NIGHT VISION IMAGING SYSTEM LIGHTING COMPATIBILITY ASSESSMENT METHODOLOGY

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Aircraft cockpit lighting can interfere with the proper operation of night vision goggles (NVGs). Methods to verify compatibility between cockpit lighting and NVGs involve expensive equipment. An inexpensive alternative method to assess compatibility, that provides the same quality of results, is needed. Since the quality of the existing lighting compatibility methods has not been studied, it was necessary to determine the quality of existing methods and compare them to alternative methods using a night lighting simulator. The visual acuity-based evaluation method is relatively imprecise, but it can be implemented using alternative, inexpensive equipment and techniques. An alternative evaluation method, that makes use of the light output of the NVGs, looks promising. It provides a more precise acceptance/rejection criteria than the visual acuity method.

INTRODUCTION

Night vision goggles (NVGs) amplify and convert available ambient light at night to produce an image viewable by the observer that is hundreds or thousands of times brighter than the same scene viewed with the naked eye (see Fig. 1). Current NVGs used for flight are sensitive to wavelengths from about 625 nm or 665 nm (depending on objective lens coating) to about 900 nm. Unfortunately, most unmodified aircraft cockpit lighting emits considerable energy in this wavelength range that can make it very difficult or impossible to see through the windscreen with the NVGs.

Figure 1. F4949 night vision goggles

Unmodified aircraft cockpit lighting can interfere with the proper operation of NVGs in several specific ways. For each interference mechanism, the effect on the image seen through the NVGs is a reduction of the light level or contrast of the view outside the aircraft. This reduction in light level or contrast can be manifested as a reduction in visual acuity and/or as an observed loss of contrast or brightness. Many techniques have been developed to produce cockpit lighting, including instrumentation and displays, that are reasonably compatible with the operation of NVGs[1]. *Reasonably compatible* means there is sufficient light for the pilot to view his/her instruments and displays (note, pilots look under the NVGs to directly view their instruments) but the lighting is such that it does not significantly interfere with the image of the exterior scene viewed through the NVGs.

The US Air Force, Army, and Navy have pursued the use of NVGs for piloting aircraft for over 20 years. One of the first major issues to be addressed was cockpit lighting compatibility with the NVGs.[2] The military eventually developed a criteria that could be relatively easily, but not inexpensively, implemented to determine whether or not the cockpit lighting was night vision imaging system (NVIS) compatible. These criteria have been expanded considerably from their original concept and are documented in various publications[1,3,4,5,6,7]. The original basic concept was that no lighting source in the cockpit, when adjusted to the specified luminance level, should appear brighter through the NVGs than tree bark illuminated with natural clear starlight[7]. This concept was converted to photometric and radiometric criteria for various cockpit lighting sources. For example, electronic displays adjusted to produce an output luminance of 0.5 foot-Lamberts should not exhibit an NVIS radiance greater than 1.7 x 10^{-10} watts/cm^2-sr. The NVIS radiance is the radiance of the display as weighted by the spectral sensitivity curve of the NVGs. There are currently two published spectral sensitivity curves for NVGs used in flight, designated NVIS A and NVIS B. NVIS A spectral sensitivity starts at about 625 nm and NVIS B sensitivity starts at about 665 nm.

Although this approach provides easy to understand criteria for passing or failing a lighting system for NVIS compatibility, it also requires the use of expensive equipment to accurately measure the luminance and NVIS radiance values of the various light sources. Since this equipment is not conducive to a field assessment of NVIS compatibility, there is a secondary approach that is used, based on visual acuity, that is described in the various military publications.[3] In this secondary approach, a trained evaluator sits in the cockpit of the aircraft while it is located in a dark, light-controlled hangar. A visual acuity chart (e.g., USAF 1951 Tri-bar Resolution Chart) is positioned 20 feet from the objective lens of the NVGs and illuminated to an NVIS radiance of 1.7 x 10^{-10} watts/cm^2-sr (tree bark in clear starlight). The cockpit lighting level is adjusted to an *operational level* so that it is easily visible to the evaluator. The evaluator then determines his/her visual acuity with the cockpit lighting system on and off. If there is any decrement in visual acuity between the on and off conditions, then the lighting system is considered unacceptable. If there are any reflections noted in the aircraft windscreen, then the visual acuity chart is to be repositioned, if possible, so that the evaluator is viewing directly through the reflection.

There has been essentially no research to determine the repeatability and/or reproducibility of either the NVIS radiance measurement method or the visual acuity assessment method of determining NVIS lighting compatibility. The primary objective of the research described herein was to develop an inexpensive NVIS lighting methodology that would produce essentially the same or better results than the documented military assessment techniques[8]. Particular emphasis was placed on the visual acuity approach, since it is the most often used method for performing a field assessment of cockpit lighting. It was therefore necessary to assess how good the currently used visual acuity method is and what other possible methods could be used to achieve equivalent or better results.

APPROACH

In order to develop an alternative method for the visual acuity-based approach, it was necessary to identify the specific elements of the method and produce inexpensive alternatives. The specific elements identified for devising alternatives were: 1) the visual acuity chart, 2) the calibrated illuminator, 3) a means of verifying the chart radiance, and 4) a means of determining that the test facility is sufficiently dark to conduct the test.

Several alternative methods to the visual acuity-based method were discussed and documented. One of these was selected for inclusion in the study.

In order to evaluate different NVIS compatible lighting assessment methodologies, it was necessary to devise a night lighting simulator (NLS) so that numerous assessments could be conducted under various controlled conditions.

VISUAL ACUITY METHOD ELEMENTS

Visual Acuity Chart: The baseline military method[6] uses a commercially available USAF 1951 Tri-bar resolution chart (medium or high contrast) that costs approximately $600. The alternative method chosen uses a PDF file of the USAF 1951 Tri-bar resolution chart that was located on the World Wide Web. The chart was laser printed on 8.5 x 11-inch white bond paper and mounted to a foam core back. Photometric and radiometric measurements of the alternative chart verified that it was comparable to the commercially available chart.

Illumination Source: The baseline military method uses a commercially available, calibrated illumination source that costs approximately $5000. The alternative method uses an inexpensive goose-neck lamp. A baffle with a 1/8 inch diameter hole covers the open end of the lamp housing. When the 7.5-watt light bulb is powered by 115 VAC, it provides approximately the correct irradiance at 20 feet. To correct for variability in line voltage and lumen output differences among light bulbs, an inexpensive ($150) illuminance meter was used. An empirically derived look-up table was used to adjust the chart-to-illuminator distance, in order to achieve the correct NVIS irradiance.

Verification of Illumination Level: The baseline military method makes use of two different NVIS radiance measurement devices (approximately $20,000 and $28,000) to verify the NVIS radiance of the white background of the chart. The alternative method verifies the light level by making use of the illumination meter, noted above, and the look-up table.

Test Facility Light Level: The baseline military method makes use of the NVIS radiance measurement equipment to verify that the facility is dark enough to conduct the test. The alternative method is to use the inexpensive visual acuity chart and verify that the evaluator, when looking through the NVGs, cannot resolve the largest pattern on the chart (20/90.3 Snellen acuity).

EVALUATION COMPARISON STUDY

Introduction: Although there are several mechanisms by which cockpit lighting can affect the NVGs, only two basic conditions were selected to be studied. These two conditions were: 1) a uniform light source (display) reflecting in the windscreen, and 2) a uniform display that is blocked by a glare shield from reflecting in the windscreen but may still be within the NVG field of view. The NLS was designed to produce these two conditions and provide a selectable level of NVIS radiance compared to visible luminance. Using the NLS, three different assessment approaches were studied: 1) visual acuity decrement, 2) direct radiance measurement, and 3) NVG luminance output level measurement.

Observers: Six males and four females ranging in age from 23-51 participated in this study. Prior to participation in the study, all observers underwent a visual examination to insure they had normal or corrected acuity of 20/20 or better.

Apparatus: The lighting simulator (see Fig. 2) was positioned directly in front of the observer. The visual acuity chart was positioned 20 feet from the objective lens of the NVGs and illuminated with an incandescent lamp. The NVIS radiance on the chart was monitored using a Photo Research 1530AR radiometer. Model F4949C NVGs were used in this study. A Hoffman Engineering NVG 103 radiometer was used by the observers to measure the NVIS radiance of the interfering light source. The actual radiance and luminance of the lighting simulator was measured using an Instrument Systems Model 320 spectral scanning radiometer.

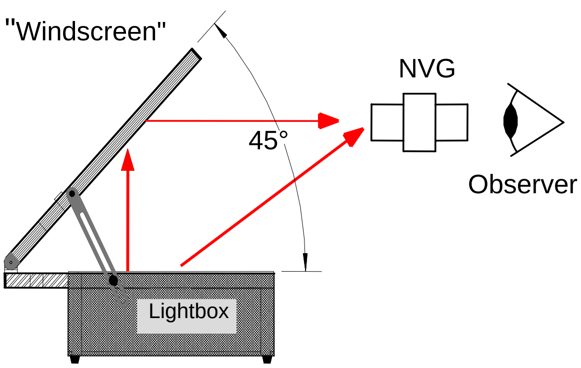

Figure 2. NLS in Reflective Mode

Procedure: Observers were seated behind the NLS and the armrest and seat height were adjusted. Since the NVGs were hand held, the armrest was positioned to allow proper alignment with the stimulus and to reduce fatigue. The room lights were turned off and the observer dark-adapted for 12 minutes. If the session involved the use of NVGs, observers were asked to focus them according to the procedure taught to them during their orientation. Prior to each task, the observer received a sufficient number of practice trials for familiarization with the task and equipment. For the reflected and non-reflected conditions, the following three tasks were counterbalanced. The NVIS radiance light levels were randomly presented for each task.

Task 1: Observers looked through a pair of F4949C NVGs at a USAF 1951 Tri-bar chart. A Photo Research 1530AR was used to monitor the NVIS radiance of the target. The observers identified the group and element number of the smallest pairs of horizontal and vertical bars they could resolve. They closed their eyes between each trial while the experimenter adjusted the NVIS radiance of the NLS. The experimenter instructed the observers to open their eyes and begin the next trial. Five data points were collected per NVIS radiance light level, for a total of 35 data trials for each of the reflective and non-reflective lighting conditions.

Task 2: The observers rested their elbows on the armrest while holding the Hoffman NVG 103. After focusing it, the observer aimed the device so it was perpendicular to the center of the NLS. They adjusted the brightness of the internal test patch located inside the Hoffman NVG 103 to match the brightness of the NLS. Once they were satisfied with their setting, the observers read the digital output on the NVG 103 and the experimenter recorded the data. Ten data points were collected per NVIS radiance level, for a total of 70 data trials for each of the reflective and non-reflective lighting conditions.

Task 3: The observers rested their elbows on the armrest and focused the right ocular of the NVGs. The experimenter attached an Extech Light ProbeMeter to the eyepiece of the right ocular with black masking tape. The observers held the goggles steady while aiming them through the simulated windscreen at the Tri-bar target. When the NVGs were steady, the observer signaled the experimenter, who then recorded the measurement (lux) from the digital readout of the light meter. The experimenter then adjusted the light level of the NLS and indicated when the next trial was to begin. This procedure was repeated ten times per light level for a total of 70 data trials for each of the reflected and non-reflected lighting conditions.

Results: Figure 3 is a summary of the raw data from one of the ten observers. The two columns correspond to the reflected and non-reflected conditions, respectively, and the three rows correspond to the visual acuity assessment (Task 1), NVIS radiance measurement using the NVG 103 (Task 2), and the NVG output luminance measurement (Task 3), respectively. For each observer, these raw data were converted to acceptance/rejection results and then combined. The visual acuity data were converted to an acceptance/rejection decision by comparing each of the individual's visual acuity data points for both the *off* and *on* cockpit lighting conditions. If the observer's visual acuity was worse for any given *on* condition than for the *off* condition, then that pair of points was scored as a *reject*. If the two acuities were the same or if the *on* condition was actually better than the *off* condition, then it was scored as an *accept*.

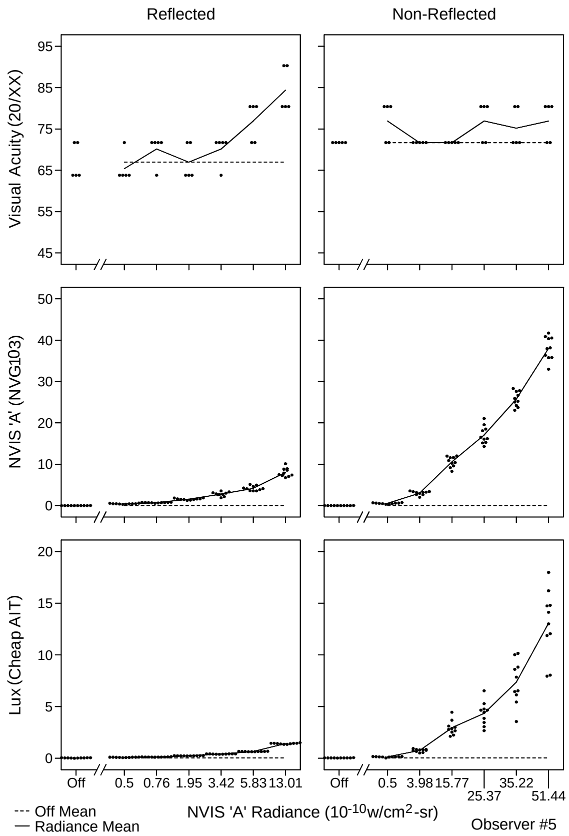

Figure 3. Example of one observer's raw data. Top row is visual acuity data, middle row is NVG 103 data, and bottom row is NVG luminance output data.

This pairing technique produces 25 scores for each NVIS radiance level (five *off* acuities paired with 5 *on* acuities for each radiance). The top row of Figure 4 shows the results of this acceptance/rejection scoring technique for the visual acuity, Task 1.

For the NVG 103 level, the NVIS radiance level of 1.7×10^{-10} watts/cm^2-sr was selected as the acceptance/rejection criteria level. For the NVG luminance output, a value of 0.32 was selected, since that approximately corresponded to the 1.7×10^{-10} watts/cm^2-sr NVIS criteria level determined by empirical measurement.

Figure 4 is a summary of the percent rejection across all 10 observers as a function of the NVIS radiance levels. Note that the radiance levels used for the non-reflected condition were much higher than for the reflected condition, in an attempt to obtain a visual acuity effect in the non-reflected mode.

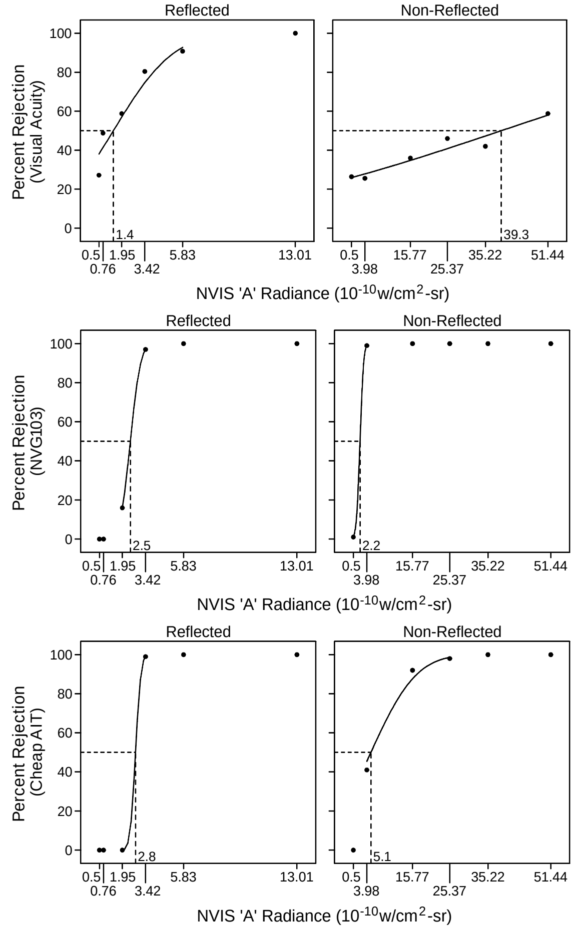

Figure 4. Acceptance/Rejection study results for the two reflection conditions and the three assessment tasks. Vertical axis in each chart is the percentage (or probability) of rejection of the lighting system as incompatible.

Sample sizes for each radiance level were as follows: visual acuity task, n = 250; NVG 103 task, n = 100; NVG luminance output task (labeled as "cheap AIT"), n = 100. Probit analysis was used to fit the percent rejections[9]. The dashed lines indicate the estimated NVIS radiance level that corresponds to a 50% rejection probability.

DISCUSSION

Although the 50% rejection probability NVIS radiance values are noted on the six graphs of Figure 4, these values may not depict the most important aspect of these curves. Ideally, one would like an acceptance/rejection criteria that produces a steep curve cleanly separating the acceptance from the rejection regions. The specific NVIS radiance values used were subjectively set by the experimenter to cover the gamut from no visual acuity interference to essentially 100% visual acuity interference. It is apparent in the upper left graph of Figure 4, that the visual acuity assessment task resulted in a fairly slowly rising curve, even in the relatively tightly controlled reflected condition. For the non-reflected condition, there is certainly a trend toward higher probability of rejection, as the NVIS radiance increases, but the curve is exceedingly wide, indicating a considerable lack of precision.

Another point should be made regarding the visual acuity curves. It appears that the current rejection criterion of $1.7x10^{-10}$ watts/cm^2-sr is probably not low enough for light sources that reflect in the windscreen but excessively low for light sources that do not reflect in the windscreen.

The middle row of figures illustrates the NVG 103 radiometer data. This device uses an actual image intensifier tube and a brightness matching technique to determine the NVIS radiance. While looking through the device, the user adjusts the brightness of a small internal luminance patch until it matches the brightness of the object of interest. Figure 4 shows that the NVG 103 provides a very sharp rejection criterion when compared to the visual acuity method, even though it is a relatively inaccurate device. It should be noted that this condition was different than the other two. For both the reflected and the non-reflected conditions, the NVG 103 was pointed directly at the light source of the NLS, since the military baseline method ignores the reflection or non-reflection issue.

Figure 4, row 3, illustrates the results of the data collected with the inexpensive illuminance meter (cheap AIT). The concept behind this approach is that the cockpit lighting should add very little light to the output of the NVG image, if the lighting is properly compatible. Since the NVGs, with the attached illuminance meter, were always pointed toward the windscreen of the NLS, the mechanism by which they received light differed between the reflected and the non-reflected conditions. In the reflected condition, the NVGs were amplifying the reflected image of the NLS light source. In the non-reflected condition, some light from the NLS light source could have been imaged directly into the NVGs. This was due to the observer holding the NVGs, such that the NLS light was within the field of view. Nevertheless, the cheap AIT provided a rejection curve that fell between the curve of the visual acuity method and that of the NVG 103.

CONCLUSIONS

Results from the alternate visual acuity assessment study clearly show that NVG cockpit lighting compatibility assessment can be accomplished using inexpensive equipment. It is also evident from Figure 4 that the visual acuity assessment procedure is prone to both Type 1 and Type 2 errors, due to the relatively broad nature of the curve. Furthermore, it is apparent that the NVIS radiance-based criteria, currently used by the military, does not adequately address the difference in visual impact of a reflected light source versus a non-reflected light source.

The NVG 103 provided much better results than the visual acuity assessment, although it does not differentiate between reflected and non-reflected light sources, as noted above.

The NVG light output measurement (cheap AIT) looks very promising as a possible objective method of verifying NVG compatible cockpit lighting. Issues that still need to be addressed, using this device, are calibration procedures and the establishment of a criterion level.

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