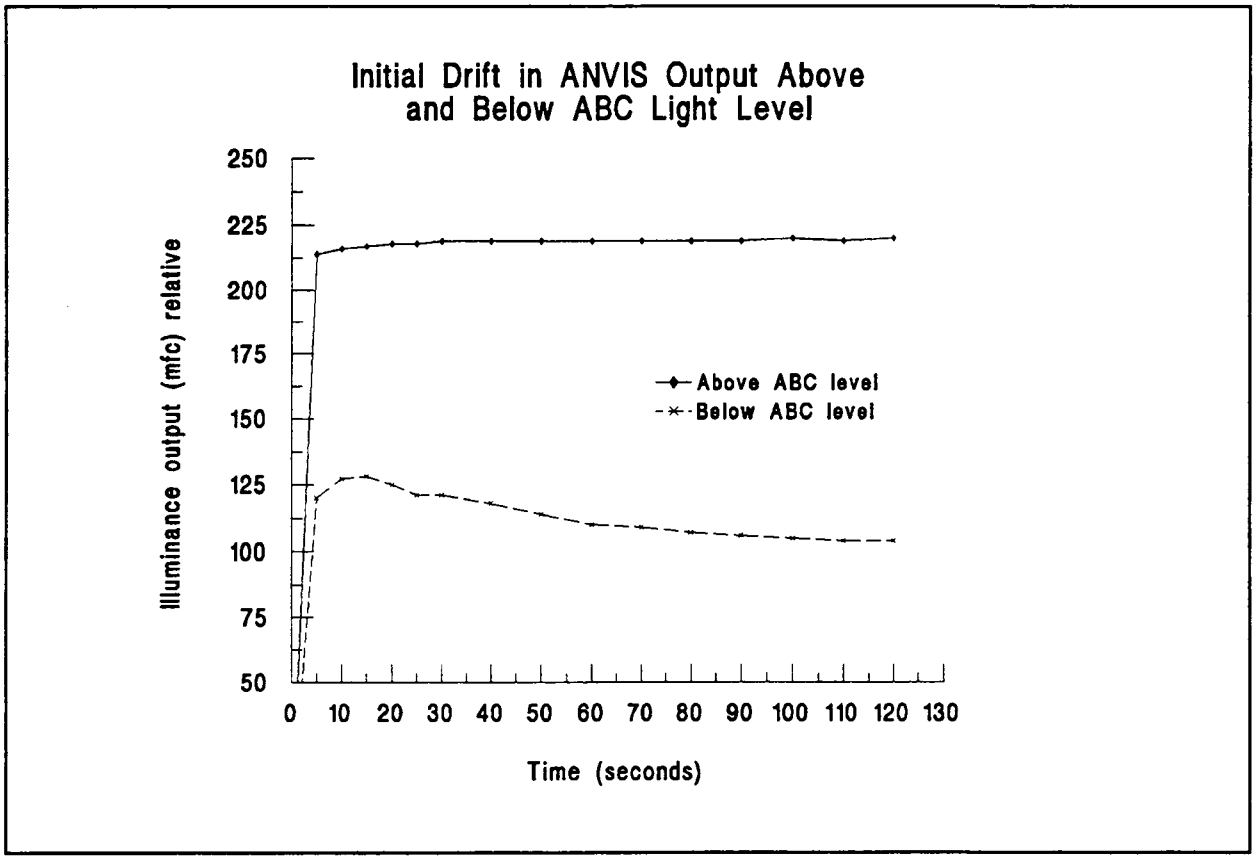

Figure C-1. ANVIS output drift with time above and below ABC light levels.

Eyepiece diopter value effects

Changing the diopter setting on ANVIS eyepieces also changed the readings on the illuminance values of the radiometer. This function of output readings versus eyepiece diopter values was determined using the NVG test set on the high light level from the maximum to the minimum diopter values on the eyepiece in 2.00 diopter steps.

Figure C-2 shows the function and regressions between illuminance values from the radiometer and ANVIS eyepiece diopter settings using the laboratory ANVIS. Note that each diopter change results in approximately 1 percent difference in illuminance readings.

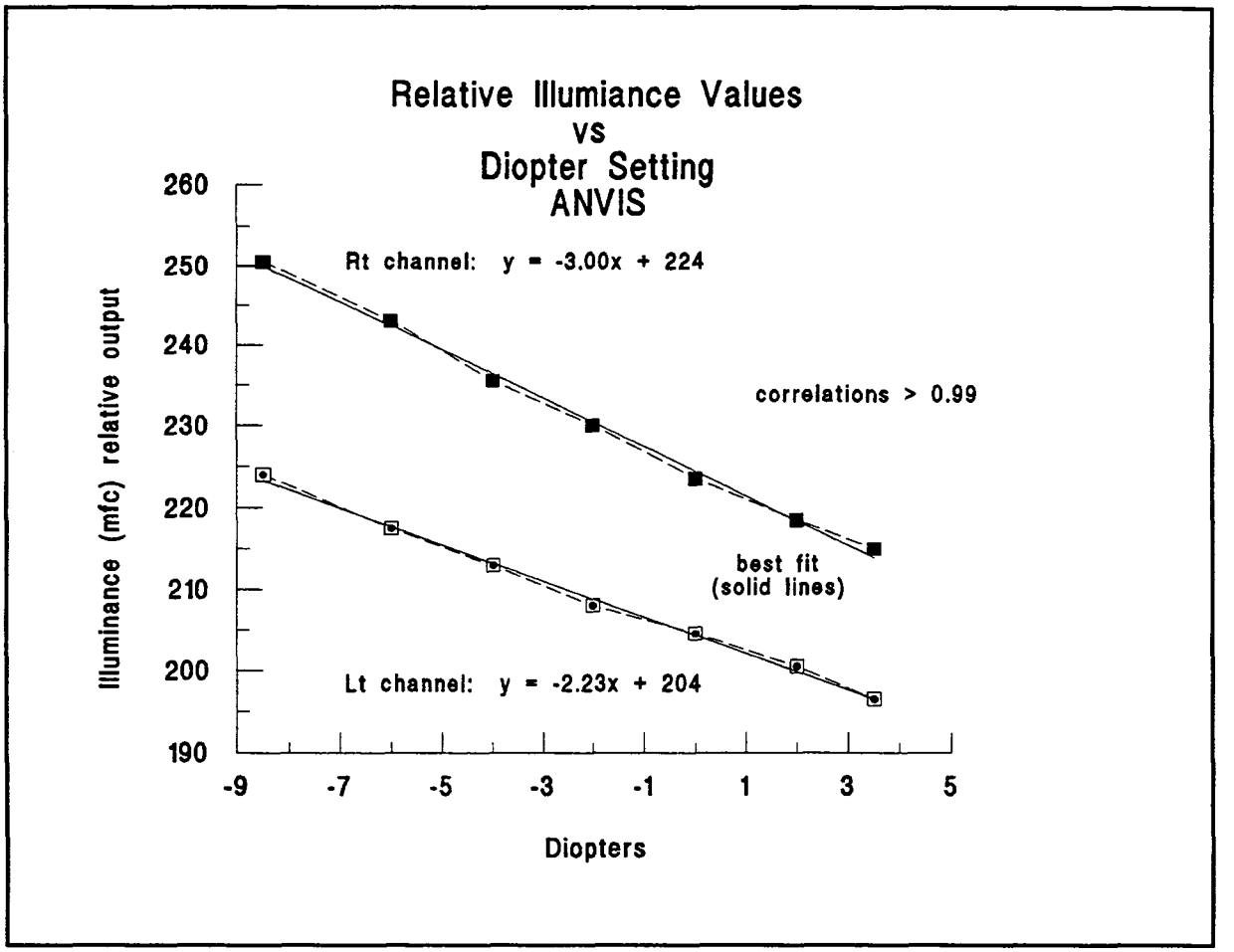

Figure C-2. Effects of diopter settings on illuminance output.

Calibration between Pritchard 1980A photometer
and Photodyne XL-88 radiometer

Aperture on photometer

The standard objective lens of the Pritchard photometer is a 7-inch focal length, F# 3.5, with a diameter of 50 mm. The diameter of the ANVIS eyepieces are slightly less than 20 mm. Therefore, to directly measure the luminance through the eyepieces of the ANVIS with the photometer, a fixed 8-mm aperture was attached to the front of the objective lens of the photometer. (We do not recommend using variable apertures, since recalibration would be required for each use.) After calibrating the photometer with an internal standard, alternate measurements with and without the aperture were taken using a light standard to determine the

correction factor for the aperture values. During initial calibration, it was noted that the distance between the light standard and the objective lens and the internal aperture of the photometer affected the correction value. The distance effects are due to the external aperture on the objective lens not being located with the limiting aperture of the objective lens. Measurements were taken at three different viewing distances (1, 2, and 4 meters) and with two different internal angular apertures of 1 degree and 20 arc minutes, except at the 4 meter distance. The mean of three readings with and without the aperture were determined and are shown in the table C-3.

Table C-3.
Photometer objective lens correction factor.

Aperture	1 meter	2 meters	4 meters
1 degree	32.2	27.3	-- --
20 arc min	34.3	27.5	25.1

The 4 meter focus of the photometer was used for calibration of the aperture and used for the eyepiece focus in the laboratory to determine absolute central luminance values through the ANVIS with the test set.

Photometer and radiometer measurements

NVG test set for the light source:

The NVG test set was mounted on its side such that the NVG openings for the test ports and the ANVIS tubes were aligned horizontally. During the field study and the laboratory testing with the radiometer, the NVG test set was placed in its normal flat position with the NVG tubes aligned vertically with the test ports. The ANVIS was mounted on a standard rigid ANVIS visor that was mounted on a vertical adjustable metal stand. The objective lenses of the ANVIS were aligned and moved into the right and left test ports until contact was made. The ANVIS metal stand was locked into place to prevent inadvertent moving during the measurements. The photometer was mounted on a heavy tripod with adjustments for tilt, vertical, and horizontal movements.

Using the NVG test set as the luminance source, luminance readings for each condition were taken with the Pritchard photometer with the 8 mm restrictive aperture and the Photodyne radiometer using the high and medium light level on the test set. The photometer was placed approximately 15 mm behind the ANVIS eyepieces and aligned with one ocular initially by eyeball. The alignment was then refined by noting the midrange between vignetting points as the three axes of adjustment on the tripod were individually adjusted. The midranges between the visible vignetting also produced the highest luminance readings. The measurement point in the background was approximately 2 degrees below the apparent FOV center and the resolution test

targets. As one ANVIS ocular was measured with the photometer, the other ocular was measured with the radiometer. The procedure was reversed until seven readings were obtained for each ocular for each condition. The right and left ocular values for the high and medium light levels are reported separately.

The following tables (C-4a-4d) are descriptive statistics for the calculated footlambert values, measured millifootcandles, and radiometer correction values of the ANVIS used in the laboratory for the high (above ABC level) and the medium (below ABC level) settings on the NVG test set. A value of 25.1 was used for the aperture correction factor for the photometer.

Table C-4a.
Descriptive statistics of luminance, illuminance, and correction factors.

Right High	footlambert	millifootcandles	**correction factor** mfc to fL
mean	3.39	221.4	0.0153
standard deviation	0.0343	0.535	N = 7
minimum	3.34	221	
maximum	3.43	222	
median	3.39	221	

Table C-4b.

Left High	footlambert	millifootcandles	**correction factor** mfc to fL
mean	2.93	203.7	0.0144
standard deviation	0.0196	1.113	N = 7
minimum	2.89	202	
maximum	2.95	205	
median	2.92	204	

Table C-4c.

Right Medium	footlambert	millifootcandles	correction factor mfc to fL
mean	1.47	106.57	0.0138
standard deviation	0.0792	3.78	N = 7
minimum	1.41	104	
maximum	1.64	115	
median	1.44	105	

Table C-4d.

Left Medium	footlambert	millifootcandles	correction factor mfc to fL
mean	0.705	62.57	0.0113
standard deviation	0.0782	2.507	N = 7
minimum	0.542	61	
maximum	0.798	68	
median	0.72	62	

Due to the luminance non-uniformity of the backgrounds in the NVG test set, particularly with the medium light level (below the ABC level), the correction factors from the central fL measurements and the overall illuminance values in mfc vary. The percentage difference between the correction factors are shown in table C-5, where percentage difference is defined as: 100 x (1 - min/max).

Table C-5.
Percent differences between right and left channels at high and medium light levels.

	Right High	Left High	Right Medium	Left Medium
Right High	----	5.9%	9.8%	26.1%
Left High		----	4.2%	21.5%
Right Medium			----	18.0%
Left Medium				----

Perimeter for uniform light source:

Using a Haag-Streit perimeter as the uniform background illumination for the ANVIS, measurements with the radiometer and photometer were taken above the ABC level and two different readings below the ABC level, but above a simulated starlight level. The perimeter consists of a semi-hemispherical white bowl with a radius of 30 centimeters. Small central fixation points were marked in the perimeter for each ocular of the ANVIS to minimize position errors with the photometer. The objective lenses of the laboratory test ANVIS were positioned approximately 25 mm inside and below the center of curvature for the perimeter. The background illumination for the perimeter was controlled with an aperture, which does not affect the color temperature of the incandescent light source of the perimeter.

The luminance and illuminance readings always began above the ANVIS ABC level to minimize ANVIS drift below the ABC level. The photometer was aligned for one ocular by adjusting the vertical, tilt and lateral rotations of the tripod to find the midpoint between the vignetting range. Measurements between the radiometer and the photometer for each ocular were alternated by rotating the photometer to one side for the radiometer reading for a given background illumination. Rotating the photometer minimized any position errors. After the third pair of measurements, the illumination of the perimeter was increased to the original background level of slightly above the ABC level, and the photometer and radiometer measurements were repeated to determine any significant drift.

Table C-6 gives the maximum ANVIS output values for the uniform background and the average correction factors for the right and left oculars.

Table C-6.
Illuminance and luminance ANVIS output with uniform background and correction factors.

	footlamberts	millifootcandles	**mean correction factor** mfc to fL
Right channel	1.89	200	0.00937
Left channel	1.55	189	0.00802

Note the 14 percent difference between the mean right and left correction factors. This difference could be due to position and alignment errors of the photometer or slight differences in the central luminances between the two oculars. With the full FOV uniformly illuminated with the perimeter, the maximum central luminance values are slightly less than 50 percent lower than with the NVG test set above the ABC level. In comparison, the radiometer values for the perimeter are only approximately 10 percent lower than with the NVG test set above the ABC level.

Standard versus 25-mm ANVIS eyepiece measurements

One of the ANVIS measured in the field evaluation had 25-mm eyepieces instead of the standard 18-mm eyepieces. To determine the possible difference in the radiometer and photometric readings between the 25-mm and the standard 18-mm eyepiece, the eyepieces of an ANVIS were switched using the standard 18-mm convex, 18-mm concave, and production 25-mm eyepieces on the same ANVIS. The light sources were the NVG test set when using the radiometer and the perimeter with the uniform background for both the radiometer and photometer. The eyepiece diopter values were all set at 0.25 diopters (4 meters) using a diopterscope. The results showed that the 25-mm eyepieces measured 20 percent lower than the standard 18-mm convex eyepieces with the radiometer, but there was no difference in the luminance when measured with the Pritchard photometer. However, the 18-mm concave eyepiece measured approximately 33 percent lower than the standard 18-mm convex eyepiece with the radiometer and 19 percent lower with the photometer.

Appendix D.

List of equipment manufacturers.

ANVIS, AN/AVS-6
NSN 5855-01-138-4749
MFG 13567

Haag-Streit AG
Ophthalmological Instruments
3097 Liebefeld/Switzerland

Hoffman Engineering Corp
20 Acosta Street
Stamford, CT 06902

Photo Research
3000 North Hollywood Way
Burbank, CA 91505

Photodyne Inc.
5356 Sterling Center Drive
Westlake Village, CA 91361

Test Set TS-3895A/UV Electronic System
NSN 6625-01-301-6894
MFG 62362