This paper has been cleared by ASC 99-2354

Optical Characterization of Wide Field-Of-View Night Vision Devices

Peter L. Marasco and H. Lee Task

Air Force Research Laboratory
Human Effectiveness Directorate
AFRL/HECV
2255 H. Street
Wright-Patterson AFB, OH 45433-7022
(937) 255-7602

ABSTRACT

An advanced night vision device, the Panoramic Night Vision Goggle (PNVG), presents the wearer with a large horizontal field of view (100 degrees) by combining the output from multiple image intensifier tubes. This significantly complicates the testing and evaluation of this state-of-the-art device. Current tests were considered insufficient and required modification to fully characterize conventional night vision device parameters. In addition, new tests were required to characterize parameters unique to the current PNVG design. This paper discusses the optical performance testing of the PNVG, concentrating primarily on four night-vision-device parameters: field of view, visual acuity, eyepiece diopter setting, and image discontinuity.

INTRODUCTION AND BACKGROUND

Night vision goggles (NVGs) have become a key technology for covert military and law enforcement operations at night in both fixed wing and rotary wing aircraft. With the success of NVG technology came a flood of NVGs in different configurations designed to improve their characteristics and usefulness. In order to evaluate these different NVG designs it was seen as desirable to have a collection of measurement procedures capable of characterizing new systems and acquiring data necessary for critical comparisons. Much work was done in the early 1990's to design and document tests used to characterize conventional NVGs. However, depending on the design of the NVG (folded optics, offset input/output axes, eyepiece combiners, etc.) some of the procedures become more difficult to apply.

One such system that required unique tests to fully characterize its capabilities was the Panoramic Night Vision Goggle, or PNVG. This design combines the outputs from four image intensifier tubes into one continuous image, providing the wearer an unusually large (100 degrees horizontal, 40 degrees vertical) field of view. The PNVG comes in two basic designs, the PNVG I and PNVG II. The first and more exotic PNVG I liberally incorporates folds into the imaging optics to achieve a design that fits close to the wearer's face and is ejection compatible. PNVG II is a more conventional, less folded design, intended to be less expensive and to interface with existing AN/AVS-6 NVG hardware for use on platforms that do not require ejection compatibility.

While many of the procedures documented earlier could be applied to the PNVG, some could not. This paper documents the procedures specifically designed for the PNVG to measure field of view, halo diameter, visual acuity, eyepiece diopter setting, and image discontinuity. In addition this paper documents some of the results of these and other optical tests conducted on several PNVG prototypes.

MEASUREMENT PROCEDURES

Field of View

The most significant parameter associated with the PNVGs is probably the total field of view (TFOV) since the objective of the PNVG program was to provide the pilot with significantly more TFOV than existing fielded systems. However, the field of view of PNVG is somewhat complicated because of the way it is achieved.

There are a total of 4 oculars that are aimed in 3 different directions. The center two oculars are pointed directly ahead. The left and right outboard channels have their optical axes pointing 30 degrees to the left and right of the center channels respectively. Each ocular is designed to provide a 40 degree circular field of view; although the full 40 degree FOV of each ocular may not be visible to the observer because of eye position. This combination of ocular axes and the interaction of visible FOV with eye position makes it somewhat difficult to easily characterize field of view.

Two approaches were taken to characterize the PNVG's total field of view. The first method was simply to verify that the PNVG's total field of view was at least 100

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1999**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Optical Characterization of Wide Field-Of-View Night Vision Devices**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Air Force Research Laboratory Wright-Patterson AFB, OH 45433**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**		
13. SUPPLEMENTARY NOTES **The original document contains color images.**		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

degrees (all except one of the PNVGs demonstrated this total field of view) and the other method was designed to directly measure the individual ocular FOVs and the angular locations of their FOVs with respect to the right, in-board ocular, which was used as a reference channel.

To conduct the first test, the PNVG was fixed to a bench and placed a known distance from a wall. Two small marks were made on the wall a distance from each other that subtended 100 degrees from the position of the PNVG on the bench, 50 degrees off to each side of the test goggle (see Figure 1). If both marks were visible, then the PNVG field of view was at least 100 degrees. This test was sufficient to determine if the requirement of the wide, 100-degree, field of view was met.

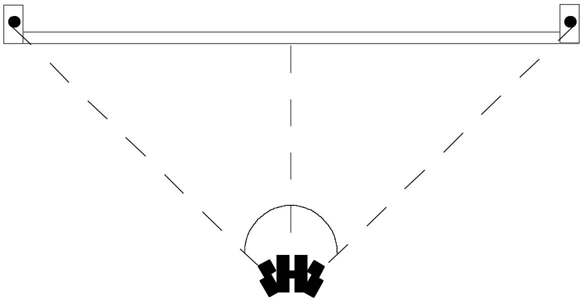

Figure 1. Relative position of LEDs for the assessment of field of view.

Table 1. Field angles for center, left edge, and right edge of PNVG oculars.

Ocular	Left Edge	Center	Right Edge
Right In-board	-20 deg	0 deg	+20 deg
Left In-board	-20	0	+20
Right Out-board	+10	+30	+50
Left Out-board	-10	-30	-50

A similar approach was used for the second FOV test in that the right channel objective lens of the PNVG was positioned a known distance from a long horizontal rail. Two red LEDs were positioned a distance to either side of the center point corresponding to ± 20 degrees. The observer then viewed through the right central channel only and adjusted the position of the PNVG until the two red LEDs were visible at the right and left edges of the FOV. The PNVG was then kept in this position for all of the following measurements. While observing through the left ocular only, and moving the eye if necessary, the LEDs were then positioned at the left and right boundaries of the left ocular field of view. If the PNVG was perfectly aligned and the oculars were exactly 40 degrees, the position of the LEDs would shift to the left by the observer's inter-pupillary distance. By knowing the edges of the left ocular field of view, it is possible to determine where the center of the left ocular FOV is directed. The edges of the left and right outboard ocular FOVs were measured in a similar fashion and their field angles with respect to the right ocular axis were determined and compared to what they should be. If the PNVG were perfectly assembled the field angles for the different oculars should be as shown in Table 1.

Visual Acuity

This procedure was designed to measure how well a human observer could see high contrast targets at a specified light level through the PNVG.

High contrast, square-wave acuity targets were used as the visual acuity opto-types. These square-wave targets were in steps of one Snellen acuity point (e.g. 20/24, 20/25, 20/26, etc). The test PNVG was fixed to a bench at a distance of 30 feet from the acuity targets. The observer was then allowed to dark adapt for about 10 minutes. An illuminator with a color temperature of 2856K was used to light the target acuity targets to a luminance level corresponding to quarter moon illumination ($5x10^{-3}$ foot-Lamberts (fL) and starlight only illumination ($5x10^{-4}$ fL). The observer then focused the test PNVG objective lenses (central only; outboard objective lenses were fixed focus for these PNVGs) on the square wave acuity target. A technician then prompted the observer to read the chart, first through each channel of the NVG using their dominant eye, and then through both oculars using both eyes (binocular vision). The target with the highest spatial frequency the subject could clearly see was then recorded. This procedure was repeated three times per observer.

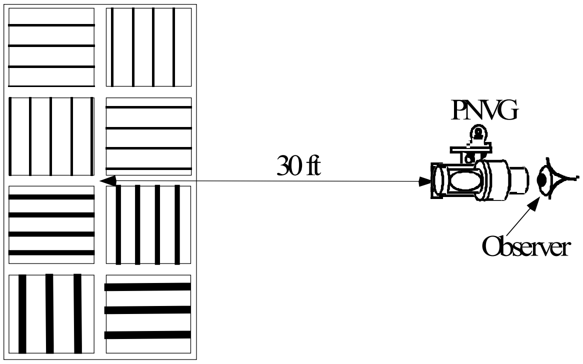

Figure 2. Relative position of equipment for visual acuity measurements.

Three trained observers familiar with the operation of the test PNVG having 20/20 vision or vision corrected to 20/20 and no astigmatism were used. Each observer viewed through each ocular 3 times selecting the highest spatial frequency pattern that could be resolved. These three readings were averaged across the three observers for each ocular of each of the PNVGs measured to obtain a final "visual acuity" value through the PNVG oculars.

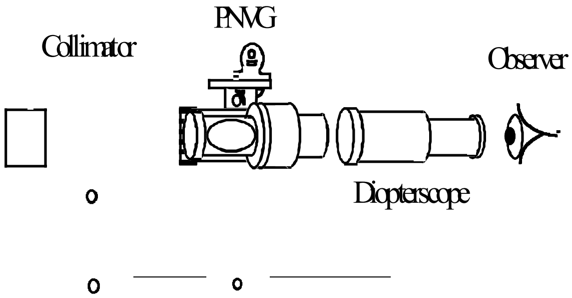

Figure 3. Measurement of eyepiece focus.

Eyepiece Focus

The current PNVG design features a fixed focus eyepiece. In order to improve observer visual performance, the manufacturer set the eyepiece to –0.75 diopters. Due to the optical complexity of the PNVG, it was considered necessary to verify this using a diopterscope. To do this, an activated PNVG was fixed to a bench and focused into collimated light source that projected an image of a grid. Once acceptable image of the grid was achieved, a calibrated, eight power diopterscope was used to measure eyepiece diopter setting by focusing the scope through the NVG eyepiece onto the grid. The diopter setting was then read directly from the diopterscope. This was repeated three times for each eyepiece and averaged.

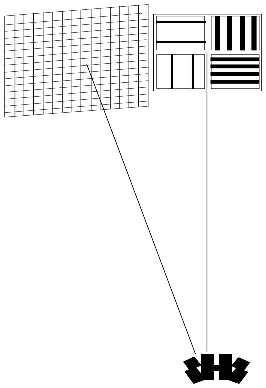

Figure 4. Relative positions of charts used in the assessment of image discontinuity

Image Discontinuity

Extending a night vision device's horizontal field of view by combining the output of multiple image intensifier tubes creates the possibility of image overlap errors arising from poor alignment of the optical system. These errors can be the result of excessive overlap of the adjacent fields of view, gaps in coverage in the observer's field of view, image discontinuities, or shifts, as objects move between the adjacent fields of view. This procedure is designed to visually assess and measure these defects by imaging a grid through a night vision device and comparing the defects to the size of grid features.

To start, the test NVG was placed in a mount that was firmly fixed to a test bench a known distance in front of a focusing target. A large grid was then position at the edge of the central ocular's field of view and oriented such that the plane of the grid was perpendicular to a line from the grid to the test NVG. Then the grid was observed through the NVG from the proper eye position. The technician would then describe the grid in terms of grid features that would appear or not appear in the field of view of the central and outboard ocular and determine the magnitude of the continuity errors.

This technique can be used to quantify image discontinuities if the angular size of the grid elements is known. The size of one grid square could be calculated using trigonometry once the separation between the lines of the grid and the distance between the test goggle and the grid were measured.

An alternative method of capturing the image discontinuities between central and outboard channels was developed using photography. The PNVGs were mounted and positioned a known distance from a large (8 ft by 8 ft.), back-illuminated grid board with lines spaced 8 inches apart. With the room lights off and the grid board lighting set to a very low level both the in-board and out-board ocular FOVs were photographed using a camera with a wide angle lens (see Figure 5).

Figure 5. Geometric arrangement to photograph both the left central and outboard oculars of a PNVG II.

From the distance to the grid board and the grid board line spacing it was possible to calculate the angular subtense of each of the 8-inch grid squares. Using this information and the photograph obtained using the Figure 5 set-up it was possible to quantitatively assess image discontinuity.

Ideally, the angular size of a grid square should be small, on the order of a few milliradians. However, it is important to choose a grid size and grid line thickness that the NVG under test can image. This test should be conducted using distances of 30 feet or longer if any of the NVG objective lenses are fixed and focused at infinity in order to minimize errors due to the inherent misfocus common in infinity focused NVG lenses when tested at distances shorter than "infinity."

Gain

The gain of an NVG is an assessment of its ability to amplify available light. For the PNVG, gain was measured using a Hoffman ANV-120. This device was used to implement a test outlined in earlier documents [Task, 1993] in which the luminance output of the NVG is measured and compared to the luminance input to the NVG from a spatially large, Lambertian, 2856K black body source. Gain is calculated simply by dividing the luminance output by the luminance input.

Maximum Output Luminance

The maximum output luminance of an NVG is an assessment of the maximum brightness an NVG can produce when presented with a uniformly bright input. For the PNVG, this was measured by using a Hoffman ANV-120 to implement a test outlined in earlier documents [Task, 1993] in which the luminance from a Lambertian, 2856K black body source is increased to a level where the NVG output cannot become brighter.

Eye Relief

This procedure is to measure the physical distance separating the last optical surface of the NVG eyepiece and the front surface of the user's cornea. For the PNVG, eye relief was measured using a test outlined in earlier documents [Task, 1993] in which a video camera was used to monitor the collapse of field of view as a function of distance. This method normally required the technician to monitor all edges of the collapsing field of view. However, only the top and bottom of the PNVG oculars were monitored since the individual fields of view were not perfectly round.

RESULTS

Over the course of several months, eleven PNVG systems were characterized to some degree at AFRL/HECV. Unfortunately, due to the limited availability of the PNVG prototypes, not all tests were performed on all systems. Far more data were collected than presented here. The following is a summary of the data collected between January and May 1999 on four systems. Only a representative sample of data from some of what are considered the more important tests and the tests documented in this paper appears below. For comparison purposes, similar data collected from an AN/AVS-9, F4949 D in 1995, when the goggle was new, was also provided.

Field of View Results

Table 2. Field of view PNVG I and PNVG II.

PNVG I	Left Edge	Center	Right Edge
Right Central	-17.6 deg	0.3 deg	18.2 deg
Left Central	-23.3	-4.5	14.3
Right Outboard	14.2	33.2	52.1
Left Outboard	-13.1	-32.7	-52.3
PNVG II			
Right Central	-18.2	2.0	22.2
Left Central	-20.1	0.0	20.1
Right Outboard	12.5	32.3	52.2
Left Outboard	-11.9	-32.3	-52.7

One should note that while that each of the F 4949 oculars is as large or larger that any individual PNVG ocular, the total PNVG field of view (105 degrees) is far larger than that of the F 4949 (40 degrees). This is the benefit of the PNVG's additional, non-overlapping outboard channels.

Visual Acuity Results

Table 3. Acuity _ Moon.

Conf., S/N	Left Out.	Left Cent.	Both	Right Cent.	Right Out.
1, 05	20/33	20/30	20/29	20/34	20/30
2, 01	20/33	20/33	20/32	20/31	20/32
4, 02	20/36	20/27	20/26	20/27	20/34
5, 01	20/42	20/28	20/27	20/29	20/34
F4949		20/26	20/26	20/26	

Table 4. Acuity Starlight.

Conf., S/N	Left Out.	Left Cent.	Both	Right Cent.	Right Out.
1, 05	20/37	20/37	20/33	20/40	20/35
2, 01	20/38	20/36	20/34	20/36	20/36
4, 02	20/41	20/31	20/29	20/30	20/36
5, 01	20/50	20/33	20/35	20/33	20/41
F4949		20/35	20/36	20/36	

Tables 3 and 4 above show that the PNVG performs approximately as well as the F 4949 at _ moon and starlight illumination on target. While obscured somewhat by the variability in the PNVG data, one might argue that at starlight, the PNVG actually outperforms the F 4949. This is not entirely unexpected. The PNVG's faster f/# objective lenses allow it to make better use of available light than the F4949, improving low light acuity.

Eyepiece Focus Results

Table 5 indicates that the original PNVG feature of a fixed focus eyepiece, set to –0.75 Diopters was not easy to achieve. This could be due to two reasons. Either manufacturing techniques are not quite capable of setting this parameter repeatability or the mechanics are not capable of holding the eyepiece elements in place for long periods of time. More effort is required to optimize this PNVG parameter.

Table 5. Eyepiece Diopter Setting.

PNVG, Conf., S/N	Left Out (D)	Left Cent (D)	Right Cent (D)	Right Out (D)
I, 1, 05	-1.0	-0.5	-0.8	-0.8
I, 2, 01	-0.4	-0.4	-0.3	-0.2
II, 4, 02	-0.2	-0.5	-0.5	-0.5
II, 5, 01	-0.6	-0.8	-0.8	-1.0

Image Discontinuity Results

The data listed in Table 6 was collected using the first Image Discontinuity procedure described above. One should remember that the sign of the Shear measurements between channels is with respect to the central image. Outboard images which appear lower than the central image are considered to have negative shear. Also, the image flaw labeled "Holes" is an assessment of the lack of overlap between central and outboard oculars, or holes in the field of view. A negative sign in the "Holes" category overlap in adjacent fields of view. One should also note that due to the way these measurements were made, there is a measurement threshold, below which the defect is noticeable but not measurable. Noticeable image flaws smaller than 3 minutes of arc were listed in Table 5 as "Minor."

Table 6. Discontinuity.

PNVG,	**Shear**	(MOA)	**Holes**	(MOA)
Conf., S/N	Left	Right	Left	Right
I, 1, 0005	Minor	-4.8	Minor	Minor
I, 2, 0001	Minor	Minor	23.9	28.6
II, 4, 0002	7	14	-7	9
II, 5, 0001	-4.8	-9.5	Minor	Minor

Although the photographic procedure (the second Image Discontinuity procedure described above) has not yet been fully developed, it is apparent from the few photos taken so far that we should be able to use it to estimate the errors of interest. The following photo (Figure 6) were taken through the left oculars and right oculars respectively. In each of these photos it is apparent that there is some discontinuity between the pair of oculars captured in the photo. For example, in Figure 6 the horizontal lines are almost matched at the top of the interface between the oculars but they are very clearly separated at the bottom of the photo indicating that there may be a slight magnification difference between the two oculars (note: magnification of oculars was not measured in this series of tests but this photo indicates it should be). In addition, the horizontal lines of the two oculars in Figure 6 are not co-linear indicating the one of the ocular channels has an image rotation compared to the other.

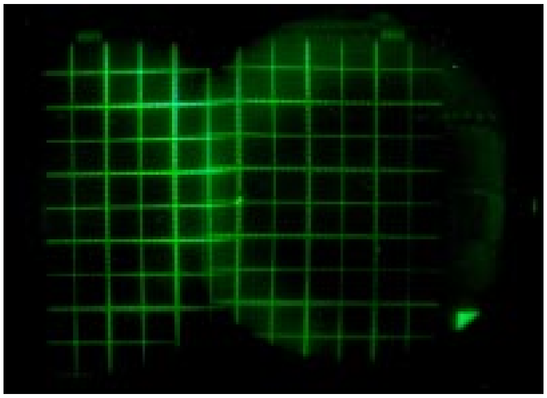

Figure 6. Image discontinuity photo taken through the left central and outboard oculars simultaneously.

In Figure 6 the faint double line in the center of the photo indicates the two ocular channels do not have their input and output optical axes properly aligned (this has been termed "collimation" in test procedures for earlier NVGs). This results in a minor "double image" at the interface of the two ocular channels. All of these effects are not readily apparent when viewing through these PNVGs at natural outdoor scenes. It is expected that further work will be done on this measurement procedure to provide quantitative results instead of just qualitative insight.

Gain Results

Table 7. Gain.

PNVG, Conf., S/N	Left Out	Left Cent	Right Cent	Right Out
I, 1, 05	5158	3579	4579	4316
I, 2, 01	3850	4400	4297	3082
II, 4, 02	4758	5569	5888	4978
II, 5, 01	4743	5595	4368	6270
F4949 D		8427	7837	

The data in Table 7 indicate that the tested PNVG systems did not exhibit gain as high as the F 4949. It should be noted that the newness of the PNVG tube and optical design created difficulties for the manufacturer in setting system gain. This should be overcome in later versions. Also, the comparison F 4949 was a prototype high gain design.

Maximum Output Luminance Results

Table 8 shows that the tested PNVGs exhibited maximum output luminance between 2.15 and 4.9 fL. This wide spread in the data is most likely due to the newness of the PNVG image intensifier tube and the lack of experience on the part of the manufacturer in setting this parameter. This should be overcome in later versions.

Table 8. Maximum Luminance Output.

PMVG, Conf., S/N	Left Out (fL)	Left Cent (fL)	Right Cent (fL)	Right Out (fL)
I, 1, 05	2.95	2.40	3.24	3.22
I, 2, 01	3.01	2.49	2.63	2.15
II, 4, 02	2.90	2.56	2.29	3.07
II, 5, 01	2.21	3.92	2.15	4.92
F4949 D		2.77	2.82	

Eye Relief Results

Table 9. Eye relief.

PNVG, Conf., S/N	Left Out (mm)	Left Cen (mm)	Right Cen(mm)	Right Out(mm)
I, 1, 05	24.5	25.8	24.8	24.5
I, 2, 01	24.8	24.7	24.3	25.0
II, 4, 02	30.4	29.9	31.4	31.3
II, 5, 01	29.9	27.7	28.8	27.4
F4949 D		23.7	23.0	

One should note from the data listed in Table 9 that the PNVG I was able to exhibit eye relief on par with the F 4949 in spite of its folded optical design, which tends to reduce eye relief. Eye relief performance of the optically simpler PNVG II well exceeded both the PNVG I and the F 4949 due in part to its simpler optical design and faster f/# optics.

DISCUSSION AND CONCLUSIONS

The procedures documented in this paper and in Task, et al, 1993 still stand incomplete. Little is known about the repeatability and reproducibility limits of these tests, as defined by ASTM E 177-90a and ASTM E 691-92. Some attention has been paid to determining the repeatability of the AFRL NVG test procedures. But, at this time only work on gain measurement repeatability has been published (Aleva, 1998). Unfortunately, the results of this work were less than encouraging. Future work is clearly required to resolve this issue.

However, even after considering all this, one can still draw relevant comparisons between PNVG systems. PNVG II tends to have better visual acuity performance and longer eye relief than PNVG I due in part to the simpler optical design. It is also possible to draw relevant comparisons between the PNVG and the F4949 since both sets of data presented here were collected using the same equipment, experimental conditions, laboratory, and technicians. One can conclude, from the data provided here, that the PNVG is capable of performing at least as well as the F4949 D NVG.

Some of the inconsistency in the PNVG data can be attributed to the fact that the systems examined were prototypes and not production quality models. The newness of the PNVG image intensifier tube and optical design created difficulties for the manufacturer in setting certain parameters. This should be overcome in later versions. Much improvement is expected as the manufacturer becomes more familiar with this complex imaging system.

It should also be pointed out that the PNVG is clearly superior to the F4949 in one category in particular, field of view. And, the operational benefit of this much-needed improvement is just now becoming known.

REFERENCES

Aleva, D.L., Task, H.L., Goodyear, C. (1998) *Repeatability and reproducibility of NVG gain measurements using the Hoffman ANV-126 test device*, Journal of the SAFE Society, Vol. 28 (2).

ASTM E 177-90a, (1990) *Standard practice for use of the terms precision and bias in ASTM test methods*, American Society for Testing and Materials, Philadelphia.

ASTM E 691-92, (1992) *Standard practice for conducting an interlaboratory study to determine the precision of a test method*, American Society for Testing and Materials, Philadelphia.

Craig, J.L., Geiselman, E.E. (1998) *Further development of the panoramic night vision goggle*, Proceedings of the SAFE Society's 36th Annual Symposium.

Task, H.L., Hartman, R., Marasco, P.L., Zobel, A, (1993) *Methods for measuring characteristics of night vision goggles (U)*, (Report No. AL/CF-TR-1993-0177). Wright-Patterson AFB, OH: Armstrong Laboratory.

ACKNOWLEDGEMENTS

The authors acknowledge the help of several members of the research team who contributed much to this work. Sharon Dixon of Sytronics, Inc. was invaluable in the collection and analysis of the visual acuity data. Dave Sivert, also of Sytronics, Inc. contributed much in the development of the photographic discontinuity and field of view assessments.