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USAARL Report No. 93-8

In-flight Field-of-View with ANVIS

By

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December 1992

United States Army Aeromedical Research Laboratory
Fort Rucker, Alabama 36362-5292

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Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) USAARL Report No. 93-8	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Aeromedical Research Laboratory 6b. OFFICE SYMBOL (If applicable) SGRD-UAS-VS	7a. NAME OF MONITORING ORGANIZATION U.S. Army Medical Research and Development Command
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 577 Fort Rucker, AL 36362-5292	7b. ADDRESS (City, State, and ZIP Code) Fort Detrick Frederick, MD 21702-5012
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
0602787A	3M1627 87A879	BG	174

11. TITLE (Include Security Classification)
In-flight Field-of-View with ANVIS

12. PERSONAL AUTHOR(S)
Kotulak, John C.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM ____ TO ____	1992 December	60

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
23	02	
20	06	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
field-of-view, ANVIS, eye relief, vertex distance eyepiece, night vision goggle

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This investigation had four major goals: (1) to measure the in-flight field-of-view (FOV) of a large sample of aviators (n = 105) using the AN/AVS-6 Aviator's Night Vision Imaging System (ANVIS), (2) to assess the degree to which in-flight ANVIS FOV restrictions result from improper user adjustments as opposed to equipment limitations, (3) to determine which epidemiological factors might be associated with reduced FOV, and (4) to evaluate options for optimizing in-flight ANVIS FOV. It was concluded that only about 15 percent of aviators actually achieve a 40° FOV with ANVIS during flight. The FOVs were reduced mostly because of equipment limitations, and not because of user misadjustments. Specifically, the fore-aft adjustment of the ANVIS helmet mount lacks sufficient range in the aft direction. Among the epidemiological factors studies, only total flight hours, hours in current aircraft, hours in last 12 months, and aircraft type are statistically related to in-flight ANVIS FOV. Total night vision goggle flight hours, ANVIS flight hours, helmet size, type of

(Continued)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Chief, Scientific Information Center	22b. TELEPHONE (Include Area Code) (205) 255-6907 22c. OFFICE SYMBOL SGRD-UAX-SI

19. ABSTRACT (Continued)
helmet liner, and spectacle use are not related to in-flight ANVIS FOV. Finally, it was determined that most aviators could achieve a 40° FOV if either of two hardware modifications were made: improving the fore-aft adjustment range of the ANVIS mount, or switching to a different eyepiece with a greater eye relief.

Acknowledgments

The author wishes to acknowledge the contributions of the following units of the Aviation Training Brigade (ATB): Night Vision Devices Section, ATB Headquarters; S3 Section, Company A (AH-1), Company B (OH-58A/C), Company C (OH-58D), Company E (OH-58A/C), and Company F (CH-47) of the 1st Battalion, 14th Aviation Regiment; S3 Section and Company B (UH-1) of the 1st Battalion, 212th Aviation Regiment; S3 Section and Company C (UH-60) of the 1st Battalion, 223rd Aviation Regiment. In addition, the following personnel from the U.S. Army Aeromedical Research Laboratory (USAARL) are thanked: LTC James M. King, Dr. John A. Caldwell, and Dr. Robert L. Stephens for help with the statistical analysis; Dr. William E. McLean for help with experimental methods; and SPC Mark A. Kenzie for providing technical assistance with all phases of the study.

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Introduction

The field-of-view (FOV) of the AN/AVS-6 Aviator's Night Vision Imaging System (ANVIS) (Figure 1) is usually reported to be 40° (Neal, 1983; Brickner, 1989; Verona and Rash, 1989; Crowley, 1990). What is often not made explicit, however, is that a 40° FOV cannot be obtained unless the ANVIS eyepiece is positioned within a certain critical distance of the eye, i.e., the ANVIS eye relief distance. There is mounting evidence that during flight, the ANVIS eyepiece is typically not positioned within its eye relief distance, and thus a 40° FOV is typically not achieved.

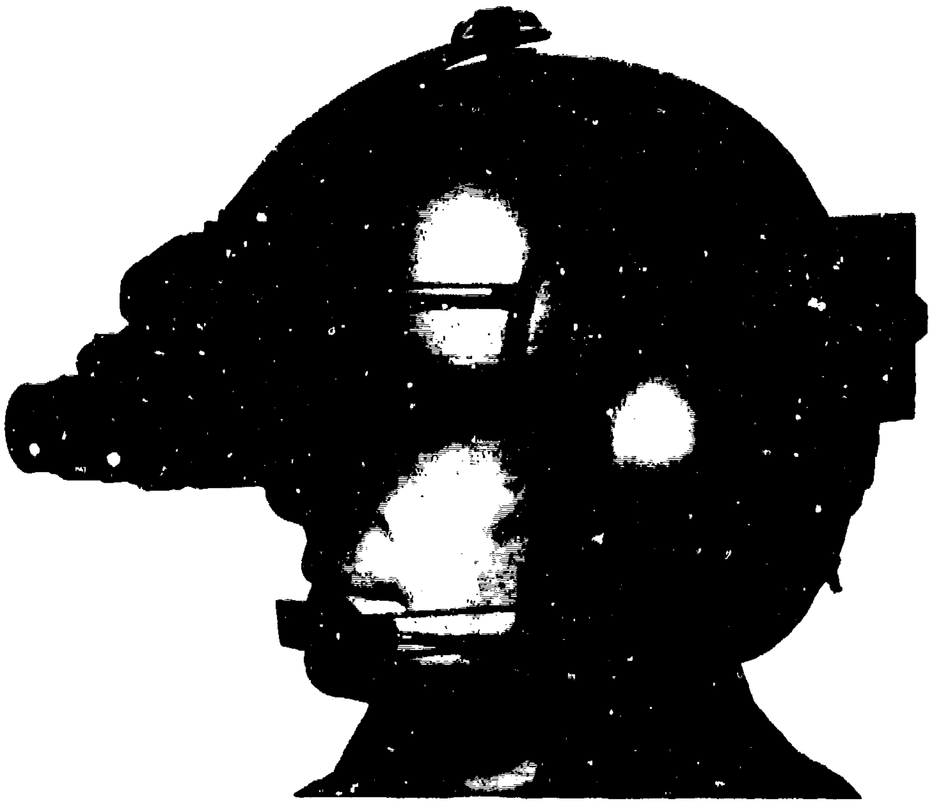

Figure 1. AN/AVS-6 Aviator's Night Vision Imaging System (ANVIS) mounted on the SPH-4 flight helmet.

Kotulak and Frezell (1991) reported that the average ANVIS FOV was 36° when the fore-aft adjustment of the helmet mount was set to the maximum-aft position (n = 2). Kotulak and Frezell also found that the mean distance between the eyes and the eyepiece lenses (vertex distance) was 24 mm when ANVIS was in the full-aft position, and that the ANVIS eye relief distance was around 20 mm. A similar value for the ANVIS eye relief distance was reported by Walsh (1990) (n = 1). Osterlund and his colleagues determined that the average ANVIS FOV was 36° when the fore-aft adjustment was set to the position used in flight, at which the mean vertex distance was 23 mm (n = 19).

This investigation, which was requested by the Directorate of Combat Developments of the U.S. Army Aviation Center (Appendix A), had four major goals. The first was to measure the in-flight ANVIS FOV of a large sample of aviators (n = 105). To accomplish this, the ANVIS fore-aft position, which can span a range of 16 mm (Department of the Army, 1983), had to be adjusted consistent with individual user preferences, because ANVIS FOV varies considerably from one end of the fore-aft adjustment range to the other (Kotulak and Frezell, 1991). The in-flight ANVIS FOV distribution was obtained by means of a two-phase study. In the first phase, the quantitative relationship between vertex distance and FOV was determined in the laboratory, while in the second phase, in-flight vertex distances were measured in the field.

The second goal of this investigation was to assess the degree to which in-flight ANVIS FOV restrictions (if any) result from user adjustments as opposed to equipment limitations. To accomplish this, the full-aft ANVIS vertex distance was measured on each subject, and compared to the in-flight vertex distance. The difference between the two, which is the fore-aft position of the ANVIS eyepiece relative to the full-aft position, was calculated.

The third goal of this investigation was to determine which epidemiological factors, such as flight experience, aircraft model, type of helmet liner, use of glasses, etc., might be associated with reduced FOV. The epidemiological data was collected to determine whether certain subpopulations of aviators might be more disposed towards reduced FOV than others, and to identify ways in which subpopulation-specific FOV restrictions could be alleviated.

The final goal of this investigation was to evaluate options for optimizing in-flight ANVIS FOV. Two options were considered: (1) extending the range of the ANVIS fore-adjustment in the aft direction, and (2) replacing the current ANVIS eyepiece with one with greater eye relief. Both of these options are based on existing technology.

Methods

Laboratory study

Because our knowledge of the relationship between ANVIS FOV and vertex distance is based on limited data, a psychophysical study was done to determine the exact linkage between these two variables. Subsequently, this relationship was described in mathematical terms, and the strength of the correlation between FOV and vertex distance was tested. The laboratory study had a repeated measures design, with one independent variable (vertex distance) and one dependent variable (monocular FOV).

Apparatus

The laboratory apparatus is shown in Figure 2. Horizontal

Figure 2. Laboratory apparatus used to measure relationship between field-of-view and vertex distance.

FOVs were measured with an ANVIS monocular equipped with a self-contained power supply that enabled it to operate detached from the flight helmet. FOVs were measured at vertex distances ranging from 17 to 52 mm in 5 mm steps. This range, which was derived from Kotulak and Frezell (1991), was thought to contain both the ANVIS eye relief distance and the full-fore vertex distance for the majority of aviators. Vertex distance, as used in this report, is the distance measured along the observer's line-of-sight from the anterior surface of the cornea to the geometric center of the posterior surface of the ANVIS eyepiece lens. (The ANVIS eyepiece is actually made up of a series of lenses. For simplicity, however, the term "eyepiece lens" refers only to the most posterior of these lenses.) Vertex distance was measured with a caliper designed for clinical use in optometry. Although the caliper had a range of only 23 mm, greater vertex distances could be measured in the laboratory by means of the scale that was attached to the track over which the ANVIS monocular travelled.

A Gentex* polished-surface filter, which attenuates incident radiant flux approximately 5 log units across the wavelengths to which ANVIS is sensitive, was placed over the ANVIS objective lens (Figure 3). The transmittance spectrum of this filter was

Figure 3. ANVIS with filters which permit operation in ordinary room light.

* See list of manufacturers.

described by Rash and Martin (1989). The filter enabled the experiment to proceed under dim room illumination (as opposed to simulated night sky conditions), which facilitated the tasks of manipulating the experimental apparatus and collecting the data. The filter also eliminated the problem of blooming, which is the expansion of the image of a luminous source that occurs with image intensifiers (Bender, 1991).

Test stimulus

The test stimulus was a circular spot of white light having a luminance of 13.4 cd/m^2, which was projected onto a flat, semi-reflective, white background having a luminance of 9.6 cd/m^2. Through the filter described in the preceding paragraph, the luminance of the target and the background was ~10^{-4} cd/m^2, which is approximately that of clear starlight. The test spot subtended an angle of 0.3° at the ANVIS objective lens. The luminance contrast of the test spot was 0.40 as determined by the equation below, in which L_T and L_B are the photometrically measured luminance values of the test stimulus and background respectively.

$$C = \frac{L_T - L_B}{L_B}$$

The above equation is typically used to specify the contrast of small projected spots of light (Blackwell, 1946; Adams *et al.*, 1984; Newacheck, Haegerstrom-Portnoy, and Adams, 1990). Contrast can readily exceed 100 percent by this equation. Stimulus contrast was selected to be representative of non-luminous objects typical of the Army aviation environment (Pollehn, 1988).

Procedures

The ANVIS objective lens was focused for the 4 m test distance, and the eyepiece lens for -1 diopter (D). The latter was done to provide some compensation for instrument myopia (Shimojima, 1967; Schober, Dehler, and Kassel, 1970; Hennessy, 1975; Miwa, 1992), while controlling for the effects of dioptric focus on vertex distance, i.e., as the eyepiece focus moves from +2 to -6 D, vertex distance increases by 5 mm (Table 1). A forehead rest and chin cup were used to prevent head movements. The right eye of the subject was centered behind the ANVIS monocular using a field alignment procedure (Department of the Army, 1988). Eye movements were allowed because they are likely to occur in flight, although eye movements reduce the FOV somewhat from the size obtained with a stationary eye (Westheimer, 1957). The psychophysical method of adjustment was used. The subjects determined the left and right FOV limits for each vertex distance by moving the head of a projector laterally until the test stimulus straddled the FOV border (Figure 4).

Table 1.

Distances from range extension cap

To ANVIS eyepiece lens

Eyepiece dioptric setting (D)	Short range extender distance to		Long range extender distance to	
	Convex lens (mm)	Concave lens (mm)	Convex lens (mm)	Concave lens (mm)
+2	5	6	20	21
+1	6	7	21	22
0	6	7	21	22
-1	7	8	22	23
-2	8	9	23	24
-3	8	9	23	24
-4	9	10	24	25
-5	10	11	25	26
-6	10	11	25	26

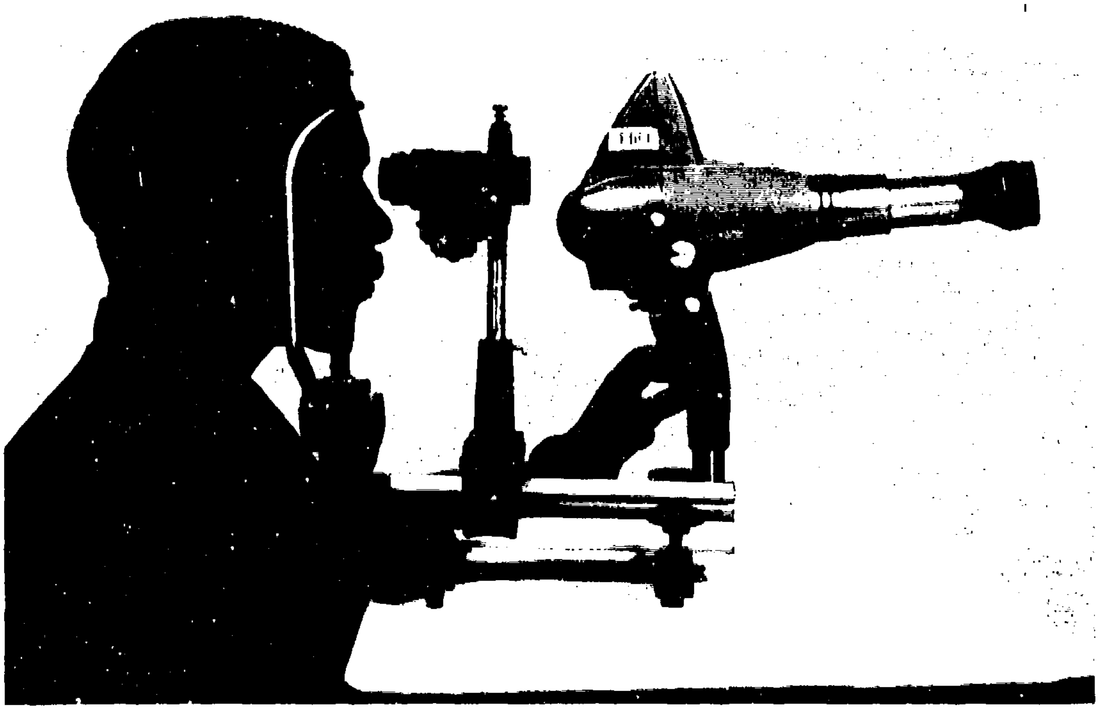

Figure 4. Subject aiming projector to position test stimulus at ANVIS field-of-view limit.

Unintentional head movements by the subject were a potential problem. To control for these, the investigator marked the first of each pair of FOV limits with a strip of white tape. The subject was required to keep this marker in his FOV when he determined the field limit on the opposite side.

To insure that the FOV measurements were not kept artificially small by the choice of stimulus contrast, a control experiment was run in which the above procedures were repeated for one subject at a contrast that was over one log unit higher than in the main experiment. The top graph in Figure 5 gives the results of one subject for the experiment described in the preceding paragraph, in which the stimulus contrast was 0.40. The bottom graph gives the results for the same subject when the contrast was increased to 8.05. In both graphs it can be seen that the relationship between FOV and vertex distance is linear. A comparison of the slopes and intercepts of the respective regression lines reveals no significant difference ($df = 2/12$, $F = 0.577$, $p > 0.57$), which suggests that FOV is independent of target contrast when contrast is between 0.40 and 8.05.

<u>Subjects</u>

The laboratory study used 20 subjects, who were not required to be aviators. They were required to have no history of visual field loss, and a visual acuity (VA) of at least 20/50 in the test eye while viewing a high contrast target through ANVIS under simulated clear starlight. This VA cutoff comes from Kotulak and Rash (1992), who found that the mean acuity for subjects viewing a high contrast target through ANVIS under simulated clear starlight was 20/50. Ametropic subjects were required to wear their spectacles during the experiment.

Field study

The field study had two distinct purposes: (1) to measure vertex distance, and (2) to collect epidemiological data. The vertex distance portion of the field study had a within-subjects 2 X 2 factorial design, in which the dependent variable (vertex distance) was measured across two independent variables: eye laterality (right versus left) and ANVIS eyepiece position (in-flight versus full-aft). The vertex distance data provided the means for calculating both FOV and the precise in-flight position of the ANVIS eyepiece along the fore-aft axis. The epidemiological portion of the field study had a between-subjects design, with one dependent variable (in-flight FOV), and nine independent variables (total flight hours, flight hours in current aircraft, flight hours in last 12 months, total night vision goggle (NVG) flight hours, ANVIS flight hours, aircraft

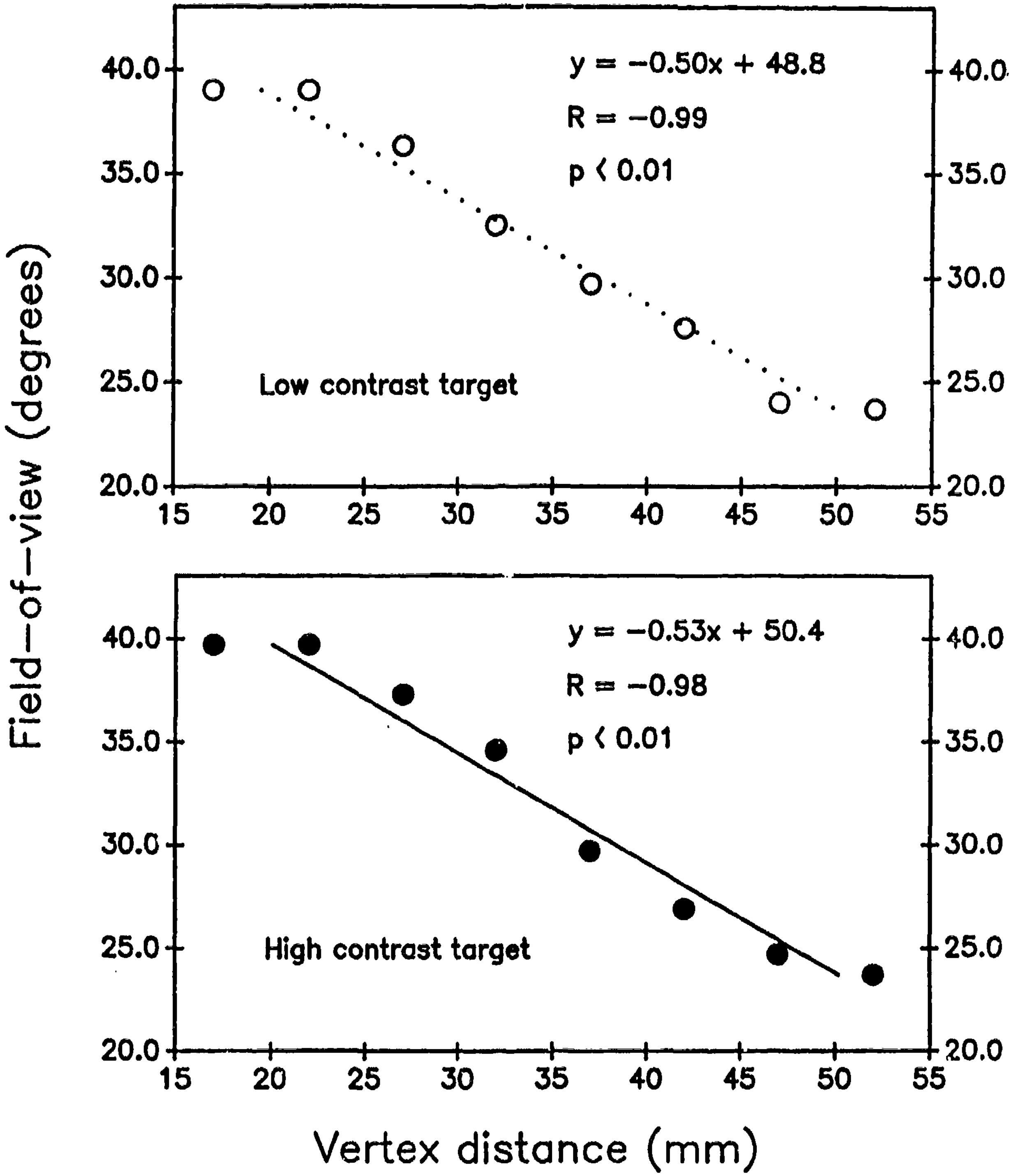

Figure 5. Effect of stimulus contrast on ANVIS field-of-view.

type, helmet size, helmet liner type, and use of glasses in flight).

Aviator night vision goggles

In addition to ANVIS, the Army's other aviator NVG is the AN/PVS-5. However, the AN/PVS-5 is gradually being replaced with ANVIS, and its use in aviation is expected to be discontinued in 1994 or 1995 (Spadafore, 1991). Therefore, only ANVIS was included in the study.

Two versions of the ANVIS eyepiece have been fielded: one with the eyepiece lens convex, and the other with it concave. The difference in vertex distance between the two versions is approximately 1 mm (Table 1). To avoid a confounding variable due to lens shape, only convex eyepieces were used in the field study.

Apparatus

Vertex distance was measured with the caliper that was used in the laboratory phase of the study (Figure 2). Because the caliper is limited to vertex distances of 23 mm or less, range extension devices were needed to measure vertex distances greater than 23 mm. Two such devices were used: one for vertex distances from 24-31 mm, and the other for vertex distances greater than 31 mm. These devices are referred to as the short and long range extenders respectively. The short (24-31 mm) range extender was merely a standard ANVIS eyepiece lens cap, while the long (>31 mm) range extender was a cylinder with the same internal diameter as the ANVIS eyepiece lens cap, but with 15 extra mm of length longitudinally (Figure 6). The use of these range extenders introduced another potential confounding variable because they attached to ANVIS in a manner which dissociated them from any independent movement of the eyepiece. The eyepiece moves independently of the ANVIS monocular as a function of the degree of dioptric focus (Table 1). To control for this dissociation and to be consistent with the technique used on other subjects, the degree of dioptric focus was recorded for each subject who required a range extender, and the true vertex distance was calculated from the measured vertex distance using the matrix described in Table 1.

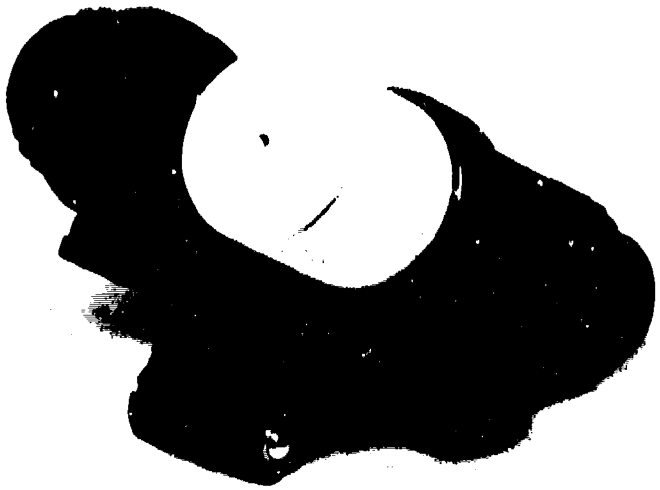

Figure 6. Vextex distance long range extender cap attached to ANVIS eyepiece.

Procedures

Data collection took place in preflight briefing areas just before NVG training flights. The subjects were instructed to adjust ANVIS as they would during flight. A similar technique was used by Osterlund et al. (1991), who proposed that aviators do not require the cockpit environment to reproduce in-flight ANVIS fore-aft adjustments. A control experiment was done in the present study to validate Osterlund's technique. In the control experiment, the ANVIS vertex distance of seven aviators was measured immediately after they returned from night helicopter missions. The subjects were briefed in advance not to change any of their in-flight ANVIS adjustments until they reported to the investigator for measurement. After the in-flight vertex distance was measured, the investigator reset the ANVIS fore-aft adjustment to a random position, and asked the subjects to duplicate their typical in-flight fore-aft adjustments. The results, which are given by Figure 7, show that pilots can successfully replicate their in-flight ANVIS fore-aft adjustments when they are not in the cockpit. The two outliers in Figure 7 were from subjects who normally set the fore-aft adjustment while viewing through operating (turned on) goggles. There was no provision to turn on the goggles during the control experiment, which was done in a brightly lit area. However, for subsequent data collection, the filters shown in Figure 3 and described earlier, were used so that subjects who wished could make their adjustments with ANVIS turned on.

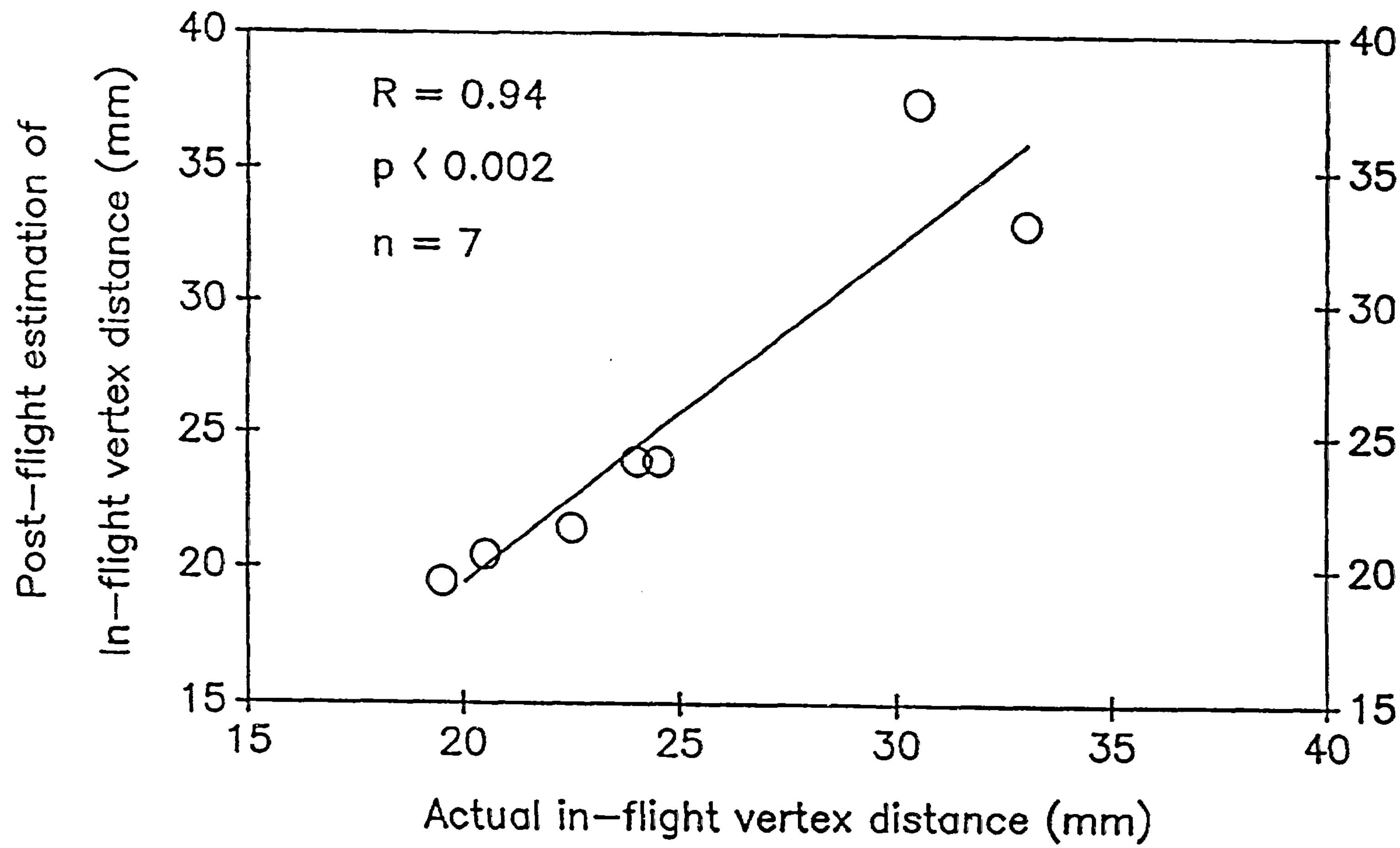

Figure 7. Correlation between post-flight estimation of in-flight vertex distance and actual in-flight vertex distance.

Epidemiological data

During the course of the vertex distance measurements, the experimenter also collected the epidemiological data (see items 1-9 on the data collection sheet in Appendix C). The epidemiological variables are of two types: flight-experience and equipment-related. The flight experience variables, which are continuous, are: total flight hours, flight hours in the current aircraft, flight hours in the last 12 months, total NVG flight hours (all types of NVGs), and ANVIS flight hours. To permit analysis by chi-square and analysis of variance (ANOVA), the flight experience variables were categorized. Individual one-way ANOVAs were used to analyze the epidemiological variables. For chi-square, the subjects were divided about the median into "low" and "high" experience groups. For ANOVA, the subjects were divided about the 33rd and 67th percentiles into "low," "medium," and "high" experience groups. In some instances, several individuals reported the same flight experience for a given variable. When this happened at the dividing line between categories, all subjects reporting identical flight experience were assigned to the same category, even though this caused the categories to vary slightly in size. The equipment-related variables, which are categorical, are: aircraft type, helmet size, helmet liner type, and use of glasses in flight. The levels of each of the equipment-related variables are described in the next paragraph.

Subjects

Approximately equal numbers of volunteer rated aviators were recruited from the crews of the Army aircraft in which ANVIS is typically used: AH-1 (n = 19), CH-47 (n = 13), OH-58A/C (n = 15), OH-58D (n = 13), UH-1 (n = 18), and UH-60 (n = 16). In addition, a group of Initial Entry Rotary Wing (IERW) students (n = 11) was included to insure that both extremes of the spectrum of flight experience were represented. The IERW students flew UH-1 aircraft, but their results were reported separately from the other UH-1 aviators. The total sample size was 105. All subjects were NVG qualified, and wore their customary SPH-4 flight helmet with ANVIS mount during data collection. Fifty-one subjects wore size regular helmets, while 54 wore extra large. Twenty-four subjects used web helmet liners, 35 used standard (unmodified) thermoplastic liners (TPLs), while 46 used modified TPLs. (Modifications were defined as either removing layers or heating the TPL.) Ninety-one subjects did not wear glasses during flight, while 14 did. Table 2 gives statistical information about the flight experience of the subjects.

Table 2.

Descriptive statistics of subjects

By flight experience

Variable	Mean	Median	Mode	Standard deviation	Normal
Total flight hours	2364	2000	160	2127	No
Hours in current aircraft	1463	1050	130	1572	No
Hours in last 12 months	307	283	400	154	No
Total NVG hours	366	250	500	371	No
ANVIS hours	170	100	10	211	No

Results

The error bars and the symbol "s" on the graphs represent one standard deviation of the mean. In the text, the value following each "±" sign is also one standard deviation.

Laboratory study

Effect of vertex distance on field-of-view

Figure 8 shows how ANVIS FOV varies for 20 subjects as vertex distance increases from 17 to 52 mm. The change in FOV with vertex distance was found to fit a number of models, e.g., linear ($R^2 = 0.99$, $p < 0.0001$), cubic ($R^2 = 1.00$, $p < 0.0001$), quartic ($R^2 = 1.00$, $p < 0.0001$), and quintic ($R^2 = 1.00$, $p < 0.004$). The linear model, which is described by the regression equation in Figure 8, was used to convert vertex distances measured in the field to FOVs because of its simplicity and because the higher order models failed to add significantly to the variance explained.

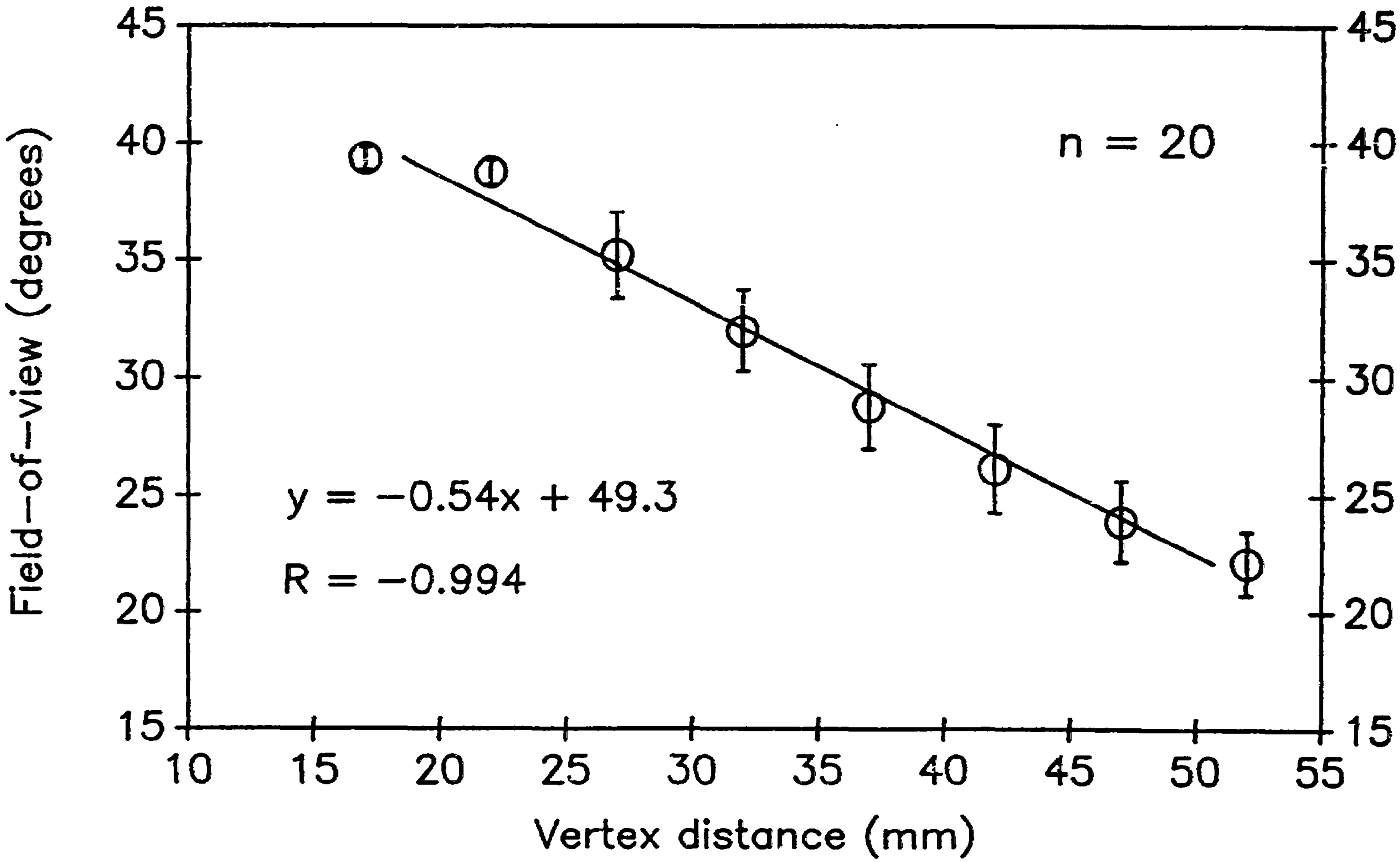

Figure 8. Relationship between ANVIS field-of-view and vertex distance.

Field study

Measured variables

In-flight vertex distance

Table 3 gives the descriptive statistics for the in-flight vertex distances of the right and left eyes, as well as for the mean of the two eyes, of 105 aviators. The difference in vertex distance between the two eyes is probably due to anthropometric asymmetry. Similar asymmetries have been reported for protective mask visual corrections (Kotulak and Crosley, 1992). The magnitude of the ANVIS vertex distance asymmetry, which appears to be only 0.5 mm in Table 3, is partially masked by averaging the data for each eye separately. When the absolute values of the within-subject vertex distance differences are averaged across subjects, the vertex distance asymmetry increases to 1.8 ± 1.4 mm. The "W" statistic is from a test for normality, in which a p-value greater than 0.05 indicates that there is no reason to question the assumption of normality (Shapiro and Wilk, 1965; Royston, 1982). Thus, all three distributions are normally distributed. Figure 9 (top) gives the distribution of mean in-flight vertex distances.

Table 3.

Descriptive statistics of

In-flight vertex distance distribution

Statistic	Right eye	Left eye	Mean
Mean	22.9	23.4	23.2
s	4.9	5.2	4.9
Median	20.0	23.0	23.0
Mode	20.0	23.0	23.0
W	0.98	0.97	0.97
p	>0.43	>0.23	>0.19

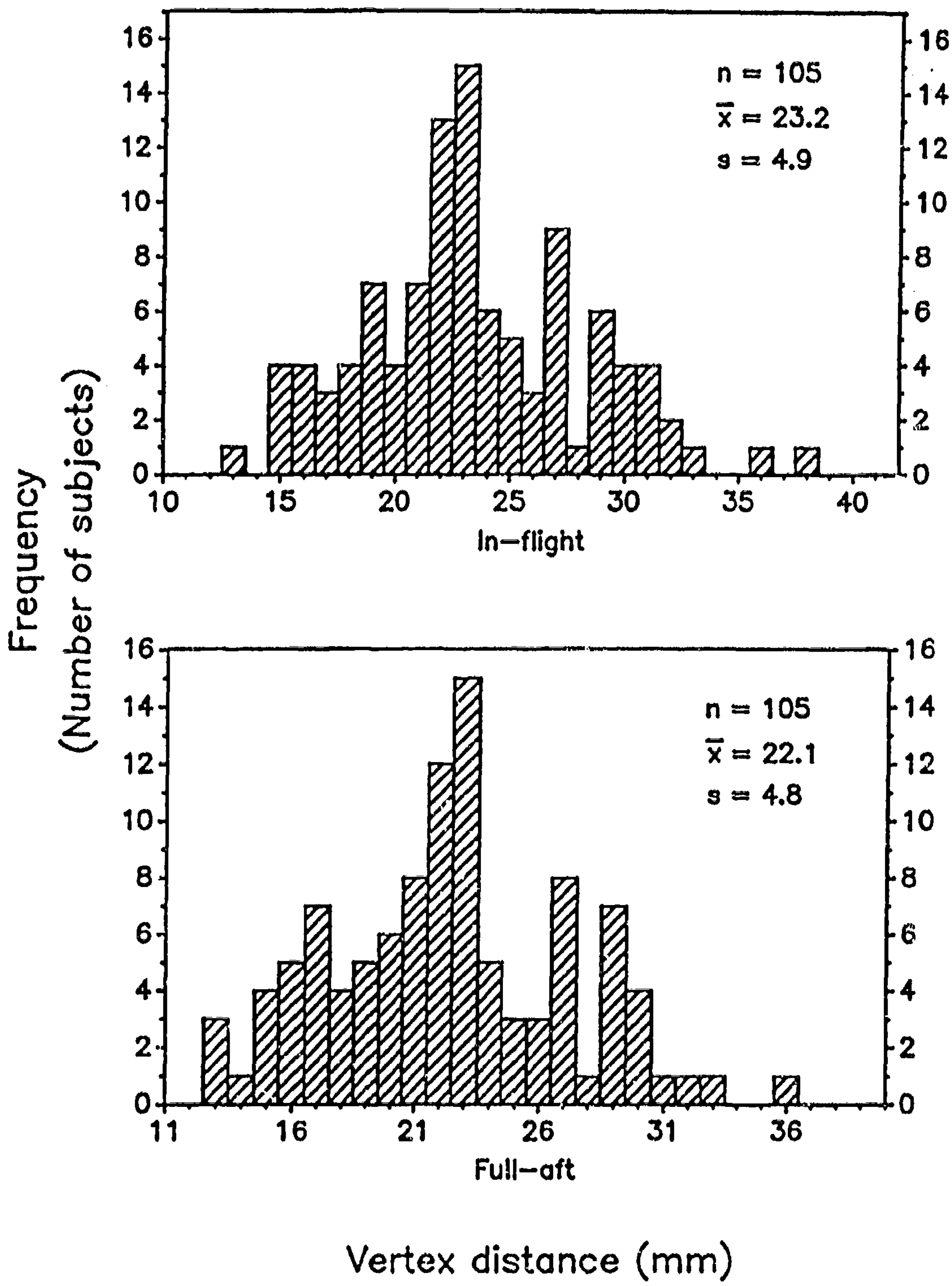

Figure 9. Distribution of in-flight (top) and full-aft (bottom) ANVIS vertex distances.

Full-aft vertex distance

Table 4 gives the descriptive statistics for the full-aft vertex distances of the right and left eyes, as well as for the mean for the two eyes, of 105 aviators. Figure 9 (bottom) gives the distribution of mean full-aft vertex distances from which full-aft FOV was calculated. A repeated-measures analysis of variance revealed that the in-flight vertex distances are statistically greater than the full-aft vertex distances ($df = 1/104$, F 17.39, $p = 0.0001$). Also, the left-eye vertex distances were statistically greater than the right-eye distances ($df = 1/104$, $F = 7.32$, $p < 0.01$). However, there was not statistically significant interaction between fore-aft position and eye ($df = 1/104$, $F = 0.47$, $p > 0.49$).

Table 4.

Descriptive statistics of

Full-aft vertex distance distribution

Statistic	Right eye	Left eye	Mean
Mean	21.8	22.4	22.1
s	4.8	5.2	4.8
Median	21.0	23.0	22.0
Mode	None	23.0	23.0
W	0.97	0.98	0.97
p	>0.14	>0.35	>0.12

Derived variables

Fore-aft adjustment selection

Figure 10 shows the distribution of ANVIS fore-aft adjustment selections. This distribution was derived from the difference between the mean in-flight and the mean full-aft vertex distance distributions (Figure 9). A value of zero indicates that the aviator flies with ANVIS in the full-aft position, and a value of 16 indicates that the aviator flies with ANVIS in the full-fore position. The mean, median, and mode of this distribution are 1.1, 0, and 0 mm respectively. The

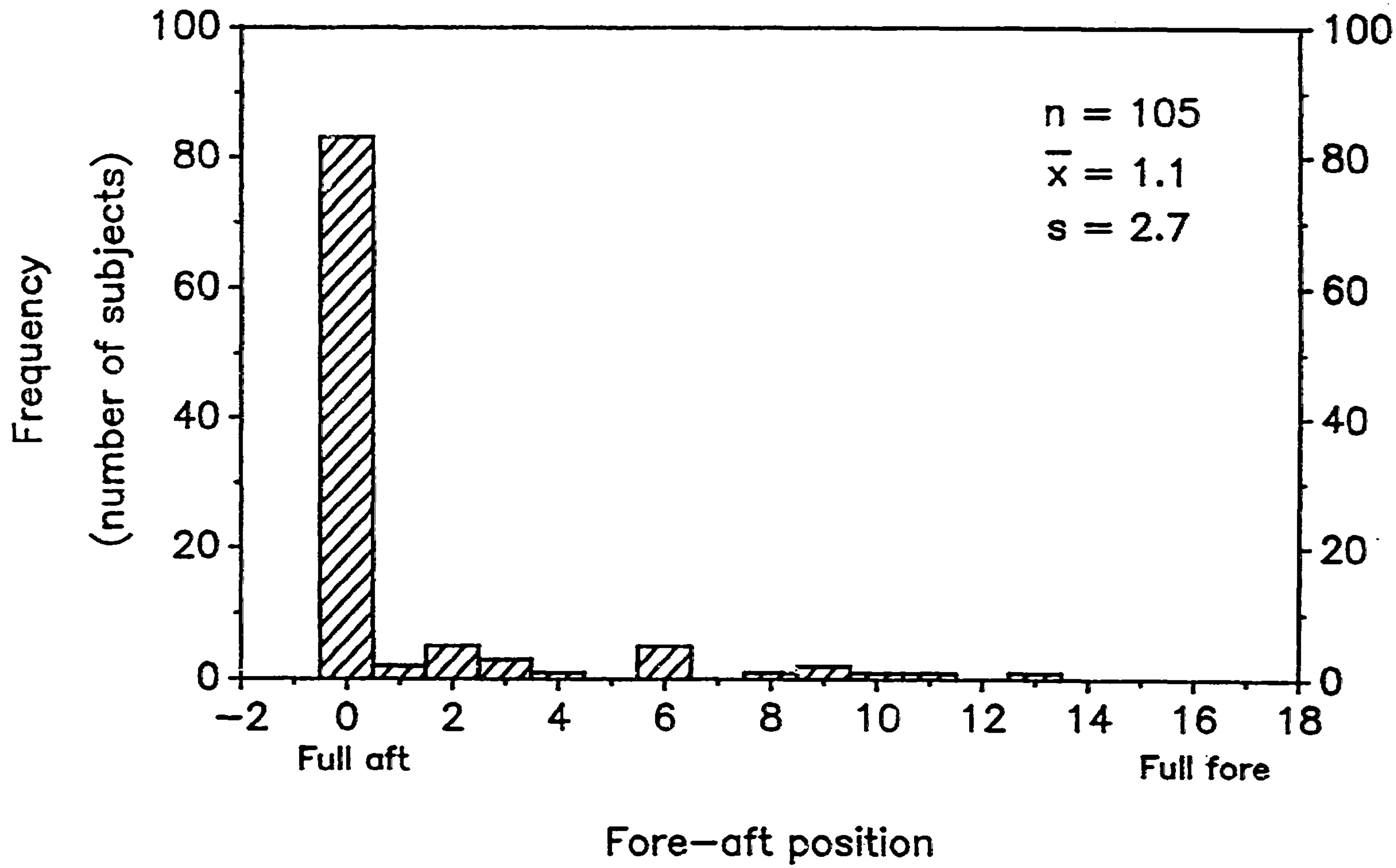

Figure 10. Distribution of user preferences for in-flight ANVIS fore-aft position.

distribution is not normally distributed ($W = 0.49$, $p < 0.0001$). Only 22 of the 105 subjects failed to select the full-aft position. Of the 22 subjects who selected other than the full-aft position, 11 stated that they did so for greater look-under/look-around capability, 7 stated that glasses physically prevented the eyepieces from going farther back, and 4 gave other reasons. Ten of the 22 subjects who selected other than the full-aft position had in-flight FOVs that were as large as their full-aft FOVs, i.e., they incurred no FOV penalty for failure to select the full-aft position. Therefore, only 12 of the 105 subjects had FOV loss that resulted from non-selection of the full-aft position. Of these 12, seven were spectacle wearers who identified glasses as the reason they did not select the full-aft position. Thus, only 5 of the 105 subjects had FOV loss which they could have reduced by changing the fore-aft adjustment.

In-flight fields-of-view

Figure 11 (top) illustrates the distribution of in-flight ANVIS FOVs. This distribution was derived from the linear transformation of the mean in-flight vertex distances in Figure 9 (top), using the regression equation in Figure 8. The mean and standard deviation of the in-flight FOV distribution are given in Figure 11 (top), and the median and mode are 37.2 and 37.0° respectively. The distribution is not normally distributed ($W = 0.93$, $p < 0.0001$) due to a ceiling effect, i.e., FOVs much greater than 40° cannot occur.

Full-aft fields-of-view

Figure 11 (bottom) depicts the distribution of full-aft ANVIS FOVs. This distribution was derived from the linear transformation of the full-aft vertex distances in Figure 9 (bottom), using the regression equation in Figure 8. The mean and standard deviation of the full-aft FOV distribution are given in Figure 11 (bottom), and the median and mode are 37.7 and 40.0° respectively. The distribution is not normally distributed ($W = 0.93$, $p < 0.0001$) due to the ceiling effect described in the preceding paragraph.

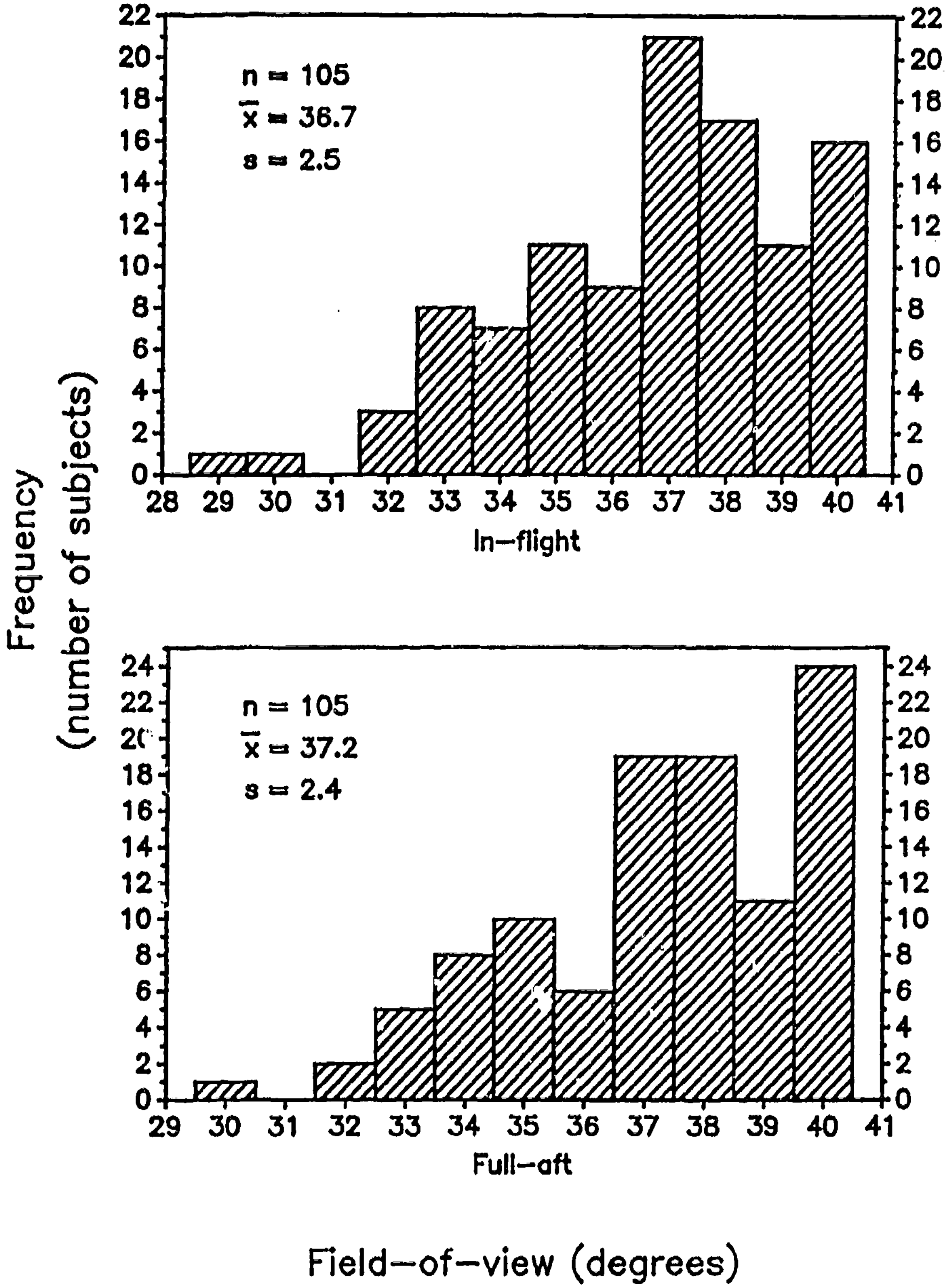

Figure 11. Distribution of in-flight (top) and full aft (bottom) ANVIS fields-of-view.

Epidemiological variables

Total flight hours

Figure 12 (top) demonstrates the relationship between total flight experience and in-flight FOV with ANVIS. The correlation is positive but not statistically significant ($p > 0.14$). In the bottom graph in Figure 12, total flight hours are grouped into low, medium, and high categories (Tables 5 and 6). A one-way ANOVA indicated that there is a statistical difference among the groups ($df = 2/102$, $F = 3.36$, $p < 0.04$). Multiple comparison testing, using the Tukey Studentized range method, revealed that the low experience group has a statistically smaller FOV than the medium experience group ($p < 0.05$). However, when total flight hours are grouped into only low and high categories, this difference disappears either by one-way ANOVA ($df = 1/103$, $F = 1.62$, $p > 0.2$) or by Pearson's chi-square ($df = 1$, chi-square $= 2.70$, $p > 0.1$). This suggests a leveling-off effect, in which FOV asymptotes when total flight experience approached the cutoff between the low and medium categories, i.e., around 1300 hours.

Flight hours in current aircraft

Figure 13 (top) demonstrates the relationship between flight experience in the current aircraft and in-flight FOV with ANVIS. The correlation is positive but not statistically significant ($p > 0.08$). In the bottom graph in Figure 13, hours in the current aircraft are grouped into low, medium, and high categories (Tables 5 and 6). A one-way ANOVA indicated that the differences among the groups are not significant ($df = 2/95$, $F = 3.05$, $p > 0.05$). However, when total flight hours are grouped into only low and high categories, the difference between groups is statistically significant either by one-way ANOVA ($df = 1/96$, $F = 5.60$, $p = 0.02$) or by Pearson's chi-square ($df = 1$, chi-square $= 6.75$, $p < 0.01$). If a leveling-off effect is present for hours in the current aircraft, it does not occur as early as it did for total flight hours above.

Flight hours in last 12 months

Figure 14 (top) demonstrates the relationship between flight experience in the last 12 months and in-flight FOV with ANVIS. The correlation is positive but not statistically significant ($p > 0.07$). In the bottom graph in Figure 14, hours in the current aircraft are grouped into low, medium, and high categories (Tables 5 and 6). A one-way ANOVA indicated that the differences among the groups are not significant ($df = 2/95$, $F = 1.50$, $p > 0.22$). However, when total flight hours are grouped into only low and high categories, the difference between groups is

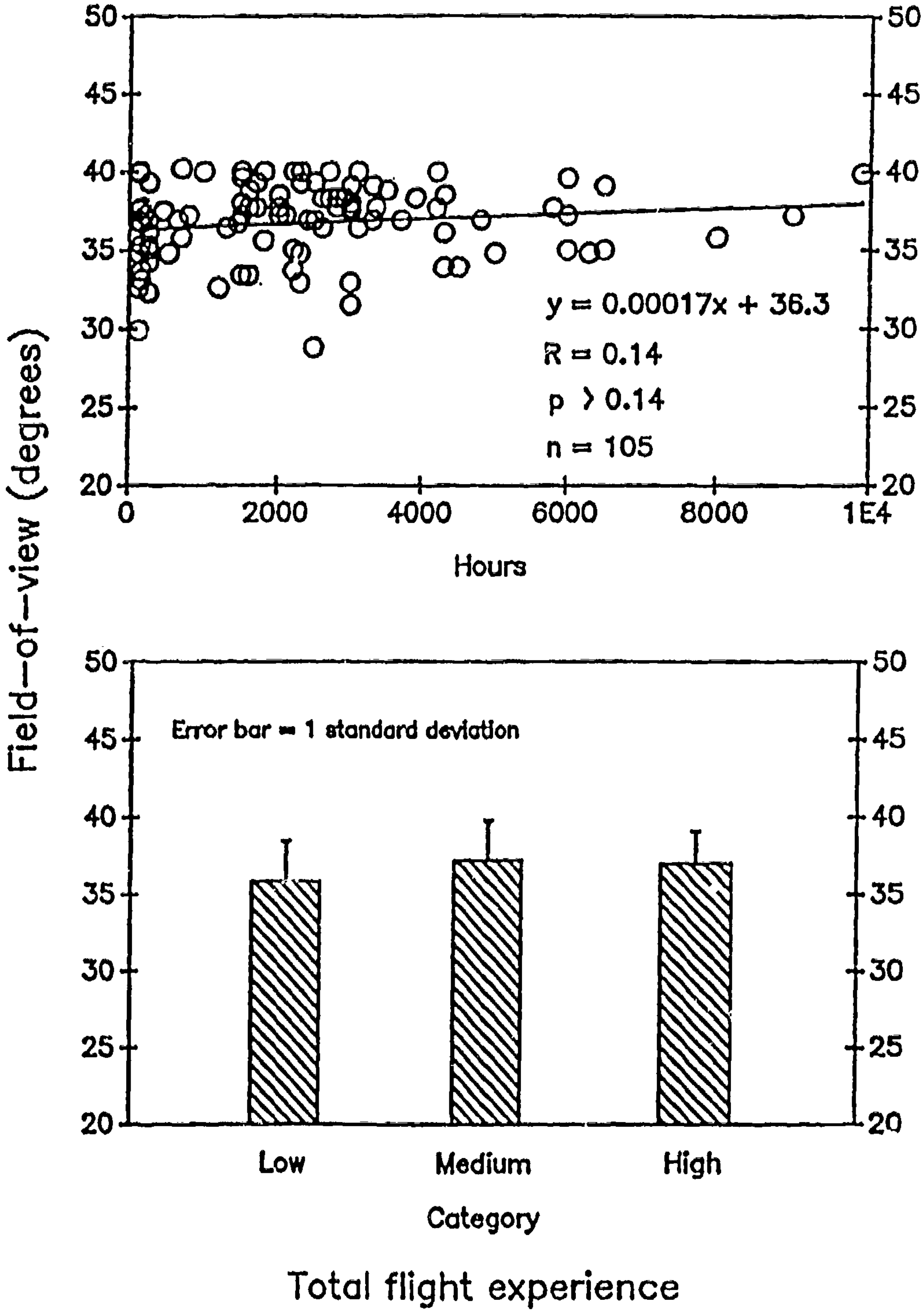

Figure 12. ANVIS in-flight field-of-view based on total flight experience.

Table 5.

Boundaries of flight experience categories

Variable	Low (hours)	Medium (hours)	High (hours)
Total flight hours	$\leq$1300	>1300 and <2800	$\geq$2800
Hours in current aircraft	<200	$\geq$200 and $\leq$1800	>1800
Hours in last 12 months	<225	$\geq$225 and <400	$\geq$400
Total NVG hours	<100	$\geq$100 and <500	$\geq$500
ANVIS hours	<20	$\geq$20 and <200	$\geq$200

Table 6.

Descriptive statistics of

Flight experience variables

Variable	Low	Medium	High
Total flight hours	$35.9\pm2.6°$ n = 35	$37.3\pm2.7°$ n = 34	$37.0\pm2.1°$ n = 36
Hours in current aircraft	$35.9\pm2.6°$ n = 33	$37.1\pm2.3°$ n = 32	37.3 ± 2.5 n = 33
Hours in last 12 months	$36.4\pm2.6°$ n = 33	$36.5\pm2.2°$ n = 29	$37.4\pm2.6°$ n = 36
Total NVG hours	$36.1\pm2.7°$ n = 35	$37.5\pm2.3°$ n = 33	$36.7\pm2.5°$ n = 37
ANVIS hours	$36.0\pm2.6°$ n = 36	$36.8\pm2.9°$ n = 32	37.3 ± 2.0 n = 37

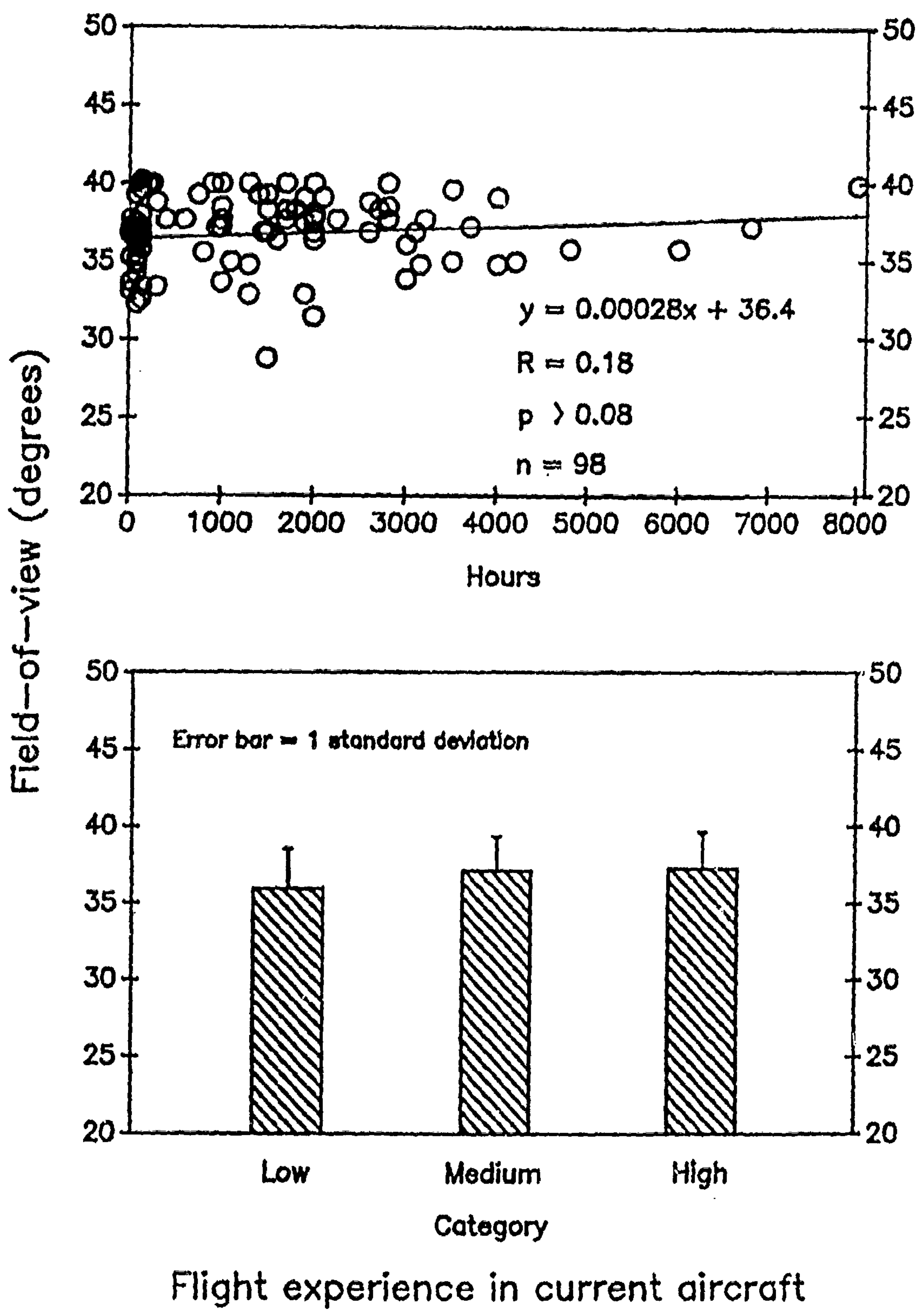

Figure 13. ANVIS in-flight field-of-view based on flight experience in current aircraft.

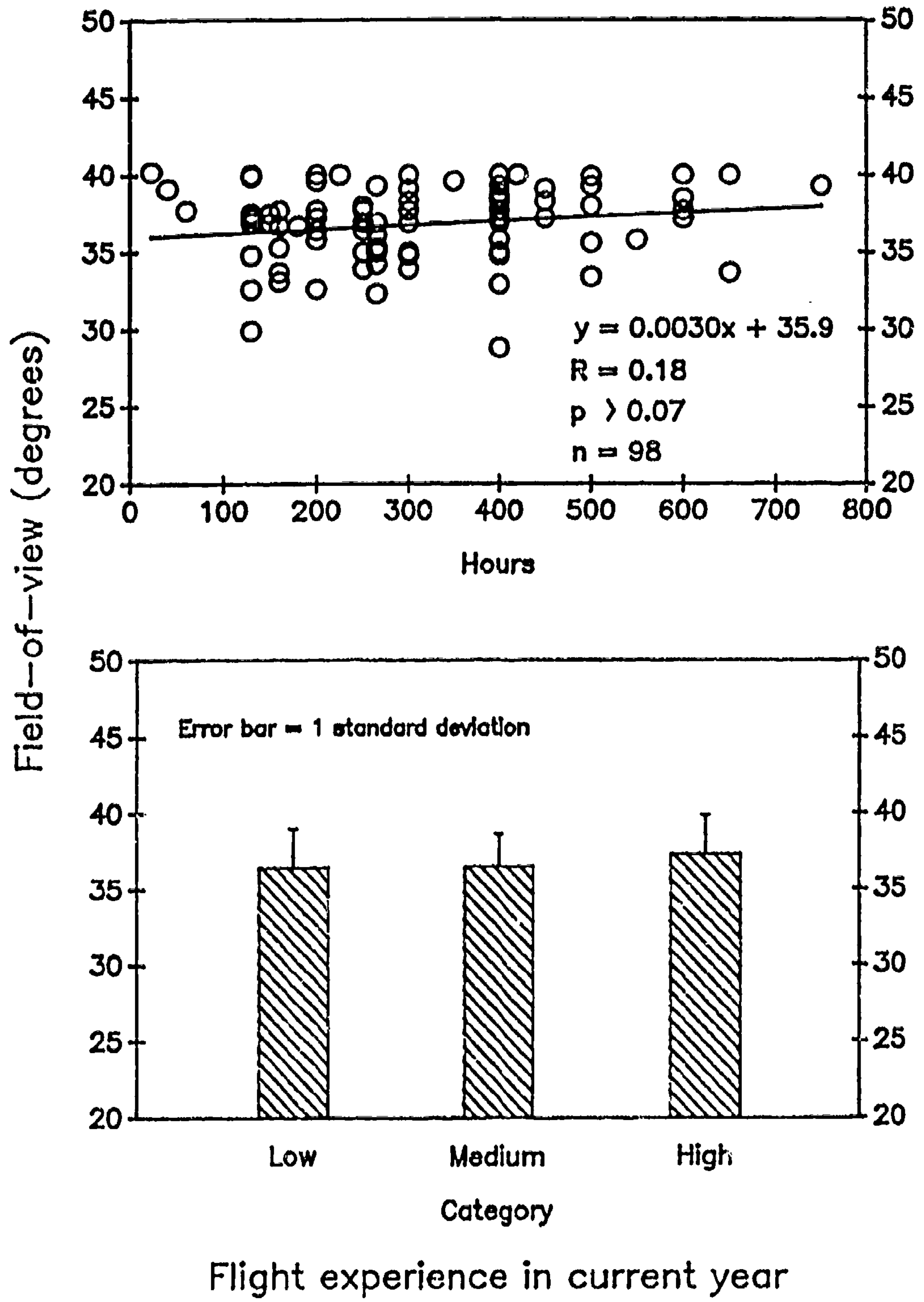

Figure 14. ANVIS in-flight field-of-view based on flight experience in last year.

statistically significant either by one-way ANOVA (df = 1/96, F = 4.06, p = 0.05) or by Pearson's chi-square (df = 1, chi-square = 6.91, p < 0.01). No leveling-off effect is apparent for hours in the last 12 months.

Total night vision goggle flight hours

Figure 15 (top) demonstrates the relationship between total NVG experience (all types of NVGs) and in-flight FOV with ANVIS. The correlation is positive but not statistically significant (p > 0.46). In the bottom graph in Figure 15, total NVG hours are grouped into low, medium, and high categories (Tables 5 and 6). A one-way ANOVA indicated that the differences among the groups are not significant (df = 2/102, F = 2.61, p > 0.07). When total NVG hours are grouped into only low and high categories, the difference between groups is still not significant either by one-way ANOVA (df = 1/103, F = 0.05, p > 0.81) or by Pearson's chi-square (df = 1, chi-square = 0.24, p > 0.62). Thus, total NVG hours do not appear to be related to in-flight FOV with ANVIS.

ANVIS flight hours

Figure 16 (top) demonstrates the relationship between ANVIS hours and in-flight FOV with ANVIS. The correlation is positive but not statistically significant (p > 0.19). In the bottom graph in Figure 16, experience is grouped into low, medium, and high categories (Tables 5 and 6). A one-way ANOVA indicated that the differences among the groups are not significant (df = 2/102, F = 2.35, p > 0.10). When ANVIS hours are grouped into only low and high categories, the difference between groups is still not significant either by one-way ANOVA (df = 1/103, F = 1.83, p > 0.17) or by Pearson's chi-square (df = 1, chi-square = 2.70, p > 0.10). Thus, ANVIS experience does not appear to be related to in-flight FOV with ANVIS.

Aircraft type

Figure 17 gives the relationship between aircraft type and in-flight FOV with ANVIS. A one-way ANOVA revealed that the group means are different (df = 6/98, F = 3.19, and p < 0.001). Multiple comparison tests using the Tukey Studentized range method indicated that crews of both the AH-1 (p < 0.05) and the OH-58A/C (p < 0.05) had smaller FOVs than crews of the UH-1. Pearson's chi-square also suggested that there is a difference in ANVIS FOV by aircraft, when ANVIS FOV is grouped into low and high categories (df = 6, chi-square = 18.07, p < 0.01).

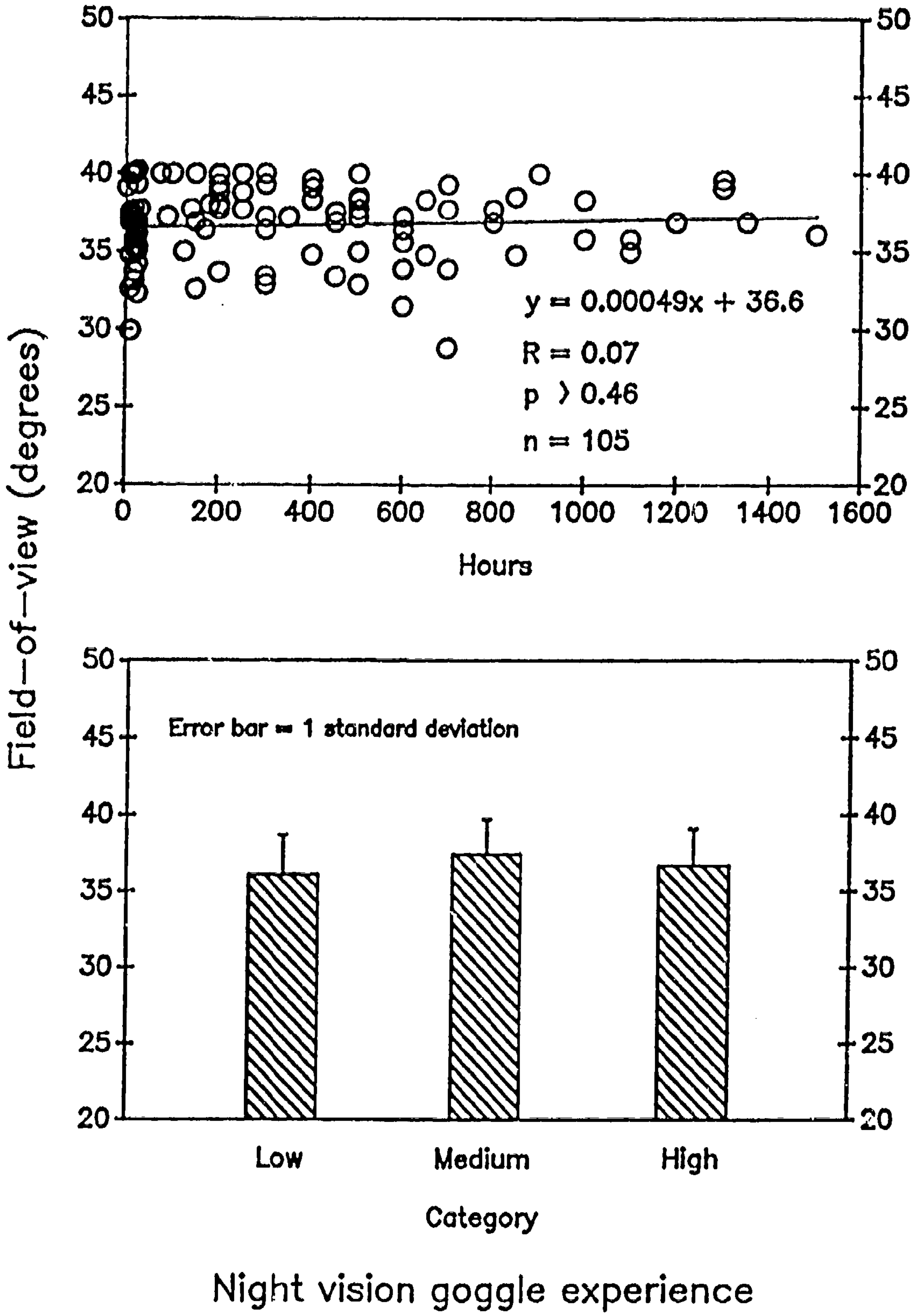

Figure 15. ANVIS in-flight field-of-view based on total night vision goggle hours.

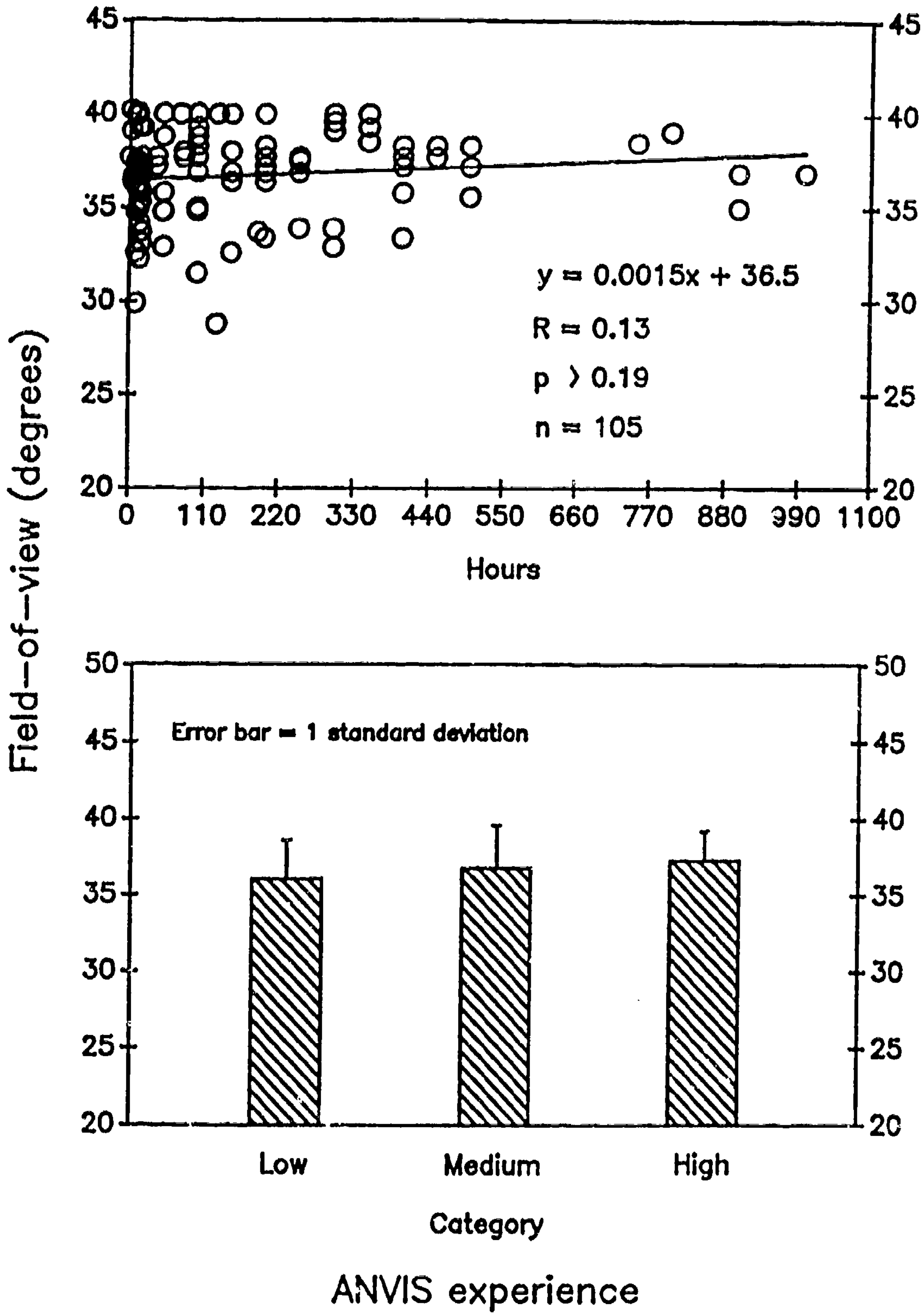

Figure 16. ANVIS in-flight field-of-view based on ANVIS hours.

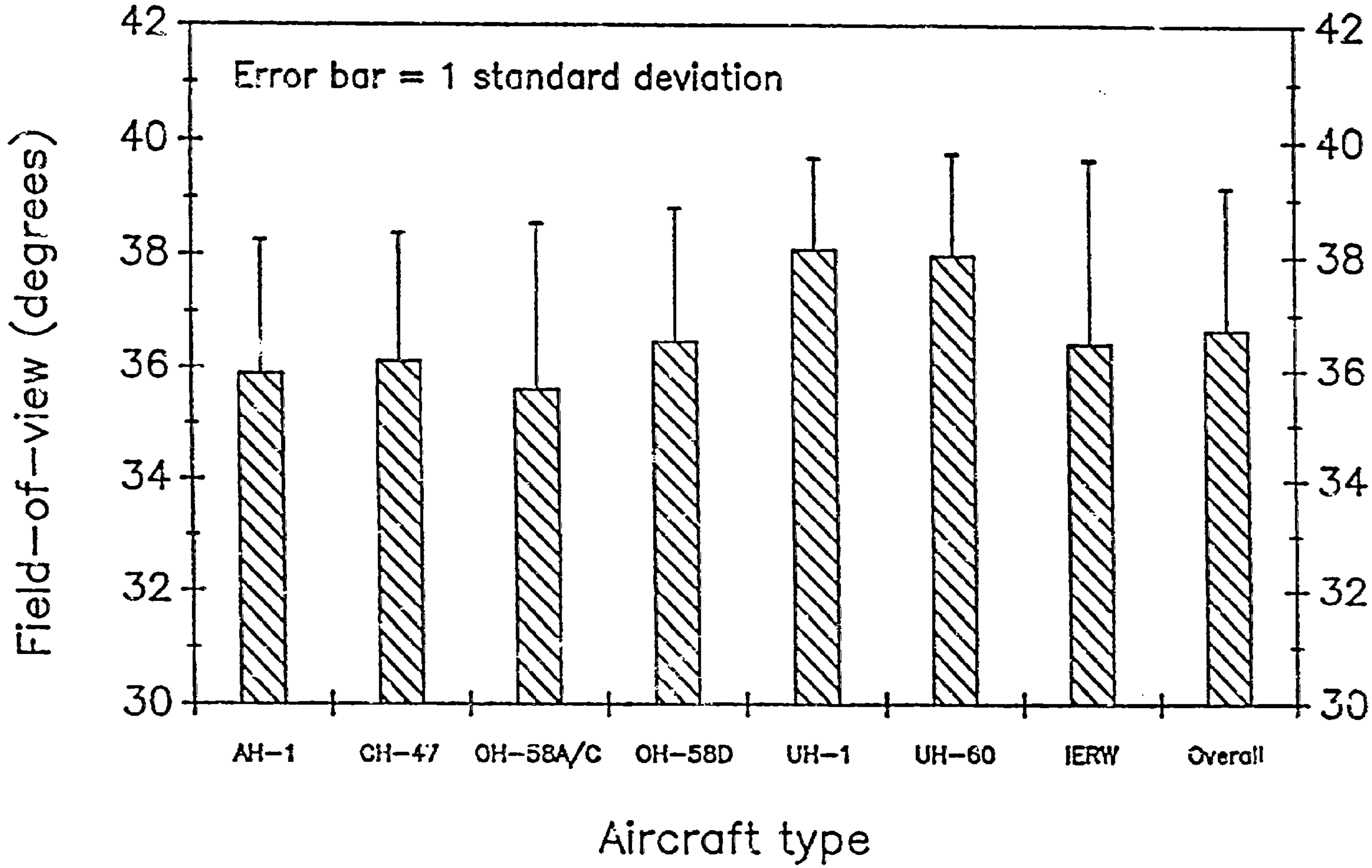

Figure 17. In-flight ANVIS field-of-view based on aircraft type.

Helmet size

Figure 18 gives the relationship between helmet size and in-flight FOV with ANVIS. A one-way ANOVA revealed that the difference between the means is not significant (df = 1/103, F = 3.01, and p > 0.08). Pearson's chi-square pointed to a similar result, when ANVIS FOV is grouped into low and high categories (df = 1, chi-square = 3.48, p > 0.06). Thus, helmet size has little effect on in-flight ANVIS FOV.

Type of helmet liner

Figure 19 gives the relationship between type of helmet liner and in-flight FOV with ANVIS. A one-way ANOVA revealed that the difference between the means is not significant (df = 2/102, F = 0.25, and p > 0.78). Pearson's chi-square pointed to a similar result, when ANVIS FOV is grouped into low and high categories (df = 2, chi-square = 2.00, p > 0.36). Thus, the type of helmet liner has no effect on in-flight ANVIS FOV.

Spectacle use

Of the 14 subjects who wore glasses while flying, 9 did not optimize fore-aft adjustment for FOV (see the paragraph above on fore-aft adjustment selection). Of the nine spectacle wearers who did not optimize for FOV, seven stated that they could not physically select the full-aft position due to interference by the glasses, while the other two stated they would not select the full-aft position even if they did not wear glasses. The seven subjects who reportedly could not select the full-aft position due to glasses had in-flight FOVs that were 6 to 13° smaller than their respective full-aft FOVs (FOVs that could be obtained if glasses were not worn and the full-aft position were selected). Figure 20 gives the relationship between use of glasses and in-flight FOV with ANVIS. A one-way ANOVA revealed that the difference between the means is not significant (df = 1/103, F = 0.00, and p > 0.97). Pearson's chi-square pointed to a similar result, when ANVIS FOV is grouped into low and high categories (df = 1, chi-square = 0.21, p > 0.64). Thus, the use of glasses has no effect on in-flight ANVIS FOV.

Flight experience variables for subpopulations

In-flight FOV was not statistically correlated with any of the five flight experience variables described above, namely total flight hours, hours in current aircraft, hours in last 12 months, total NVG hours, and ANVIS hours. However, some correlations could have been masked due to the combining of subpopulations. To uncover possible masking, correlations

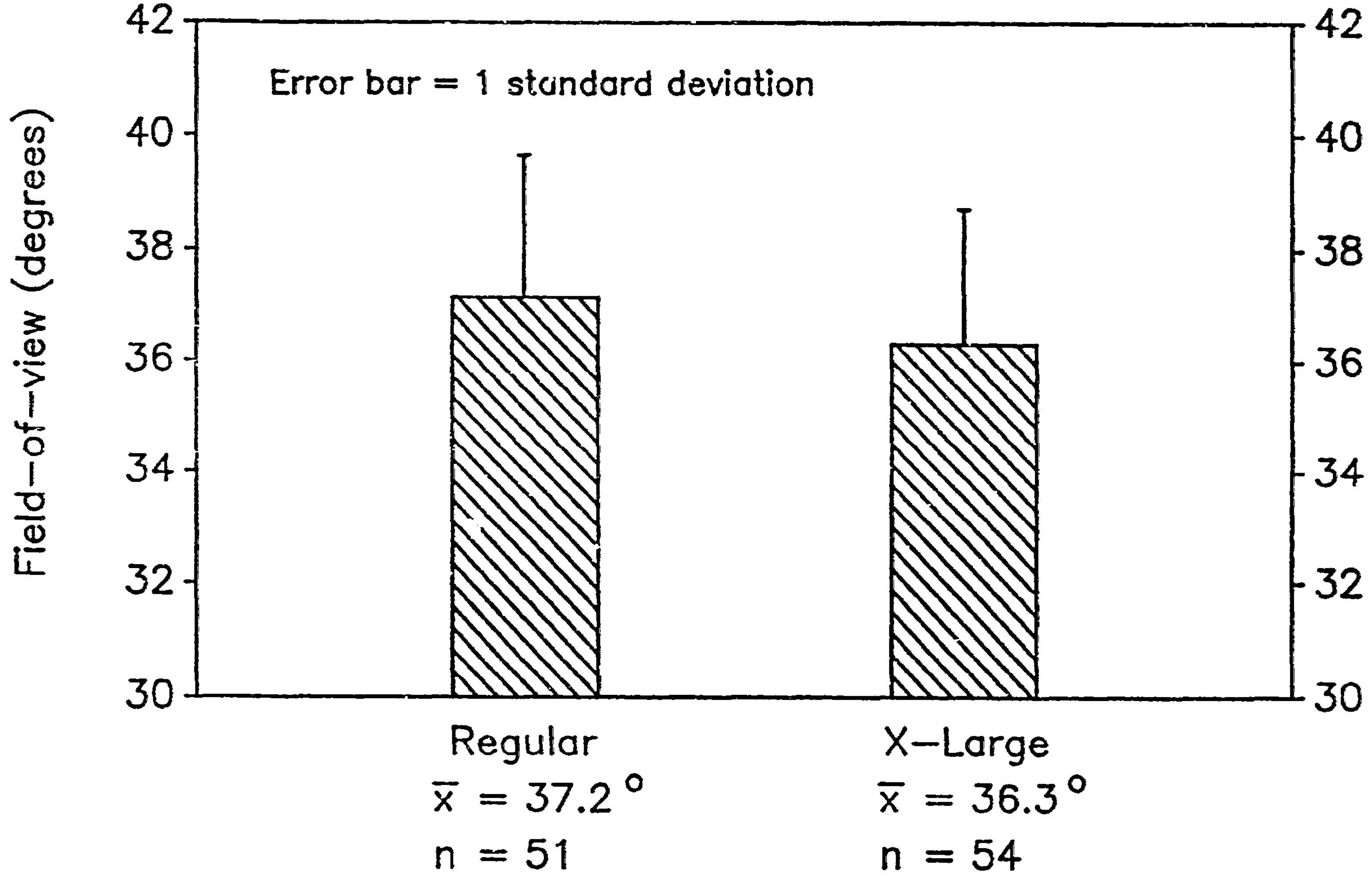

Figure 18. In-flight ANVIS field-of-view based on helmet size.

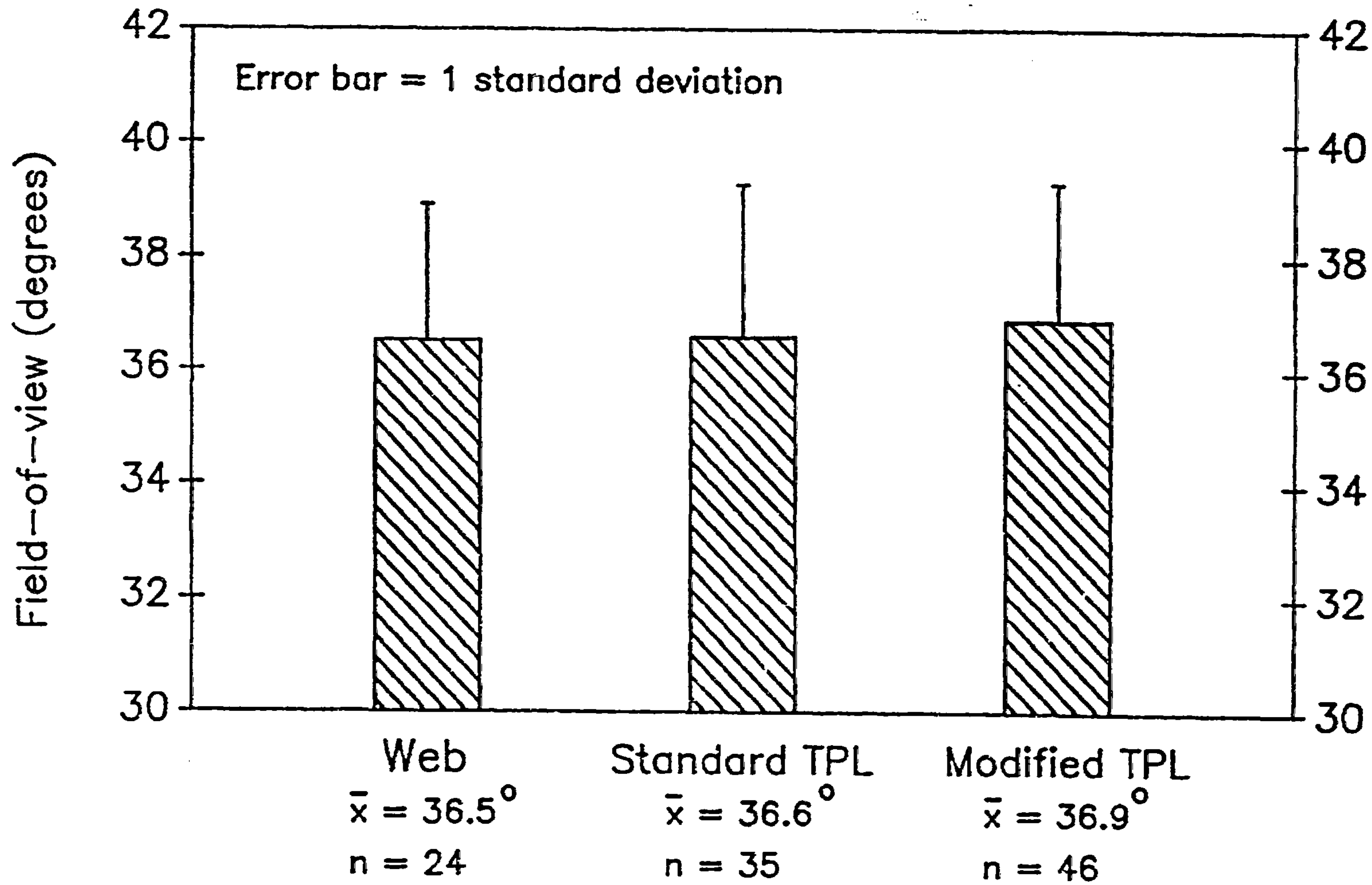

Figure 19. In-flight ANVIS field-of-view based on type of helmet liner.

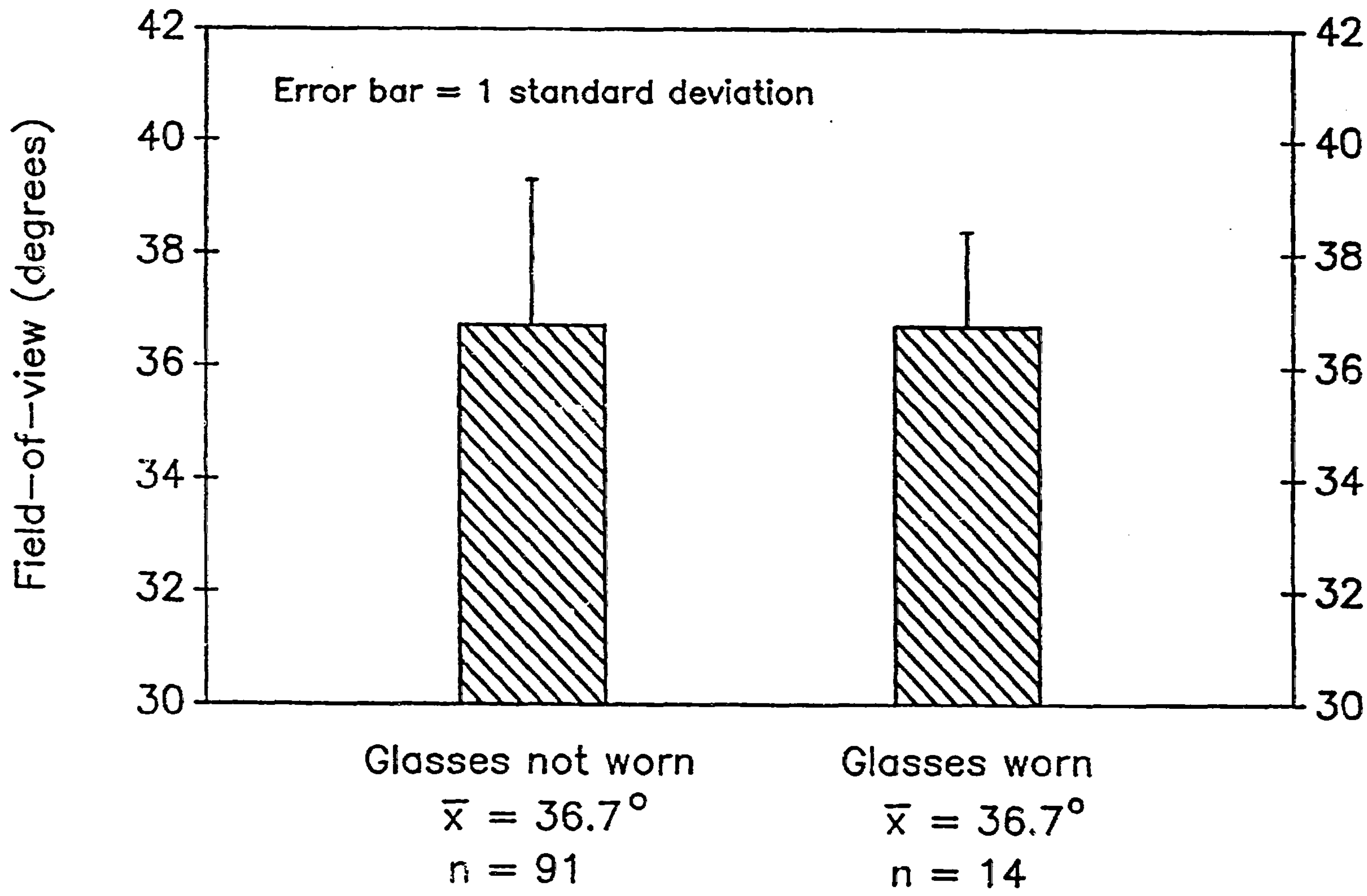

Figure 20. In-flight ANVIS field-of-view based on use of glasses.

between in-flight FOV and the five flight experience variables were tested separately for each of four subpopulations, i.e., aircraft type, helmet size, helmet liner, and use of glasses. In-flight FOV was found to be positively correlated with flight hours in the last 12 months for AH-1 aviators ($p < 0.03$), and for users of the standard web helmet liner ($p < 0.01$). Surprisingly, it was found that for UH-60 pilots, in-flight FOV was **negatively** correlated with total flight hours ($p < 0.03$). (The correlation between in-flight FOV and total flight hours increases from $R = 0.14$ to $R = 0.19$, and the p value decreases from 0.15 to 0.07 when UH-60 aviators are deleted from the rest of the sample.)

Factors that influence selection of full-aft position

An analysis was done to determine whether any of the measured independent variables were associated with the selection of the full-aft position of the ANVIS helmet mount (Figure 10). It was learned that aviators with low NVG hours tended to select the full-aft position more often than those with high hours (df = 1, chi-square = 3.87, $p < 0.05$). Also, non-spectacle wearers tended to select the full-aft position more often than spectacle wearers (df = 1, chi-square = 18.32, $p < 0.0001$). The difference between spectacle wearers and non-spectacle wearers was probably caused by the glasses physically limiting the aft travel of the ANVIS eyepieces (based on comments provided by the subjects).

Discussion

The main purpose of this study was to investigate the prevalence of FOV restrictions with ANVIS. Unfortunately, no criterion exists for what actually constitutes a reduced ANVIS FOV. Therefore, the prevalences associated with various candidate criteria are provided (Table 7). According to the strictest criterion, which is any amount less than 40°, the prevalence is 85 percent. Of course, the prevalence declines with less stringent criteria. However, even with the fairly lenient criterion of FOV less than 37°, the prevalence is still 38 percent. Table 7 also provides the percent of FOV area lost for each criterion. It is significant that, because FOV area decreases with the square of the radius, a 3° reduction in FOV diameter brings about a 19 percent reduction in area.

The results of this study are in close agreement with those of other works. The mean in-flight ANVIS FOV of $36.7 \pm 2.5°$ (n = 105) of the present study is virtually identical to the analogous measurement by Osterlund et al. (1991), which was $36.5 \pm 1.9°$ (n = 19). The two means do not differ statistically (df = 122, T = 0.41, $p > 0.68$). In addition, the mean full-aft FOV of $37.2 \pm 2.4°$

Table 7.

Prevalence of field-of-view restrictions

Based on various criteria

Criterion (degrees)	FOV area ($degrees^2$)	Area lost from full FOV (percent)	Prevalence (percent)
< 40	≤ 1195	≥ 5	85
< 39	≤ 1134	≥ 10	74
< 38	≤ 1075	≥ 14	58
< 37	≤ 1018	≥ 19	38
< 36	≤ 962	≥ 23	30
< 35	≤ 908	≥ 28	19
< 34	≤ 855	≥ 32	12
< 33	≤ 804	≥ 36	5
< 32	≤ 755	≥ 40	2

(n = 105) of the present work does not differ significantly from the analogous value of 36.0±0.0° (n = 2) from the pilot study by Kotulak and Frezell (1991) (df = 105, T = 0.72, p > 0.47). The mean in-flight vertex distance of 23.4±4.9 mm (n = 105) of the present study is similar to the analogous measurement from Osterlund et al. (1991), which was 23.3±3.6 mm (n = 19) (Figure 21). The two means do not differ statistically (df = 122, T = 0.08, p > 0.93). Also, the mean full-aft vertex of the UH-60 aviators from the present study, which was 20.2±3.7 mm (n = 16), does not differ significantly from a matched sample from McLean (1991), in which the mean was 18.5±5.0 mm (n = 8) (df = 22, T = 0.57, p > 0.57).

The FOV loss described above is purely the result of excessive vertex distance, and is not related to manufacturing tolerances or product defects. The ANVIS monocular that was used in the laboratory portion of this study had essentially a 40° FOV under optimal conditions (39.7±0.4° at a vertex distance of 17 mm). However, because the manufacturing specification for ANVIS FOV is 40±1° (Markey, 1992), not all ANVIS units can be expected to provide FOVs this large. Furthermore, it is not known whether a multiplicative effect would occur if an ANVIS unit with an inherently reduced FOV were subjected to excessive vertex distances. Fortunately, a sample of fielded monoculars (n = 10) revealed that the mean optimal ANVIS FOV is 39.8±0.5° (Walsh, 1989), suggesting that the occurrence of FOV reductions due to manufacturing tolerances and product defects is unusual.

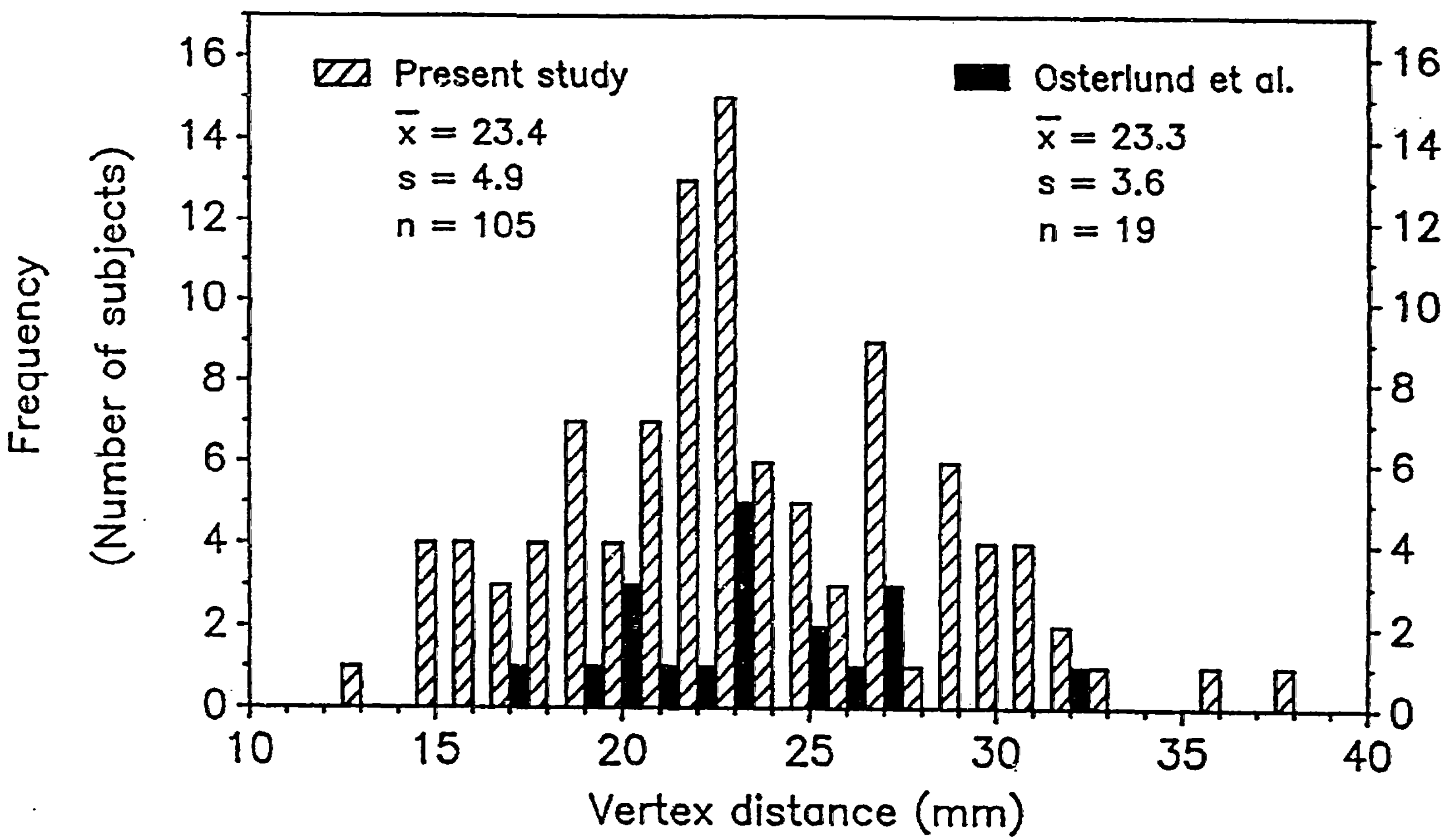

Figure 21. Distribution of in-flight ANVIS vertex distances comparing the results of the present study to Osterlund et al. (1991).

The results of the current study, which were obtained from aviators using the SPH-4 flight helmet, are expected to pertain to the newer SPH-4B helmets as well. McLean (1991) has shown that mean full-aft vertex distance varies by only about 1 mm between the dual-visor SPH-4B and the current helmet.

Figure 11 shows the distributions of in-flight and full-aft ANVIS FOVs. Because aviators overwhelmingly set the fore-aft adjustment to maximize FOV (Figure 10), these two distributions are quite similar. Therefore, the solution to the ANVIS FOV problem must come mainly from hardware improvements, as opposed to changes in training or doctrine.

Either of two hardware modifications, which are not mutually exclusive and which rely on existing technology, could be used. Neither would increase ANVIS FOV beyond 40°, but both would allow a substantial number of aviators to gain additional FOV. The first option is to extend the range of the ANVIS helmet mount fore-aft adjustment in the aft direction. Figure 22 (top) shows the distribution of in-flight FOVs that would result from an additional 7 mm of aft adjustment range. This option would not benefit aviators who have legitimate reasons for not selecting the maximum-aft position, e.g., those who wear protective masks or glasses. The second option is to replace the existing 18 mm ANVIS eyepiece with a 25 mm eyepiece. Figure 22 (bottom) provides the distribution of in-flight FOVs that would result from this option. The 25 mm eyepiece would have a more pronounced effect on the in-flight FOV distribution than improving the fore-aft adjustment range because it would benefit a greater number of aviators, even those who do not select the full-aft position. Figure 23 provides a side-by-side comparison of the in-flight ANVIS FOV distributions associated with existing hardware and the two modifications discussed above.

Another purpose of this study was to examine epidemiological factors that might be associated with reduced in-flight ANVIS FOV. The epidemiological evaluation was intended to determine whether certain subpopulations of aviators were more prone to reduced in-flight ANVIS FOV than others, and possibly suggest new ways in which FOV could be optimized. Data was collected on nine epidemiological variables, of which five dealt with flight experience, and four with equipment usage.

Three of the five flight-experience variables were found to be statistically related to ANVIS in-flight FOV, namely total flight hours, hours in current aircraft, and hours in last 12 months (Figures 14, 15, and 16). Total NVG hours and ANVIS hours were found not to be related to ANVIS in-flight FOV (Figures 17 and 18). For all three of the variables that are related to ANVIS FOV, less experienced aviators tend to have smaller FOVs

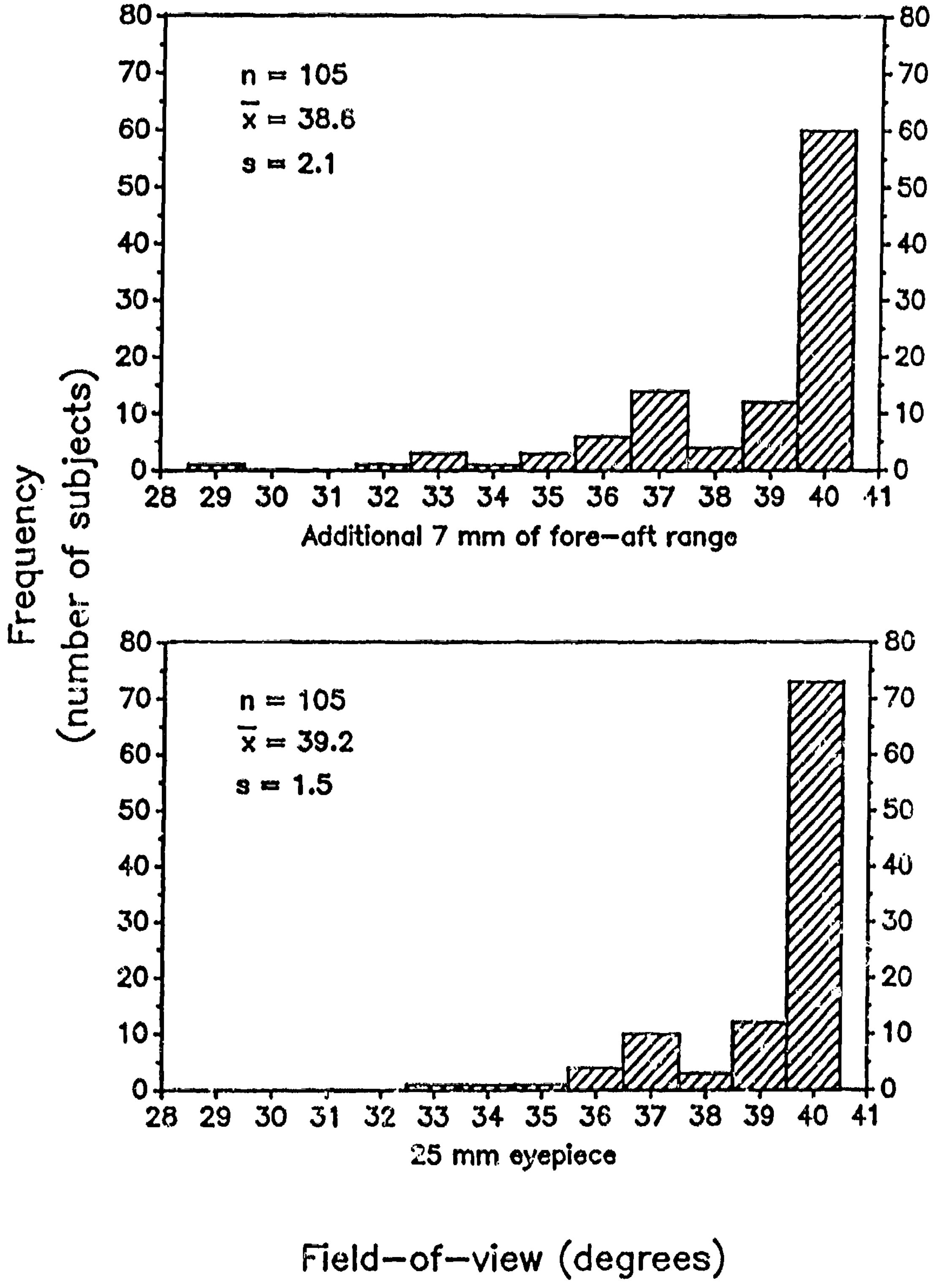

Figure 22. Distribution of in-flight ANVIS fields-of-view assuming enhanced fore-aft adjustment range (top) and 25 mm eyepiece (bottom).

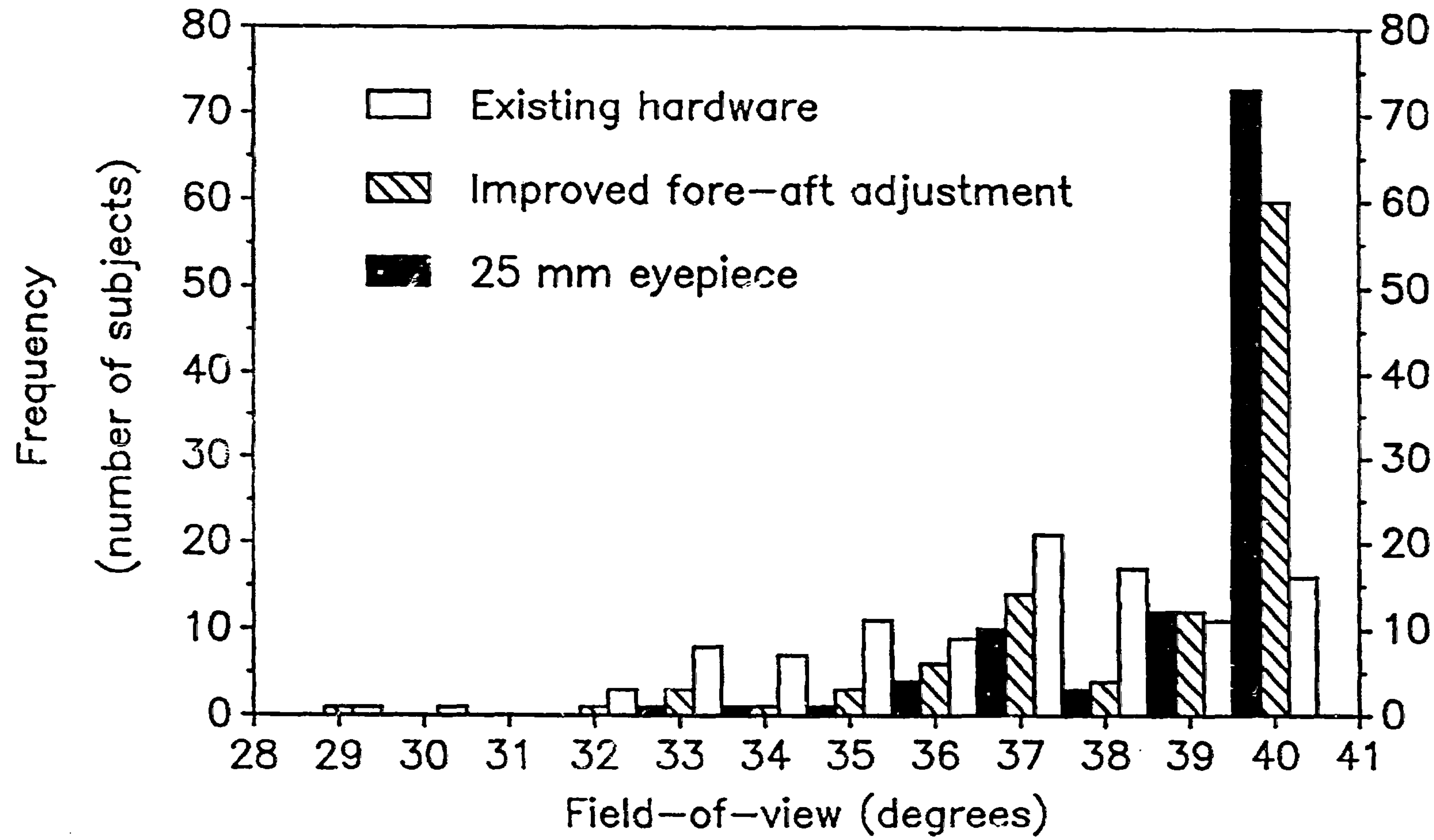

Figure 23. Distribution of in-flight ANVIS fields-of-view comparing present hardware to two proposed modifications.

than more experienced ones, up to some limiting experience level that is specific to the variable in question.

Only one of the four equipment variables was found to be related to in-flight ANVIS FOV, namely type of aircraft (Figure 17). Helmet size, type of liner, and use of glasses are not related to in-flight ANVIS FOV (Figures 20, 21, and 22 respectively). Both AH-1 and OH-58A/C aviators have smaller FOVs than UH-1 aviators. The likely cause of the FOV reduction among AH-1 pilots is the use of a peculiar ANVIS mount (the "V2" mount), which does not have as much travel in the aft direction as the standard mount (the "V1" mount) that is used for all other aircraft. The mean full-aft vertex distances for the V1 and V2 mounts are 21.8 ± 4.7 and $25.1 \pm 4.7^{\circ}$ respectively, and these means are statistically different (df = 103, T = 2.82, $p < 0.01$). The situation is less clear for the OH-58A/C aviators, but the cause may be related to optimization of look-under/look-around viewing. It is consistent with the mission of scout helicopters to place a high priority on look-under/look-around capability. Viewing with the unaided human eye may be deemed more necessary in the low-technology OH-58A/C scouts than in the OH-58D scout, which is equipped with an array of sophisticated sensors not present in the A/C models.

The statistically significant association between less flight experience and smaller in-flight ANVIS FOVs is puzzling, if one assumes that this effect is mediated by poor adjustment technique, i.e, it seems reasonable that less experienced aviators would tend to be less skillful at adjusting the ANVIS fore-aft position than more experienced aviators. In actuality, the selection of fore-aft position does not vary with flight experience, e.g., the mean in-flight fore-aft position (relative to full-aft) of aviators with low total flight hours (0.6 ± 2.0 mm) is statistically no different than the mean of aviators with medium total flight hours (1.3 ± 2.8 mm) (df = 67, T = 1.12, $p > 0.26$). Therefore, the variation of in-flight FOV with experience must be independent of fore-aft adjustment decisions, and consequently must be related to how much FOV is available at the full-aft position. By exploring the interactions between total flight hours and the equipment-related independent variables, it was found that full-aft FOV is smaller for wearers of unmodified TPL helmet liners with low experience than for wearers of these liners with medium experience ($p < 0.01$ by both the Tukey Studentized range method and the Student-Newman-Keuls multiple range test). This suggests that aviators with reduced ANVIS FOVs and unmodified TPLs tend to obtain modifications (removal of layers or heating) before they reach the medium experience level (1300 total flight hours), and that aviators with satisfactory FOVs and unmodified TPLs tend not to obtain such modifications.

The operational significance of the reductions in ANVIS FOV is not fully understood. However, it is known that FOVs less than 40° could be detrimental to at least some aviator tasks (Wells, Venturino, and Osgood, 1988; Wells and Venturino, 1989; Wells, Venturino, and Osgood, 1989; Wells and Venturino, 1990; Osgood and Wells, 1991). Dixon et al. (1989) reported that FOVs much larger than 40° were required for certain tactical aviation maneuvers. Army aviators, who have participated in Operations Desert Shield and Desert Storm, have identified limited FOV as the biggest problem with existing NVGs (Gillespie, 1991).

A potential source of error in this study is the precision to which the relationship between FOV and vertex distance can be measured. Although the psychophysical data that relate these two variables are monotonic and exhibit little intersubject variability (Figure 8), their mathematical description is open to interpretation. A linear model closely fits the data, but such a model does not reveal at what point the function changes its shape from flat (the region where vertex distance is less than the eye relief distance) to sloped (the region where vertex distance is greater than the eye relief distance). One could argue that the 22 mm data point is already in the flat region of the function, and that the regression line should be drawn as in Figure 24 (omitting the 17 mm data point). In such a case the eye relief distance would be 18.4 mm, as opposed to 17.2 mm with the current model (Figure 8). In addition, the mean in-flight FOV would increase from 36.7° in the current model to 37.2°. Fortunately, such changes are too small to have a significant impact on the study. The present model (Figure 8) was chosen because FOV is still changing between 17 and 22 mm, which suggests that the threshold does not occur at or near 22 mm. A univariate repeated measures ANOVA with contrasts indicated that the FOV at 17 mm ($39.7 \pm 0.4°$) is statistically greater than the FOV at 22 mm ($39.1 \pm 0.7°$) ($df = 1/19$, $F = 13.4$, $p < 0.002$).

Another potential source of error in this study is the precision to which the eye can be aligned with the ANVIS eyepiece lens. If the eye were misaligned vertically, then the horizontal FOV would be truncated. A horizontal misalignment could also reduce the horizontal FOV by causing vignetting on the side opposite to the displacement. It is possible to build a laboratory apparatus that would insure a high degree of alignment accuracy. However, if one is interested in extrapolating from laboratory data to FOVs obtainable under operating conditions in the field, one is probably better off aligning the eye with a field alignment technique. This is what was done in the present study.

Finally, unequal vertex distances between the two eyes posed a problem in reporting FOV, e.g., the in-flight FOV differs between the two eyes by an average amount of $1.0 \pm 0.8°$, based on the in-flight vertex distance asymmetry of 1.8 ± 1.4 mm (as explained above in the paragraph labeled "in-flight vertex distance" in the results). The problem was solved by within-

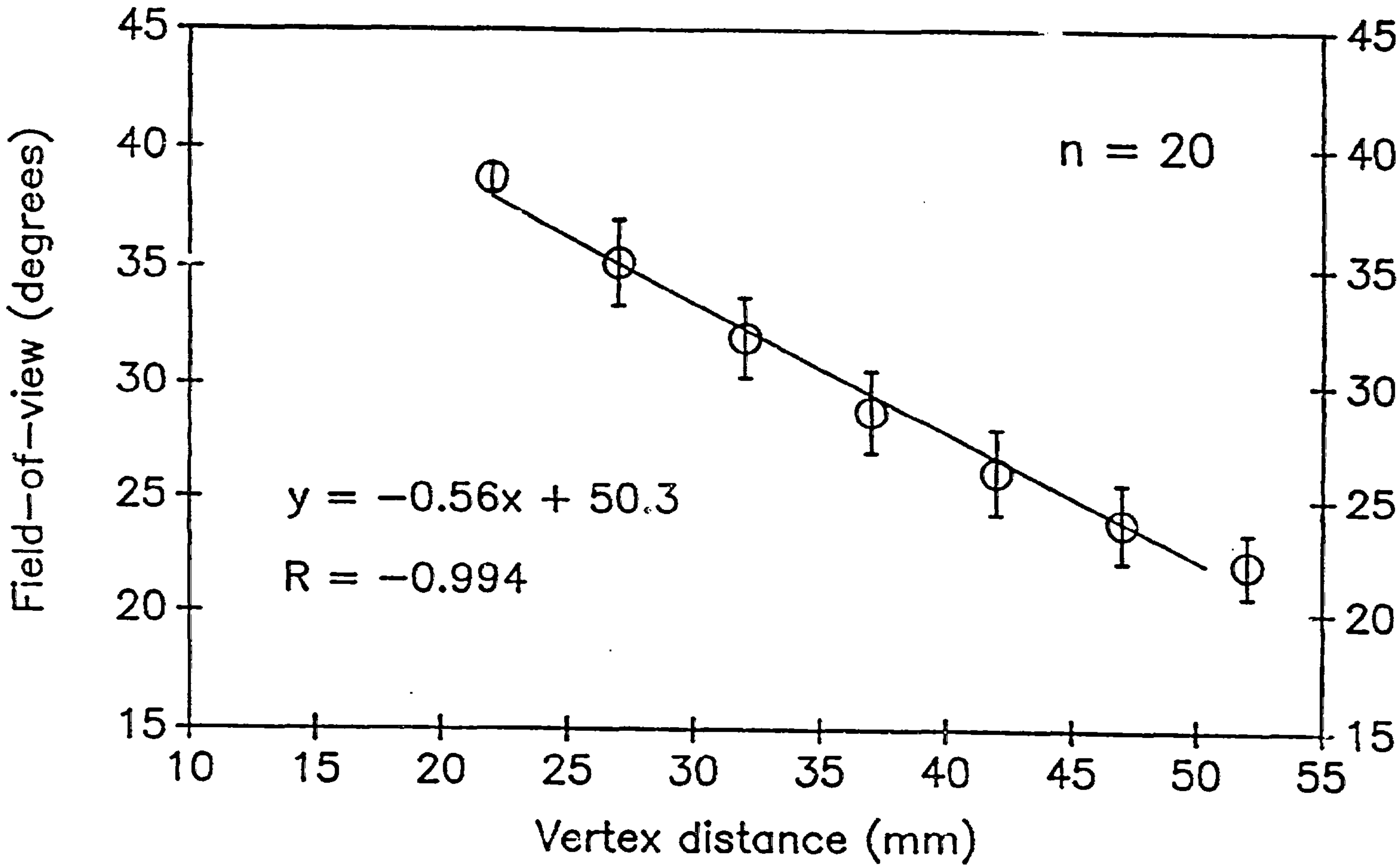

Figure 24. Relationship between ANVIS field-of-view and vertex distance, omitting data for 17 mm vertex distance.

subject FOV averaging between the two eyes, although this does not precisely represent the consequences to visual perception of the FOV asymmetry. From the observer's perspective, the smaller FOV defines the region where objects are seen simultaneously by the two eyes, i.e., the region of binocular overlap. The larger FOV, on the other hand, defines the size of the total FOV, which in addition to the binocular region contains the region where objects are seen by one eye or the other but not by both simultaneously, i.e., the monocular region. For example, if an observer has a 37° FOV in one eye and a 38° FOV in the other, the region of binocular overlap would be 37° and the total FOV would be 38°. The monocular region would be 1°.

Conclusions

1. ANVIS FOV is typically less than 40° in flight.

2. In-flight ANVIS FOV is reduced mostly because of equipment limitations, and not because of user misadjustments. Specifically, the fore-aft adjustment of the ANVIS helmet mount lacks sufficient range in the aft direction, given the eye relief distance of the current ANVIS eyepiece.

3. Among the epidemiological factors studied, only total flight hours, hours in current aircraft, hours in last 12 months, and aircraft type are statistically related to in-flight ANVIS FOV. Total night vision goggle flight hours, ANVIS flight hours, helmet size, type of helmet liner, and spectacle use are not related to in-flight ANVIS FOV.

4. Most aviators could achieve a 40° FOV if either of two hardware modifications were made: extending the ANVIS fore-aft adjustment range by 7 mm in the aft direction, or by switching to a 25 mm eyepiece. The latter option would benefit more aviators.

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<u>Appendix A</u>

Tasking document

DEPARTMENT OF THE ARMY
HEADQUARTERS UNITED STATES ARMY AVIATION CENTER AND FORT RUCKER
FORT RUCKER, ALABAMA 36362-5000

REPLY TO
ATTENTION OF:

ATZQ-CDM-ES (70-1i)

9 OCT 19[illegible]

MEMORANDUM FOR Commander, U.S. Army Aeromedical Research Laboratory, SGRD-UAS-VS, Fort Rucker, AL 36362-5292

SUBJECT: Increased Field-of-View and Improved Resolution in Night Vision Devices

1. Reference memorandum, SGRD-UAS-VS, undated, subject as above.

2. The Directorate of Combat Developments (DCD) requests the U.S. Army Aeromedical Research Laboratory provide the prevalence of aviators affected by the reduction in night vision goggles field-of-view. I would like to obtain a copy of the evaluation report or study that resulted in your recommendation for night vision goggle improvement.

3. The DCD points of contact for night vision systems are Mr. O'Donnell or Mr. Mason, DSN 558-3973/4872.

FOR THE COMMANDER:

THEODORE T. SENDAK
Colonel, Aviation
Director of Combat Developments

Appendix B

List of manufacturers

Gentex Corporation
Optical Products Group
P.O. Box 315
Carbondale, AP 18407

Appendix C

Field study data collection sheet

Subject No.__________ Date__________ Location__________

---

1. Flight hours total __________
2. Flight hours in current aircraft __________
3. Flight hours in last 12 months __________
4. NVG hours __________
5. ANVIS hours __________
6. Aircraft model __________
7. Helmet size __________
8. TPL (standard) vs TPL (modified) vs web __________
9. Glasses __________
10. Vertex distance:

	R	L
a. As worn	__________	__________
b. Best case	__________	__________

11. If 10a not equal to 10b, give reason (check one box):

__________ Look under

__________ Safety

__________ Concern about closeness (other than safety)

__________ Glasses

__________ Unaware of relationship between vertex distance and FOV

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Fort Monmouth, NJ 07703

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Fort Monmouth, NJ 07703-5304

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Technical Information Division
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Logistics School ATTN: ATSQ-TDN
Fort Eustis, VA 23604

Headquarters (ATMD)
U.S. Army Training
and Doctrine Command
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Director, Institute of Aviation
University of Illinois-Willard Airport
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Chief, Nation Guard Bureau
ATTN: NGB-ARS (COL Urbauer)
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4501 Ford Avenue
Alexandria, VA 22302-1451

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U.S. Army Aviation Systems Command
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U.S. Army Aviation Systems Command
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Product Manager
Aviation Life Support Equipment
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