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NVG eyepiece focus (diopter) study

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Abstract

Technology is advancing to the point where night vision goggle designs being developed have wider fields of view to help achieve an increase in situational awareness. The appropriate diopter setting for the eyepiece of these goggles needed to be determined. Aircrew members were surveyed to determine the range of diopter settings they were using. In order to determine what fixed setting would work the best, two diopter settings were chosen (-1.0 and –0.5) to preset aircrew members' goggles. The aircrew flew with these presettings and then filled out a 14-question survey about the diopter settings.

Keywords

Diopter, dioptometer, field of view, night vision goggles, AN/AVS-9, Panoramic Night Vision Goggle (PNVG), Integrated Panoramic Night Vision Goggle (IPNVG), eyepiece diopter setting.

1. Introduction

Night vision goggles (NVGs) were developed by the US Army, but the US Air Force first used them for flying, in the early 1970's, as a temporary aid for helicopter pilots.[1] The majority of currently fielded U.S. Air Force aircrew goggles are the AN/AVS-9 (Figure 1), which have a 40-degree field of view (FOV) and adjustable eyepieces. A large survey of U.S Air Force NVG users in 1992 and 1993 revealed that an increased FOV was the number one enhancement desired by aircrew, with increased resolution a close second.[2] The current prototype goggle, the panoramic night vision goggle (PNVG) (Figure 1) has 100-degree horizontal by 40- degree vertical FOV, but it has a fixed-focus eyepiece. Currently in development, the Integrated Panoramic Night Vision Goggle (IPNVG) will have a 95-degree horizontal by 38-degree vertical FOV, and it may also have a fixed-focus eyepiece.

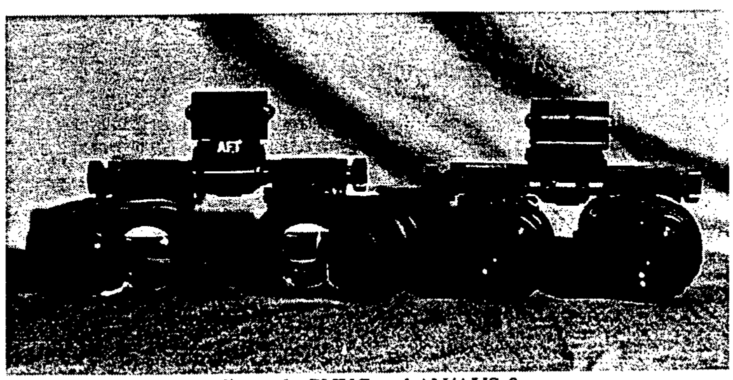

Figure 1. PNVG and AN/AVS-9

Three studies were performed to help determine what fixed diopter setting of the eyepiece will work for most aircrew. These studies were conducted at several Special Operations Squadrons in Ft. Walton Beach, Florida. This location was selected because of the large number of highly experienced night vision goggle trained aircrew in the Special Operations community. The first study investigated the diopter setting to which aircrew were adjusting their own goggles just prior to their missions. A second study addressed how repeatable aircrew were at setting their eyepieces following current NVG preflight protocol. The third study addressed how aircrew would tolerate a fixed-focus eyepiece.

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2. Study I

Study I was conducted at 5 US Air Force Special Operations Squadrons in the Ft Walton Beach, Florida area. It occurred in August 2000 over the course of a week. The purpose was to measure and record as many eyepiece settings from qualified NVG aircrew as possible.

2.1 Methodology

2.1.1 Participants: Ninety-five aircrew participated in the diopter setting study. There were 94 males and 1 female. Ages ranged from 21 to 59, with a median of 33. The 4^{th}, 5^{th}, 8^{th}, 9^{th}, and 711^{th} Special Operations Squadrons participated. These squadrons were selected for their large numbers of highly NVG qualified aircrew. There were 32 pilots, 12 navigators, 20 loadmasters, 14 flight engineers, 8 gunners, 8 radio operators, and 1 life support technician.

2.1.2 Apparatus: The aircrew used their squadron's own goggles for this study. There are three power source mounts for the goggles and three types of power sources/goggle attachments: hand-held battery pack, opera mount, and the helmet battery pack. The helmet mount has a battery pack in the back of the helmet to power the goggles. The hand-held battery pack is small and lightweight. The opera mount is also a handheld power source, but much bulkier and looks like a helmet battery pack on a stick. The pilots and loadmasters use the helmet mounts. The remainder of the aircrew would typically use either the hand-held battery pack or the opera mount. These goggles are pre-flighted by aircrew members using the ANV-20/20 (Hoffman 20/20). The ANV-20/20 (Figure 2) is a portable case containing optics with a resolution chart, which allows aircrews to adjust their goggles to infinity focus.[3] An investigator used a hand-held dioptometer (Figure 3) to read the diopter settings off the eyepieces of the NVGs after they were set by the aircrew member. A diopter is an expression of the eyepiece focus described as the reciprocal of the image distance.[4]

Figure 2. ANV-20/20.

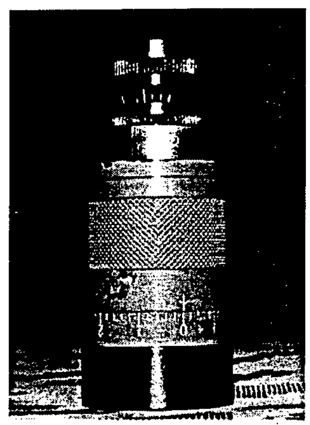

Figure 3. Dioptometer.

2.1.3 Procedure: The aircrew preflighted their own goggles as they normally did for their night missions. Preflighting is a term aircrew use to describe the focusing of the night vision goggle, typically done shortly before departing on their flying mission. After the crewmember adjusts the goggles for the distance between the crewmember's eyes, the crewmember looks into the ANV-20/20, sees a resolution chart, grossly adjusts the objective lenses by focusing on the coarser lines on the resolution chart, then adjusts one eyepiece at a time. The crewmember focuses the eyepiece by first turning the eyepiece counterclockwise which will blur the image in the positive diopter direction. Next, the crewmember turns the eyepiece clockwise until the image is clear. For that ocular, the crewmember then returns to the objective lens and "fine tunes" the objective lens so that the image of the fine lines on the resolution chart come into clarity. There are several procedures for recording visual acuity. Some aircrew members use the high-light level acuity/low-light level acuity of both eyes, and some aircrew record the visual acuity of each eye individually. We specified only that the aircrew record the acuity, as they would normally do in their squadron's logs. The goggles were then handed to the investigator, who read the left ocular diopter setting to the nearest 0.05 diopter (D) and recorded it on a data sheet. This method was repeated for the right ocular.

The eyepiece of the dioptometer was calibrated for the investigator. The investigator first sets the objective lens to 0 D. Next the investigator must find an object greater than 200 feet away (Figure 4). Looking through the dioptometer, the investigator rotates the eyepiece counterclockwise to blur the image and then rotates the eyepiece clockwise until the image is crisp and clear.

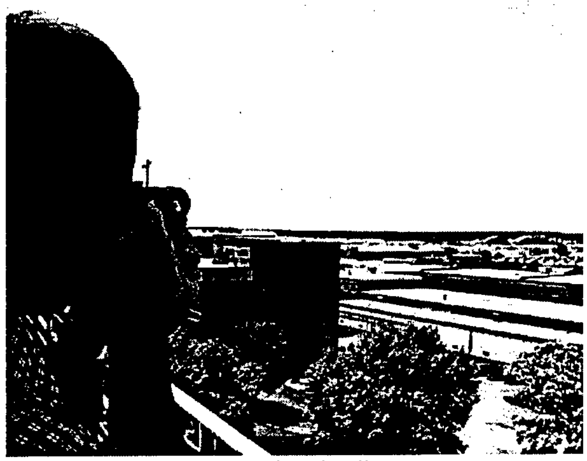

Figure 4. Focusing the dioptometer.

To read the diopter setting of the goggles, the investigator, in a darkened room, keeps the eyepiece of the dioptometer fixed. The investigator puts the objective piece of the dioptometer close to the eyepiece of the goggle. While focusing on the scintillations, the investigator rotates the objective lens of the dioptometer, counterclockwise (to blur the scintillations), and then clockwise to bring the scintillations into the best possible focus. Scintillations are the "noise" of the image intensifier tubes, which appeared as sparkles.[5] The diopter value was then recorded. All goggles were read from left ocular to right ocular. The aircrew member determined a visual acuity value by looking at the resolution chart in side the ANV-20/20. The visual acuity of the aircrew member was recorded on the data sheet.

2.2 Results

There were 95 aircrew participants who preflighted their goggles. The diopter settings of the 190 oculars (95 aircrew X 2 oculars) ranged from –3.9 to +0.5 D with a median of –1.05 D. Figure 5 shows the estimated Weibull distribution (see Appendix for a description of Weibull distribution) for the 190 oculars.

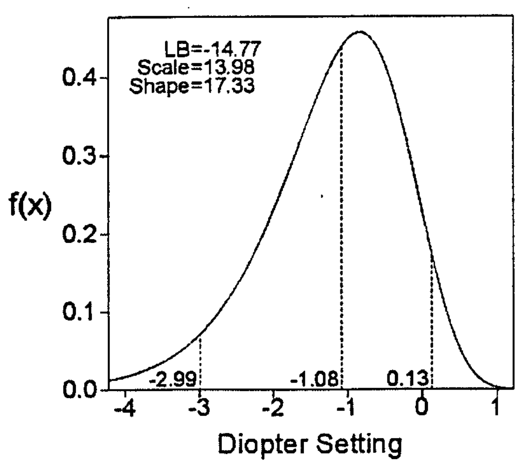

Figure 5. Estimated Weibull distribution for 95 aircrew. Referenced values are 5th, 50th and 95th percentiles.

3. Study II

Study II was conducted at the same time as Study I. The purpose was to see how consistent these highly trained aircrew were at preflighting their goggles.

3.1 Methodology

3.1.1 Participants: Eighteen aircrew members participated in the second study. There were 8 pilots, 3 loadmasters, 2 flight engineers, 3 gunners, and 2 radio operators. Ages ranged from 21 to 45 years, with a median of 32 years.

3.1.2 Apparatus: The apparatus in this study was the same as that used for Study I.

3.1.3 Procedure: The same procedure was used as in Study I, except each crewmember preflighted his/her goggles a total of five times. After the goggle was handed to the investigator, who read the settings of both oculars with the hand-held dioptometer, the investigator reset the eyepiece ocular to zero and handed the goggle back to the aircrew member.

3.2 Results

Figure 6 contains the diopter settings per aircrew individual for each of the five repetitions. The repeatability limit (rL) was defined as: approximately 95% of all pairs of adjustments from the same aircrew individual and same ocular should differ in absolute value by less than the rL. There were some individuals, such as number 15, who were much more variable than other individuals. Since some of the non-pilots appear to be less experienced than the pilots in adjusting their goggles, it was decided to utilize just the pilots (numbers 1-8) in computing the rL. The rL of the pilots was 1.2 D.

The pooled standard deviation of the left and right oculars for Figure 6 was determined for each aircrew number. There was not a significant correlation between the age and pooled standard deviation of the 18 aircrew ($R = 0.30$, $p = 0.2574$). This implies that there was not a relationship between an individual's age and the spread of his/her five settings.

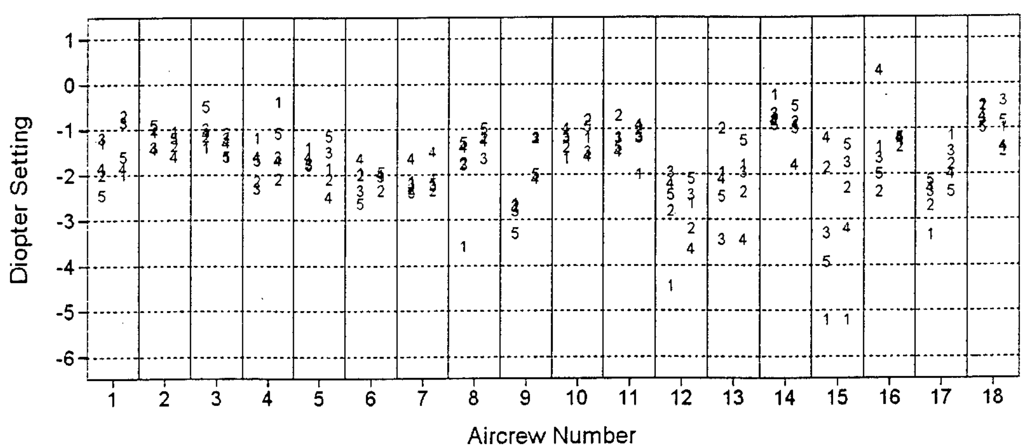

Figure 6. Diopter values for each crewmember, ocular, and adjustment are in the above figure. Within each aircrew number's window, the left ocular values are on the left and the right ocular values are on the right. The legend is the value of the adjustment (1-5). Aircrew numbers represent aircrew positions as follows: 1-8 pilot, 9-11 loadmaster, 12-13 flight engineer, 14-16 gunner, 17-18 radio operator.

4. Study III

The main purpose of Study III was to find out how aircrew liked certain fixed diopter settings. Since the median diopter setting from the first study was –1.05 D, it was decided to use –1.0 D as a starting eyepiece setting. When many of the aircrew felt that –1.0D was unacceptable, a diopter setting of –0.5 D was selected as a second setting to test.

4.1.1 Participants: Ninety aircrew participated in the November 2000 eye focus part of Study III. There were 41 pilots, 17 navigators, 12 loadmasters, 12 flight engineers, 4 gunners, 2 radio operators, and 2 flight surgeons. These crewmembers came from the 4th, 5th, 8th, 9th, 20th, and 711th Special Operations Squadrons.

Seventy-seven crewmembers filled out the questionnaire. There were 34 pilots and 43 non-pilots, consisting of 2 women and 75 men with ages ranging from 24 to 57 years and a median of 36 years. Forty-three aircrew flew with the –1.0 D setting and 34 aircrew flew with the –0.5 D setting. There were 4 individuals who responded to both the –0.5 and –1.0 D setting questionnaires. The NVG flying hours of all aircrew ranged from 15 to 3000 hours with a median of 500 hours.

4.1.2 Apparatus: The equipment was the same as in Study I, except there was a questionnaire. A logbook was used instead of data sheets and the eye focus aircrew settings were performed on a calibrated pair of goggles from AFRL. The questionnaire included background information such as name, sex, squadron, age, aircrew position, and NVG flying hours. Further questions focused on their flight with a fixed eyepiece. These questions included: (1) whether they adjusted the preset goggles in flight, and if they adjusted the preset goggles and why, (2) how long they wore the goggles continuously in-flight, and if they looked away from their goggles for an extended period, why, and for what duration, (3) whether they preferred their current goggle with the adjustable eyepiece focus or a fixed-focus goggle with a wider FOV, (4) six questions with rating scales for finding their opinions on the chosen fixed settings, and (5) a comments section at the end. Although the questionnaire had 14 questions, only a couple are considered for analysis here. We have analyzed an abridged version covering the sex of the aircrew member, the age, the aircrew member's NVG hours, briefly covering whether they preferred their own setting or the preset eyepiece, which was better with regard to eyestrain, blurriness, situational awareness, and threat detection.

4.1.3 Procedure: For this study, aircrew preflighted a pair of laboratory-owned and eyepiece-calibrated AN/AVS-9. This goggle was handed to the investigator who read the settings to the nearest 0.25 D and recorded it in the logbook. The aircrew member's flight goggles were previously preset to either –1.0 or –0.5 D using the hand-held dioptometer. The aircrew member used the ANV-20/20 to ensure that their visual acuity was acceptable by the aircrew member's own standards for flying. The specific visual acuity that is acceptable depends on the particular goggle. They recorded their visual acuity in our logbook. They flew their scheduled night sortie. When they returned to the squadron, they filled out the questionnaire.

4.2 Results

There were 185 aircrew total from (Study I and Study III) that were used for diopter setting analysis. Their ages ranged from 20 to 59 years, with a median of 34 years. Seventy-three pilots and 112 non-pilots participated, including 7 women and 178 men.

The settings of the 370 oculars (185 aircrew x 2 oculars) ranged from –3.9 to +0.5 D with a median of –0.90 D. Figure 7 shows the estimated Weibull distribution for the 370 oculars.

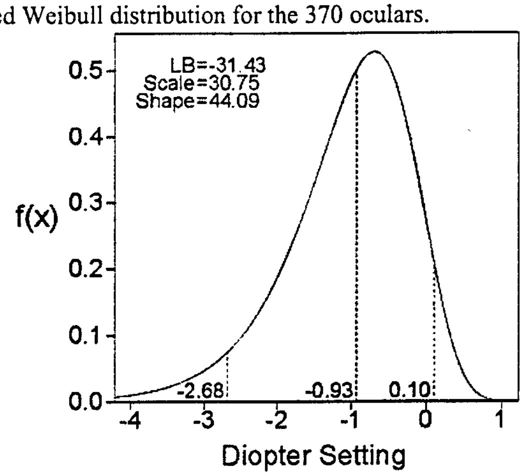

Figure7. Estimated Weibull distribution for all aircrew (referenced values are 5th, 50th, and 95th percentiles).

Figure 8 shows separate estimated distributions for the pilots and non-pilots. The parameter estimates for pilots only were: LB=-13.91, Scale=13.06, and Shape=18.11. The average of the left and right diopter settings was determined for each aircrew individual. There was a significant difference in these averages (p = 0.0216) between the pilots (N = 73) and other aircrew (N = 112) using the Wilcoxon rank sum test.

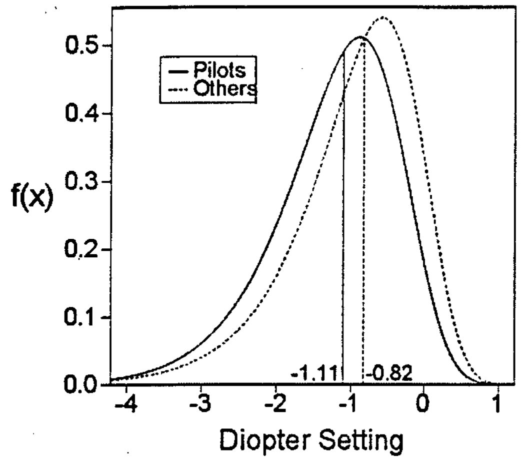

Figure 8. Estimated Weibull distributions for pilots versus others (reference values are 50th percentiles).

Ocular disparity is the difference in diopter settings between the right and left eyepiece. The absolute difference in ocular disparity ranged from 0 to 2.5 D with a median of 0.4 D. Of the185 aircrew, approximately 29% had ocular disparity greater than 0.5 D.

Table 1. This table shows a summary of the comparison of fixed settings vs. the aircrew member's personal settings. We compared fixed focus of either –1.0 D or –0.5 D to adjustable focus. The fixed settings were compared to the aircrew member's personal setting, and how it affected: the mission, reducing eyestrain, situational awareness, reducing blurriness, and threat detection.

Table 1. Percent of aircrew rating effect of fixed eyepiece setting the same, somewhat better, or much better compared to personal setting.

Effect of Fixed Eyepiece Setting	Percent Same or Better	
	-1.0 D (N=43)	-0.5 D (N=34)
compared to personal	60	47
mission accomplishment	86	71
reducing eyestrain	76	53
reducing blurriness	51	38
situational awareness	86	67
threat detection	85	67

5. Discussion/Analysis

The Study I excursion was a data gathering mission to determine to what diopter values aircrew were setting their goggle eyepieces. The data were examined to determine the best possible single diopter setting which might work for the NVG using community. The median setting of –1.05 D resulted in a starting fixed setting of –1.0 D. We were also able to see that the settings ranged from –3.9 to +0.5 D. How variable the aircrew were in adjusting their oculars was another concern, since with a fixed-focus aircrew would not have an option of different diopter settings in each ocular. Twenty-nine percent of setting disparities were over 0.5 D, possibly indicating that refresher courses in NVG focusing could be helpful. This is important because a person's eyes do not accommodation sufficiently to differential stimuli greater than 0.5 D.[6] Suppression does not occur when the diopter difference between the two eyes is less than about 0.5 D.[6] While people may have different diopter requirements in each eye, they should have been corrected to 20/20 Snellen acuity, and most people do not have large differences in their eye prescriptions. This brings up the concern that a significant percentage of the aircrew were likely adding eyestrain and accommodating with both eyes inappropriately. Of course, a fixed-focus eyepiece would alleviate this issue for most aircrew.

Looking at the 18 aircrew that performed the repeatability study, there are several issues to be discussed. The repeatability was calculated for the pilots. The pilots had a repeatability limit of 1.2 D; so for an individual pilot, focusing one eye could be 1.2 D different from one preflight to another. This raises several potential issues. It is possible that individuals are not truly sensitive to the eyepiece adjustment of their goggles. If we were to take an aircrew member and set his goggles within 1.2 D of his personal eyepiece setting, this should be tolerable. The aircrew member did not wear these setting for more than the time required to focus in the ANV-20/20. While they may have been able to achieve an acceptable level of visual acuity, it is possible that some of these settings may have caused the aircrew eyestrain during flight.

It was observed that the pilots and loadmasters were able to focus their goggles with a narrower range compared to the other aircrew members. Their use of a helmet mount for the goggle may play a role in their ability to set eyepieces within a tighter range. With goggles anchored at a fixed distance from the individual's eyes, their hands are not needed to support the weight of the goggles during the focusing procedure. For mission safety, both pilots and loadmasters must be able to see more clearly, with better visual acuity, and less eyestrain than other aircrew members. The other aircrew members do not usually use their helmets to mount their goggles; instead, they typically use the opera mount or the battery pack to power the goggles. Neither of these devices can offer the same stability as the helmet mount. If supporting the weight of the goggles, an aircrew member's hands may become less steady from one eye focusing to the next. In addition, the distance of their eyes to the goggle would likely differ from each eye focusing. Other members do not wear the goggles as much in flight, so they may not take the same time to ensure the most clear eye focus. It can be noted that some of the greatest differences in ocular disparity for goggles were from the gunners; this could be because, in the aircraft, they do not wear the goggles very often or for very long on their missions.

If one were forced to pick an acceptable diopter setting, one could draw a line through Figure 6 cutting through the adjustment range of most of the 18 aircrew. This would be done with the assumption that all settings within each individual's range would be acceptable for that aircrew member and not cause too much eyestrain. When we pass such a line through –1.0 D, it essentially passes through all but 3 aircrew members' settings. Pilot #6 and pilot #7 were within 0.5 D of this line, so they may be able to find this setting acceptable. If –0.5 D were selected, 10 aircrew would likely not find this setting acceptable. The Study I and Study II analyses helped us select –1.0 D as a starting setting for Study III.

The settings from Study III were combined with the Study I settings, yielding an even clearer picture of where aircrews were setting their goggles. The estimated Weibull distribution for all the aircrew combined showed the 50th percentile to be –0.93 D. It has been reported that the optimum power is between –1.0 and –0.5 D by Pearce et. al.[7] and between –2.25 and –1.0 D by Mouroulis and Woo.[8] The pilots had a left shift in their diopter setting plot. Pilots were approximately –0.3 D (50th percentile of –1.11 D) more minus from the rest of the aircrew (50th percentile of –0.82 D). This could be because they tried to achieve the sharpest visual acuity possible. These results are remarkably similar to an Air Force Research Laboratory technical report on an 1993 survey in which an average eyepiece setting of –1.1 D was observed.[4] This result, a setting around –1.0 D, has also been supported in the literature indicating that acuity is maximized for a target at a distance corresponding to about 1.0 D of accommodation.[9] In a short-term wear study conducted by Gleason and Riegler, it was found that the best eye focus was –1.0 D, with this setting yielding the best average visual acuity across all conditions and subjects.[4]

Examining the questionnaire data, it appears that the –1.0 D fixed setting was less distasteful to the aircrew than the –0.5 D fixed setting; however, both the –1.0 and –0.5 D fixed settings were worse than personal settings for many of the aircrew. The greatest concern of the aircrew with the fixed setting appeared to be blurriness.

6. Conclusion

Is fixed focus or adjustable focus best for night vision goggles? Single-focus eyepieces are simpler, lighter, and cheaper because focus mechanisms are not needed; shorter single-focus eyepieces would reduce a goggle's overall length, bringing the center-of-gravity closer to the head while maintaining eye relief.[4] It has not been possible to find a perfect setting for all users, but –1.0 D may be acceptable to a large number of aircrew. The aircrew have become used to the ability to set their own goggles. Since aircrew members desire as much control over their missions as possible, it is likely that they would prefer to maintain this if possible. The views of the aircrew have been positively supported in the literature, that visual acuity is always better with an adjustable-focus eyepiece, than with a fixed-focus eyepiece.[10] Recent developments may permit a limited range of eyepiece adjustable focus for the integrated panoramic night vision goggle. This would likely be a 2 D range. Based on modeling, an eyepiece having a –0.25 to –2.25 D range is probably best. According to the Weibull distribution, this range would not cover approximately 25% of aircrew. Approximately 9% would want more negative adjustment, and approximately 16 percent would want more positive adjustment.

However, given people's ability to accommodate, if we assumed aircrew could accommodate ±0.5 D, the relative range would span +0.25 to –2.75 D, which would exclude only about 7% of the aircrew. Approximately 5% of ocular settings would be more negative than –2.75 D and approximately 2% would be more positive than +0.25 D. Also, when designing an optical product there are certain production tolerances that are allowed. We would not want the margin of error to be shifted in the more positive direction. If the settings were more positive than 0 D in the most positive direction, and if there was only a 2 D span of settings, the crewmembers that required the more negative settings would not be satisfied.

If adjustable lenses do not come into production, we may need to provide "snap on lenses"on a fixed focus eyepiece. These "snap on lenses" would be additional lenses that would attach to the eyepiece and would have minus or plus power. If we had a fixed eyepiece, based on the data we would likely choose –1.0 D. We might also provide a –1.0 snap on lens that would provide a total –2.0 D, which would only have approximately 13% of aircrew requiring more negative power. A +0.75 D lens would be utilized to provide a net –0.25 D. This would leave only approximately 16%of people to the right of this range who would require a more positive setting. These people that would be out of the range may not be satisfied due to the possibility of eyestrain, fatigue and possibly blurriness.

If we must have a fixed eyepiece, we would likely select –1.0 D. This appears to be the best setting. Snap on lenses would help meet the needs of the aircrew that require it. If variable focus becomes available, it will likely be well received by the aircrews and other NVG users. It would be advisable to be able to have a range that would effectively include crewmembers that would require +0.25 to –2.75 D. If a limited adjustable eyepiece can be designed with future goggles, then this should be undertaken, since there is no one diopter setting that will best serve all of our goggle users.

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Appendix

Weibull Distribution

Following is a description of the Weibull distribution.[11] This distribution was used to model diopter settings.

$$f(x) = \left(\frac{\beta}{\alpha}\right)\left(\frac{x-x_o}{\alpha}\right)^{\beta-1} e^{-\left(\frac{x-x_o}{\alpha}\right)^{\beta}} \quad \text{where } 0 < \alpha \text{ and } 0 < \beta$$

α = scale parameter, β = shape parameter, x_o = lower bound (LB)

$$F(x) = 1 - e^{-\left(\frac{x-x_o}{\alpha}\right)^{\beta}} \quad \text{transforms to: } Ln\{-Ln[(1-F(x)]\} = -\beta * Ln(\alpha) + \beta * Ln(x - x_o)$$

regression equation: $Y' = Intercept + Slope * X'$

$$\text{so: } \beta = slope, \text{ and } \alpha = e^{-\left(\frac{Intercept}{\beta}\right)}$$

Parameter estimates are obtained by transforming the cumulative distribution F(x) to a form that can be used in linear regression. In the transformed cumulative distribution, estimates of F(x) are the cumulative proportion at every level of X from the observed data. The lower bound is determined by using the X_O value that makes the transformed cumulative distribution the most linear (i.e., yields the highest correlation). The scale and shape parameter estimates are determined from the intercept and slope estimates of the linear regression.

It is possible for the lower bound (X_O) to be an unattainable value. For example, absolute differences must be non-negative yet X_O may be negative. This negative lower bound is necessary to obtain the best fit of the transformed cumulative proportions. A desired goal in fitting the Weibull distribution is for the percentiles of the estimated distribution to match closely with the percentiles of the data. What should occur is the area under the curve ≤ 0 should closely match the cumulative proportion at $X = 0$ from the data.

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Brief Biography

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