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SUMMARY

The use of a hand-held sextant for the acquisition of navigational information in space flight may be a practical and economical method for providing an emergency or supplemental navigation mode. The present study was designed to investigate the effects of telescope objective lens diameter, aperture stop diameter, and magnification on the variability of a set of angular measurements made with a conventional marine sextant. Performance, in terms of sighting variability, improved monotonically with increasing telescope powers. Reductions in both objective lens size and aperture size were also associated with improved performance. Subjects varied significantly in their sighting ability; subjects who had the poorest performance were helped most by higher magnifications. Performance changes due to magnification changes were dependent upon the objective lens size used. Performance changes due to changes in objective lens size depended upon the aperture size.

INTRODUCTION

In marine navigation the sextant has been a primary and accurate device for acquiring angular data with which to derive lines of position and fixes. Extreme accuracy, however, in terms of, say, yards, rather than miles, has not been required because of landfall techniques and the availability of terminal navigational aids. When the use of a hand-held sextant is considered for navigation across the great distances of space, the more stringent accuracy requirements must be kept in mind. For a good discussion of these requirements see reference 1. The factors affecting sextant sighting accuracy must be explored. If the important variables can be identified and their effects quantified, the design of a space sextant can be simplified considerably. Also, as study of the sextant proceeds, the detailed task requirements will become known and techniques for training and operational use of the device will be clarified.

The present study is one of a series (refs. 1-4) of studies conducted at Ames Research Center to explore the feasibility of using a conventional marine sextant for the acquisition of back-up or emergency navigation data in space and in other tasks that require angle measurements. It is a study concerned only with telescope factors. To "isolate" these factors, the sextant was installed in a controlled laboratory setting with optical simulation of targets. The sextant vernier (fine setting) knob was fitted with a digital shaft encoder and the measured angle was displayed with a resolution of 1 second of arc. The sextant was gimbal mounted with two degrees of freedom, one in the measurement plane and one about the optical axis of the instrument (ref. 3).

The primary objective of the present study was to provide answers to the following questions:

(a) Does increasing the power of the sextant telescope beyond the powers currently available improve performance? If so, to what extent?

(b) Since target brightness in space may be high, some attenuation may be tolerated: Will aperture stops placed in the optical system to increase depth of focus and limit aberration-producing oblique rays improve accuracy?

(c) Without aperture stops, what is the effect upon performance of changes in the diameter of the objective lens?

To answer these questions, especially designed telescopes were fabricated with which the three variables of interest could be independently varied. These were:

(a) Magnification

(b) Aperture stop diameter

(c) Objective lens diameter

EXPERIMENTAL PROCEDURE

Sighting Task

The subjects saw two simulated stars in the sextant field of view. (See fig. 1.) Their task was simply to bring the two stars into coincidence by adjusting the vernier or fine control knob on the sextant. One star, the reference star, remained stationary in the center of the telescope field, corresponding to the horizon seen through the telescope when the sextant is used in marine sightings (for a full discussion of the use of the marine sextant see refs. 5 and 6). The other star, imaged in the telescope by the index mirror, was moved toward this reference star in one direction only. No reversals of direction were allowed in making the final coincidence setting so as to prevent an increase in the sighting error due to gear backlash in the sextant. If the subject moved this "secondary" star beyond the reference star in the allowed direction, the trial was considered void and he separated the two stars and began that trial anew. This movement of the secondary star to a reference position in the telescope field of view corresponds to the placing of a celestial target on the sea horizon in marine sighting (refs. 5 and 6).

When the stars were coincident the subjects rotated the sextant around the line of sight axis, making the secondary star describe an arc through the stationary reference star. This provided a check on the coincidence; with practice these two task elements were performed simultaneously in making the final setting.

When the subjects were satisfied that they had achieved coincidence of the two stars, they pressed a button that activated recording equipment, and the angle they had measured was printed on paper tape. They then rotated the vernier control knob and rotated the index mirror so that the star observed in the telescope field of view through the secondary line of sight moved away from the star observed through the primary line of sight. The experimenter monitored a digital display of the sextant angle and informed the subject when he had sufficient angular distance between the two stars for a new trial to begin. The angular distance selected was 5 arc minutes or 300 seconds on the digital display.

Experimental Variables

In a pilot study with the two telescopes and one monocular (1/2 of prism binocular) supplied with the marine sextant, it was found that sighting variability was a monotonically decreasing function of magnification. The higher the magnification the less was the variability of performance as indicated by the standard deviation of the sighted angles. Figure 2 shows this relationship. The two telescopes were 2.5× and 4.0×; the monocular was 6.0×. Also, see figure 22 in reference 2 where similar results are reported for using the sextant in a larger task context than in the study reported herein.

However, in these studies, while magnification was changing, there was no control over other optical factors that were also changing, such as the diameter of the objective lens. The objective lens diameter determines the diffraction limit of the telescope and, hence, its resolution limits. It was desired, therefore, in the present study, to control these variables independently.

In addition to evaluating magnification and objective lens diameter independently, a third independent variable was included. This was the use of a decreasing telescope aperture diameter to restrict passage of oblique rays and, thus, to increase resolution by: (a) limiting the size of the out-of-focus blur circle in the vicinity of the focal plane of the system and (b) stopping oblique rays which, according to third-order theory in geometrical optics, are responsible for the following aberrations: coma, astigmatism, curvature of field, and distortion. Spherical and chromatic aberration affect the whole field. (See ref. 7.)

Equipment

Telescopes.- The telescopes were especially fabricated for this study. From an appropriate selection of commercially available lenses it was possible to assemble telescopes in which any one of the three optical components of interest could be varied independently of the other two. Three tubes were made, each with a different objective lens diameter. Each tube could be fitted with one of four oculars to yield four different magnifications, and also with three apertures over the objective lenses. Table I shows the values of the three variables. A, B, and C are the objective lens diameters. I, II, and III are the various aperture diameters. The magnification varied both within and between objective lens sizes (AI5, BI5, CI5) because of the limited range of values for the commercially available oculars. However, there is not a serious departure in any case from nominal values of 4.5×, 8.0×, 14.0×, and 20.0×; and, in this report, these values will be used. Figure 3 shows one of the telescope tubes mounted on the sextant. Figure 4 shows the telescope and the monocular supplied with the sextant.

Simulated stars.- To simulate the stars a grain-of-wheat lamp was placed behind a 0.0005-inch-diameter aperture at the focal point of a spherical mirror, providing a collimated point source. The mirror and point source were mounted in a tube, the length of which was determined by the focal length of the mirrors. Two of these were then mounted on a steel frame and directed toward the mounted sextant (see fig. 5). Varying the voltage across the grain-of-wheat lamps varied the intensity and, thus, the magnitude of the simulated stars. For this study they remained constant at approximately +1.0 visual magnitude.

Sextant.- The sextant was mounted on gimbals which allowed rotational displacement about the primary line of sight (fig. 1). Also, the arm on the limb of the sextant attached to the indexing mirror could be adjusted by rotation of the vernier knob. All other axes were fixed.

Attached to the vernier knob was a digital shaft encoder which had 3600 counts per revolution of the vernier knob (see fig. 3). When the knob was turned one full revolution, the sextant measured one degree of arc or 3600 seconds. The resolution of the encoder was thus 1 second of arc. For comments on the reliability of this measuring device, see reference 3.

Experimental Design

The present experiment was particularly suited to the analysis of variance experimental design. The three variables of interest always occur together in a telescope: There is always an objective lens with an associated diffraction limit; there is always an aperture with certain aberration restricting characteristics that affects the depth of focus; and there is always a magnification with its beneficial increases in image size and adverse effects due to increases in image motion (although in this study image motion was not a factor).

It was desired to know what effects the three variables by themselves and in combination would have on performance. The analysis of variance provides this information in quantitative terms. The analysis of variance in psychological research is discussed in reference 8. The application used in this study is discussed on page 156. (Also, on previous pages of that reference, the rationale for the use of the F-ratio as a test statistic is clearly explained.)

There were four telescope magnifications, three objective lens diameters, and three aperture stop diameters. Thus there were $4 \times 3 \times 3$ or 36 conditions under which each subject sighted. Since each subject sighted twice under each of these conditions, there were 72 sessions for each subject. In one sighting session only one of the conditions was given to the subject. There were ten subjects each of whom was given three sessions (conditions) per day. The order of presentation of the conditions was randomized to nullify serial effects. A single subject, then, would sight three times a day (under three conditions) and in 24 days would have sighted twice under each of the 36 conditions.

Each subject took 16 sightings under each condition. A mean and a standard deviation were computed from the 16 measurements. The standard deviation, σ, a measure of dispersion and, thus, a measure of repeatability or reliability of the sightings, was the criterion measure for the conditions of the study. See appendix A for a discussion of the use of this measure as the criterion variable rather than the mean.

Since each subject sighted twice under each condition, a measure of the subject treatment interaction was available (see ref. 8, p. 156). A subject treatment interaction would exist here if, say, magnification improved performance <u>more</u> with the "poorer" subjects than with the "better" subjects. One could then conclude that sextant sighting performance could be improved either by the selection of "good" observers or, if that is not possible, by the selection of higher magnifications.

The subjects were male undergraduate students at nearby colleges. Their visual acuity was normal (Snellen 20/20 or better) as tested by the Bausch and Lomb Master Orthorater. Their color perception was also normal as tested by the Ishihara test for color blindness.

Exploratory studies had shown that a stable level of performance was reached after practice in 3 spaced sessions per day, 16 sightings per session, over 4 or 5 days. All subjects were trained for 5 days under this regimen. The training task was identical to the experimental task.

RESULTS AND DISCUSSION

The raw data for the entire study are shown in table II.

Table III summarizes the results of the analysis of variance of the data. Values of probability greater than 0.05 were considered not to be significant. A figure is provided for each variable that had a significant effect on performance (figs. 6-12). Data points in the figures are averages based on all 10 subjects.

Figure 6 shows the change in performance with objective lens diameter. As the diameter decreases, performance improves even though diffraction is increasing. This may have been due to the increasing symmetry of the diffraction images which made them easier to superimpose. When the lens diameter is decreased the increase in diffraction proceeds as in closing down the aperture, that is, decreasing the entrance pupil of the telescope (see fig. 13). However, when the size of the lens is decreased neither aberrations nor depth of field are affected as they are when the aperture is reduced. The total spread of light in the image is thus due to a combination of lens aberrations and diffraction.

Figure 7 shows that performance improvement is also associated with decreases in the aperture diameter. When the objective lens diameter was fixed (table I, A, B, or C) at one of three sizes, simply reducing the aperture improved performance (table I, AI, AII, or AIII, etc.). A decrease in the aperture diameter has three effects on the clarity of the star image: (1) Diffraction increases and produces a more symmetrical image; (2) oblique rays are "stopped," thus reducing aberrations; and (3) the depth of focus is increased. See reference 7 or any appropriate optics text for qualitative changes due to decreasing the aperture diameter. See figure 13.

Figure 8 shows that performance improved from a σ of 8 sec to 5 sec with increasing magnification up to 14.0×, but did not improve significantly with increases from 14.0× to 20.0×. See figure 14 for an illustration of qualitative changes in the image due to changes in magnification.

Subjects differed significantly in their ability as indicated by differences in variability. Figure 9 shows these results.

The analysis of variance summary in table III shows that in addition to the main effects of the experimental variables discussed above, several of the interaction terms were significant. These mean that the extent of change in performance due to changes in one of the variables was dependent upon changes in another of the variables. For instance, figure 10 shows that the effects of magnification and objective lens diameter were related. There are several ways to state this relationship. One way is to say that as magnification increased, effects of decreasing the lens size were attenuated. Another is to say that performance improvement due to decreasing the objective lens diameter was greater at the lower powers. The practical implication - a third way to state the results - is that these two may be traded off in arriving at an optimum sextant telescope design provided it is desired to increase the reliability (decrease the variability) of sightings in its use.

Figure 11 depicts the next significant interaction, that between objective lens diameter and aperture diameter. The improvement in performance due to decreasing the aperture diameter is dependent upon the diameter of the objective lens. Again, these two variables can be traded off for optimum sextant design. If only a large objective lens can be used an iris could be provided to "stop down" the system and decrease sighting variability.

The last significant interaction term in table III is that between subjects and magnification. Figure 12 shows the results. The poorest performers improved most with increases in magnification but magnification made little difference to the best performers. The practical implications are that if individuals who are to use sextants cannot be selected or trained to high performance levels, it would be wise to use higher magnifications. Note again in figure 12 the lack of a difference in performance for the 14.0 and 20.0 power telescopes.

RESUMÉ

A study was conducted to examine the effects of objective lens size, aperture size, and magnification upon performance in measuring angles with a standard marine sextant. The significant results were the following:

1. Performance variability decreased with decreases in the diameters of the objective lens and aperture and with increases in magnification.

2. Subjects differed considerably in their performance variability.

3. Magnification improved performance more with the larger objective lenses than with the smaller.

4. Decreases in aperture size were more beneficial with the larger objective lenses.

5. The better subjects sighted almost as well with lower power telescopes as they did with higher powers. In other words, all subjects benefited somewhat from higher powers, but the poorest benefited most.

6. The interactions of the variables in this study indicate ways in which trade-offs may be made in sextant telescope design for optimum human performance.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif. 94035, May 14, 1968
127-51-06-03-00-21

APPENDIX A

THE STANDARD DEVIATION AS A PERFORMANCE MEASURE

In studies of sextant sighting performance conducted at Ames Research Center, two classes of errors are recognized. One has to do with the reliability of the sighting and the other with its validity. Usually for any given experimental condition, each subject accomplished a set of 8 to 20 sightings. From the behavior of the set, the probable behavior of a single sighting could be predicted. It is not expected that in a real navigation situation there will be time for more than one or two sightings per observation.

For each set of sightings a mean and a standard deviation were computed. A normal distribution of the measures was assumed. If this assumption were correct, then the mean ($\overline{X}$) and the standard deviation (σ) provided the parameters for a complete specification of the distribution. The probability density function of the normal distribution is:

$$f(x) = \frac{1}{\sqrt{2\pi\sigma}} e^{-(x-\mu)^2\sigma^2}$$

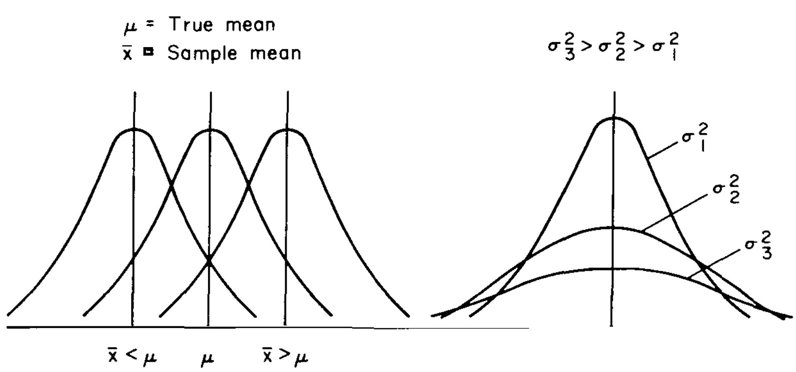
where

σ standard deviation

σ^2 variance

μ true or population mean

The mean describes the distribution as being "centered" at some particular value of X. The distribution is symmetrical about this ordinate. The variance describes the dispersion of the measures about the mean value. The smaller the σ^2, the more "peaked" is the distribution; the larger the σ^2, the "flatter" is the distribution. The two sketches below illustrate various values for the mean (a) and variance (b). Once the mean and standard



(a) Same variance, changing mean (b) Same mean, changing variance deviation of a set of sightings are known, the probability of the occurrence of a given single sighting may be computed. It can be done by integration of $f(x)$ over the appropriate interval or by reference to a table of values relating to the normal curve. (See ref. 9, pp. 40 to 69 or any mathematical statistics textbook.) It will be found that about 68% of the measures will fall between $\pm 1\ \sigma$ from the mean and about 95% between $\pm 2\ \sigma$.

Suppose that a set of sightings is taken under a prescribed set of task conditions. Suppose that the set has a mean of 300 seconds of arc and a σ of 20 seconds of arc. Now, any subsequent <u>single</u> sighting taken under precisely the <u>same</u> conditions will have a 68% ($\pm 1\ \sigma$) chance of being in the interval 280-320 seconds of arc and a 95% ($\pm 2\ \sigma$) chance of being in the interval 260-340 seconds of arc.

Suppose, now, that task conditions can be manipulated. For instance, it has been shown that training will reduce the variability of the sextant sighted angles (see ref. 2). If, in the present example, the subjects were trained prior to the determination of the mean and σ for this task, σ might have decreased to 10 seconds of arc. Now, 95% of any subsequent single sightings by a <u>trained</u> observer with all other task conditions unchanged will be in the interval 280-320 ($\pm 2\ \sigma$) rather than only 68% ($\pm 1\ \sigma$) as in the previous case.

The standard deviation interpreted in this manner refers to the reliability of the sighting or to its repeatability. Hence, it refers only to the consistency displayed by a certain measurement technique. It has nothing to do with whether the mean value sighted is equal to the true angle between the selected celestial targets, which is another matter concerning the validity of the sighting.

The mean and variance are independent parameters in the probability density function described by $f(x)$ above. The placement of $\bar{X}$ on the magnitude scale has nothing to do with the magnitude of σ. One can have a large mean or one that departs from a true value by a considerable amount and still have a very small variance. Or, conversely, a large variance can accompany a mean that coincides with a true value.

In the sextant sighting studies any influence that forces the <u>mean</u> sighted angle <u>away</u> from the true value is understood to decrease the validity of the sighting. Any influence that tends to force the sighted angles to disperse about the mean angle is understood to decrease the reliability of the sighting.

VALIDITY

When the mean angle is displaced from the true angle, a bias is present which decreases the validity of the sighting. Examples of biasing influences are:

(1) Sextant errors (mechanical, optical)

(2) Parallax and horizon dip errors (in marine navigation)

(3) Errors due to target irradiance, etc.

These are constant errors for which correction factors may be applied to sextant readings or for which the sextant may be calibrated. Factors that decrease validity by introducing a constant bias are usually thought to be localized in the physical characteristics of the sighting task, that is, the measurement apparatus, the measurement environment, and the measurement targets. Once known, they are relatively easy to correct.

RELIABILITY

Any set of sightings is perturbed by influences which result in randomly distributed errors. There are two major contributors to this kind of error: (1) random fluctuations in the physical characteristics and the techniques of the measurement process, and (2) fluctuations in the psychomotor and perceptual processes in the human observer.

The first of these can be minimized by judicious control of independent variables in the experiment or in the actual task. For instance:

(1) Always using the same observer for navigational sightings will control for individual differences.

(2) Always turning the vernier knob in the same direction will control for random mechanical discrepancies.

(3) Always reading the vernier scale under the same illumination level and from the same position of eye and scale will reduce random scale reading errors, etc.

The second error source, the human observer as random information processor, also may be thought of as composed of two parts: (1) a variance which may be reduced by manipulation such as training, as discussed above, by increasing telescope image quality, etc. In fact, this is the error component most frequently of concern in the sextant sighting laboratory at Ames. The effects of changes in the independent variables which are suspected of being important (magnification, training time, aperture stop, sighting time, etc.) have been evaluated by analysis of changes in this dependent variable, and (2) the fundamental variability in human perceptual processes and behavior which is never eliminated.

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TABLE I.- TELESCOPE SPECIFICATIONS - LINEAR VALUES IN mm

		1 Objective diameter	2 Aperture diameter	3 Objective focal length	4 Ocular focal length	5 Magnification
A	I	54	54.0	254	12.5 18 32 56	20.3 14.1 7.9 4.5
	II		25.4		12.5 18 32 56	20.3 14.1 7.9 4.5
	III		20.6		12.5 18 32 56	20.3 14.1 7.9 4.5
B	I	43	43.0	270	12.5 18 32 56	21.6 15.0 8.4 4.8
	II		12.7		12.5 18 32 56	21.6 15.0 8.4 4.8
	III		11.1		12.5 18 32 56	21.6 15.0 8.4 4.8
C	I	24	24.0	237	12.5 18 32 56	19.0 13.1 7.4 4.2
	II		10.3		12.5 18 32 56	19.0 13.1 7.4 4.2
	III		5.5		12.5 18 32 56	19.0 13.1 7.4 4.2

TABLE II.- RAW EXPERIMENTAL DATA.

[Each number in the table is the standard deviation of 16 sightings. Each subject sighted twice under each of the 36 conditions of the study. Values are in seconds of arc.]

Magnification	Subjects	Objective lens diameter																	
		54 mm						43 mm						24 mm					
		Aperture diameter						Aperture diameter						Aperture diameter					
		54 mm		25.4 mm		20.6 mm		43 mm		1[illegible].7 mm		11.1 mm		24 mm		10.3 mm		5.5 mm	
20x	1	7.35	2.68	13.24	4.34	4.55	6.75	7.86	5.20	6.14	1.79	5.33	3.40	4.31	8.80	5.90	5.10	3.81	5.40
	2	14.20	5.31	3.14	2.71	6.21	3.55	5.10	6.23	3.75	3.74	4.46	4.59	4.73	4.25	2.80	3.58	5.04	2.57
	3	9.86	4.60	5.07	6.06	5.70	7.69	9.82	8.46	8.99	3.54	5.95	5.02	4.53	8.14	4.65	4.15	8.18	4.62
	4	8.07	8.35	6.90	4.43	7.27	6.55	6.42	3.37	4.57	5.11	4.92	4.08	7.29	6.75	4.39	7.08	4.93	6.66
	5	4.93	5.40	3.57	3.40	2.68	4.07	11.81	5.35	3.78	1.41	8.04	2.68	3.07	2.66	10.11	6.34	8.33	6.83
	6	6.92	2.82	3.30	3.40	4.36	3.01	6.30	3.55	5.84	3.55	5.52	2.70	3.91	5.66	2.77	4.23	4.76	3.79
	7	8.93	4.48	3.24	1.42	3.05	6.20	10.09	5.71	4.91	1.30	5.94	3.37	3.97	7.27	3.60	1.59	9.29	1.71
	8	6.51	4.25	4.29	2.34	8.80	6.10	4.64	3.24	3.56	1.95	7.70	2.24	4.63	2.71	7.38	5.10	7.07	2.27
	9	3.83	5.09	2.79	4.05	2.77	4.09	3.38	3.64	2.33	2.36	5.49	3.38	1.95	7.65	5.45	4.25	6.46	2.42
	10	7.26	2.49	3.38	2.63	3.48	4.39	1.92	4.04	2.90	5.79	2.80	5.26	5.56	3.77	6.66	2.28	7.67	2.56
14x	1	5.43	4.44	4.17	6.64	4.13	6.77	6.49	6.12	3.96	3.85	4.48	4.17	2.56	8.54	2.63	4.22	5.38	2.64
	2	6.25	4.60	6.54	4.30	3.95	3.33	4.42	4.41	2.21	4.95	3.86	3.60	2.92	5.62	1.90	5.89	3.64	3.55
	3	10.50	7.19	7.10	4.75	8.49	6.33	6.93	8.01	4.26	5.21	6.16	5.07	4.92	9.90	2.16	5.72	8.52	8.15
	4	7.27	5.02	5.72	6.14	6.38	2.88	5.81	8.15	5.68	6.42	8.43	7.21	9.51	4.15	4.22	5.16	6.10	4.80
	5	5.97	7.16	4.35	13.44	4.21	4.68	7.36	5.40	4.48	2.86	4.94	7.04	6.10	5.38	5.77	1.80	5.05	2.07
	6	8.27	3.47	4.92	2.59	5.00	2.77	6.92	3.03	4.01	5.05	4.24	3.83	5.12	2.82	3.19	1.29	4.54	5.02
	7	12.09	3.61	4.05	3.70	4.39	8.33	6.42	2.90	6.73	1.72	2.41	2.94	4.46	3.30	3.80	5.05	3.96	2.53
	8	7.03	3.95	9.54	6.11	8.27	2.75	2.94	2.57	6.17	6.11	5.38	5.77	8.97	3.88	5.34	6.98	3.42	5.09
	9	4.99	4.49	2.35	3.49	3.56	4.16	3.68	2.51	3.72	1.86	3.08	5.20	3.82	6.52	4.25	3.03	3.54	4.91
	10	13.95	6.70	6.46	7.24	6.59	4.73	6.11	8.40	6.16	2.85	3.01	5.49	5.04	4.16	5.52	4.92	4.52	4.06
8x	1	9.12	10.37	3.72	7.96	4.54	4.75	12.16	13.52	8.84	5.03	6.38	4.40	4.36	7.41	6.55	3.95	10.64	3.53
	2	29.69	6.38	10.44	8.09	9.12	5.12	13.62	8.33	5.62	5.74	2.38	4.28	6.94	6.13	6.13	3.40	10.07	5.94
	3	15.13	5.47	9.60	6.02	8.14	10.43	7.32	4.50	6.42	4.29	7.39	6.06	6.98	6.77	3.84	8.00	~~14.62~~	7.10
	4	6.50	3.69	9.50	10.57	6.41	16.60	8.75	8.49	5.99	7.47	5.70	8.11	8.44	6.45	5.57	7.92	5.45	4.91
	5	5.72	5.98	4.07	4.15	14.16	6.88	3.51	5.59	3.57	6.05	5.54	5.58	5.26	6.86	5.38	6.28	6.78	9.16
	6	8.99	7.17	6.79	5.06	6.01	3.30	7.14	5.98	5.42	4.54	5.35	3.88	5.64	5.63	4.13	4.90	6.20	5.21
	7	10.96	10.07	5.41	5.75	5.42	2.92	5.85	8.42	5.14	4.16	4.43	4.73	2.23	3.40	7.06	4.19	1.47	1.09
	8	4.19	7.39	5.66	9.74	4.69	10.53	3.20	10.85	2.88	4.33	5.76	4.62	2.54	1.86	1.24	6.01	1.80	3.27
	9	7.51	4.02	5.20	6.69	5.80	2.03	11.49	3.78	3.76	6.32	4.22	3.85	7.39	2.77	4.83	5.20	5.53	6.18
	10	8.75	6.02	6.82	5.61	7.65	12.31	10.07	7.81	7.51	5.13	6.55	2.00	4.16	6.53	5.06	3.67	8.46	6.83
4.5x	1	9.52	9.39	5.39	8.62	4.81	6.67	12.42	9.82	17.57	5.10	7.95	7.99	12.10	13.65	5.62	9.72	4.60	5.78
	2	9.12	7.41	7.02	5.79	6.21	5.85	15.22	14.22	15.33	5.97	12.60	4.95	6.74	7.22	7.14	6.87	7.17	3.51
	3	11.86	10.66	24.69	7.92	7.32	5.50	22.64	9.88	14.52	9.14	11.73	8.19	5.88	9.47	7.19	10.14	12.98	8.39
	4	13.16	10.11	10.42	8.09	9.55	8.94	14.39	13.85	5.49	10.62	8.71	9.43	8.29	9.55	8.34	8.57	8.86	11.45
	5	7.48	8.71	7.36	5.11	10.50	3.16	11.37	7.42	9.02	6.76	6.84	5.75	5.07	2.23	8.72	6.10	1.42	7.17
	6	9.74	5.80	6.26	4.19	12.22	5.96	12.90	10.23	6.15	5.03	8.72	5.02	8.43	8.30	6.26	3.48	11.11	4.11
	7	5.97	7.19	6.49	5.61	2.75	4.05	9.93	10.00	14.23	8.52	6.51	6.15	2.73	3.14	7.51	8.59	4.44	2.47
	8	7.45	2.63	3.14	8.49	1.64	7.91	10.58	5.79	4.49	7.38	7.51	2.11	5.20	3.83	3.86	3.72	7.61	1.41
	9	6.3[illegible]	10.32	7.80	6.04	3.26	7.52	15.65	4.82	1.79	6.47	7.05	6.18	4.83	4.54	3.36	4.42	9.17	3.22
	10	1.73	14.19	8.46	5.73	7.53	11.59	15.98	5.06	7.86	7.29	6.68	11.27	6.49	6.66	8.06	10.54	6.82	3.05

TABLE III.- ANALYSIS OF VARIANCE FOR EFFECTS OF OBJECTIVE LENS, MAGNIFICATION, APERTURE, AND SUBJECTS ON SIGHTING PERFORMANCE

Source of variance	Degrees of freedom	Sum of squares	Mean square	F ratio	Probability
Objective lens	2	149.61	74.81	19.32	<0.001
Magnification	3	944.57	314.86	26.88	<.001
Aperture	2	259.47	129.73	14.96	<.001
Subjects	9	658.68	73.19	10.22	<.001
O × M	6	261.56	43.59	7.83	<.001
O × A	4	105.07	26.27	5.22	<.005
M × A	6	51.39	8.56	1.31	n.s.
O × S	18	69.69	3.87	.54	n.s.
M × S	27	316.27	11.71	1.64	<.05
A × S	18	156.08	8.67	1.21	n.s.
O × M × A	12	79.32	6.61	.92	n.s.
O × M × S	54	300.68	5.57	.78	n.s.
O × A × S	36	181.09	5.03	.70	n.s.
M × A × S	54	351.89	6.52	.91	n.s.
O × A × M × S	108	503.32	4.66	.65	n.s.
E(O × A × M × S)	360	2576.95	7.16		

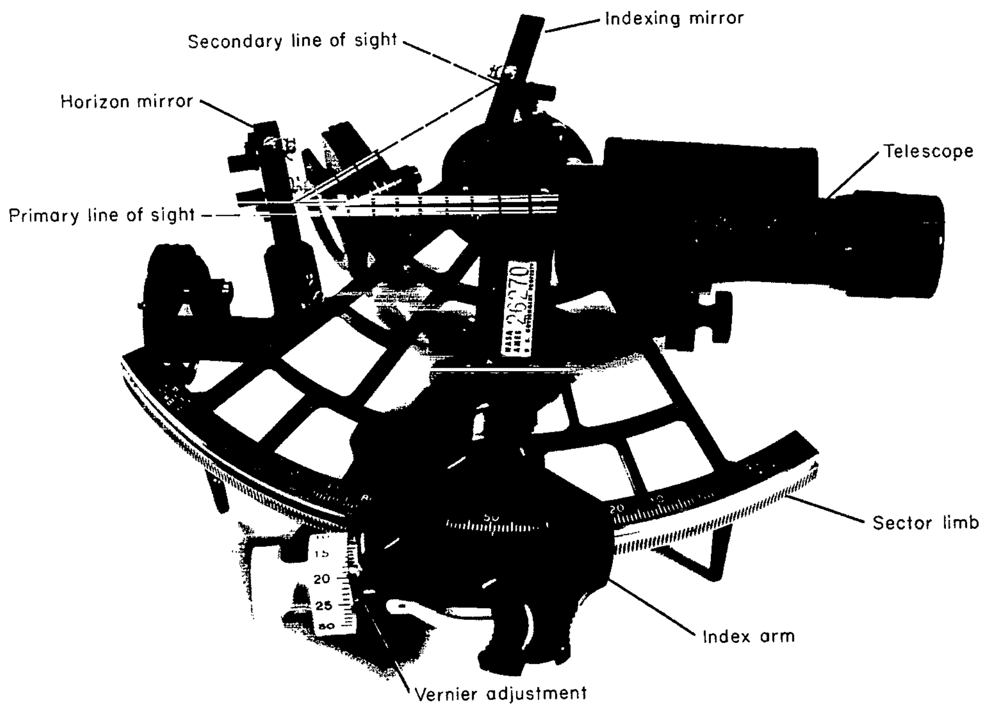

Figure 1.- Photograph of marine sextant.

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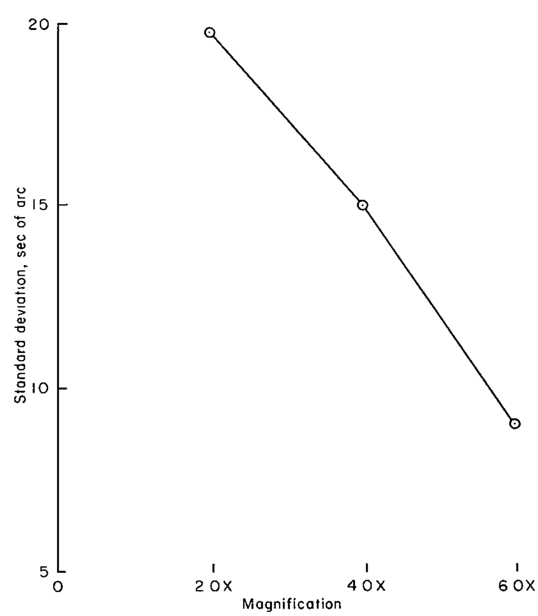

Figure 2.- Performance variability as a function of sextant telescope magnification. Pilot study using telescopes supplied with sextant.

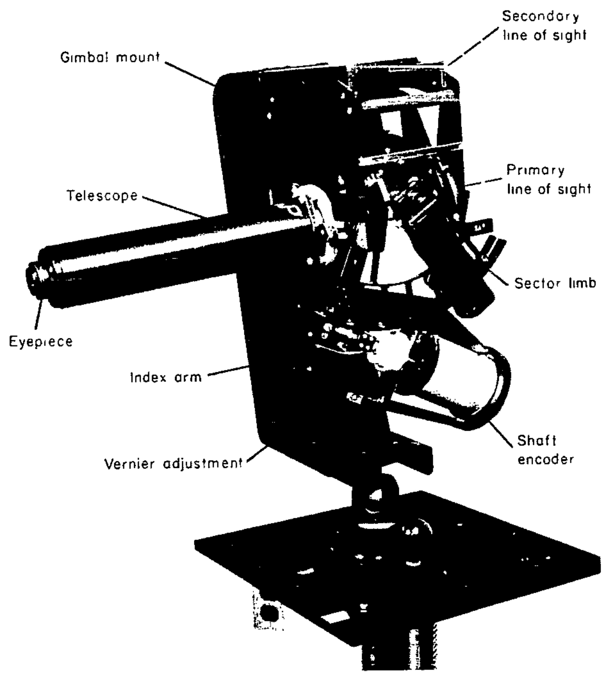

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Figure 3.- Special telescope mounted on the sextant.

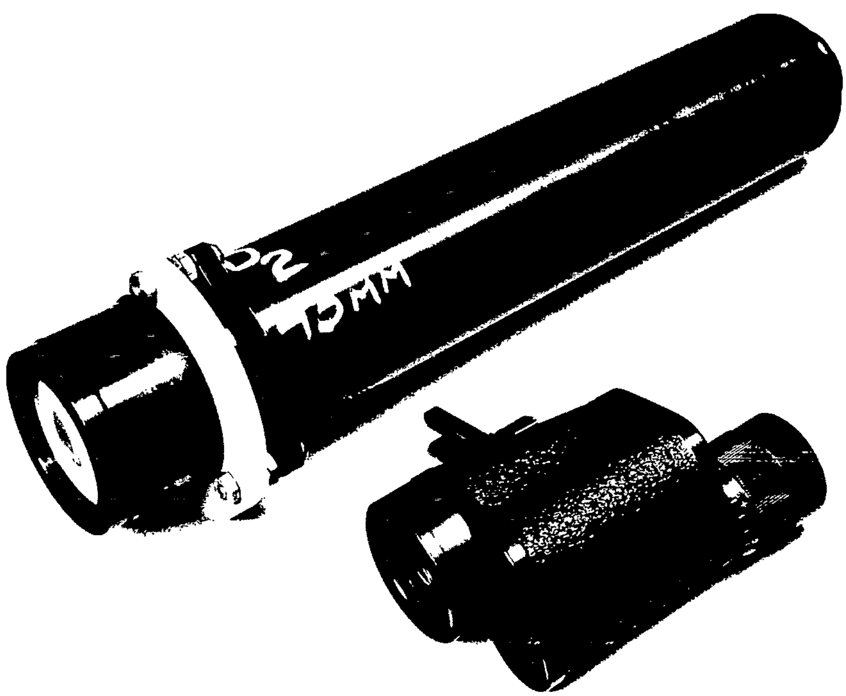

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Figure 4.- Special telescope and 6X monocular supplied with the sextant.

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Figure 5.- The collimated, simulated stars.

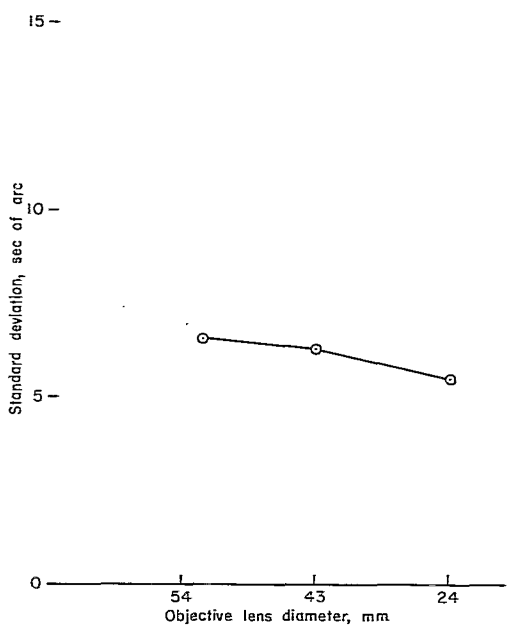

Figure 6.- Performance variability as a function of objective lens diameter.

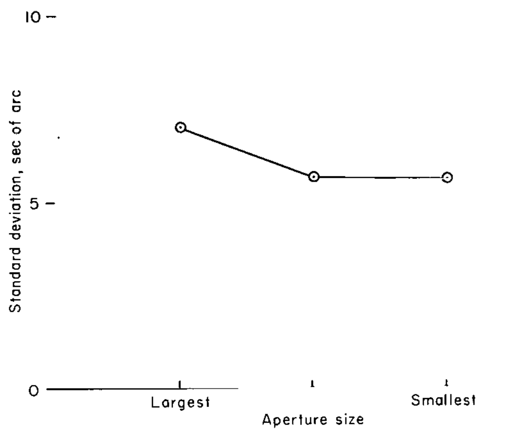

Figure 7.- Performance variability as a function of aperture size. Values on abscissa are variable. See table I, column 2.

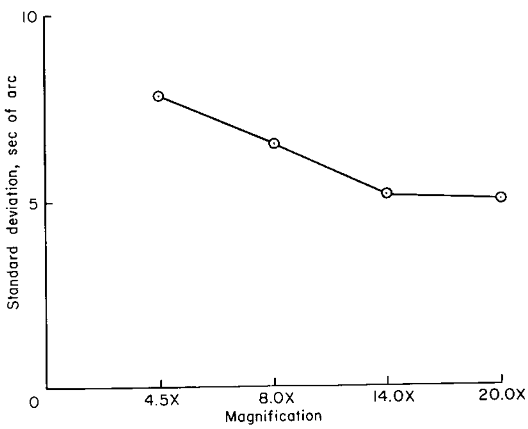

Figure 8.- Performance variability as a function of telescope magnification.

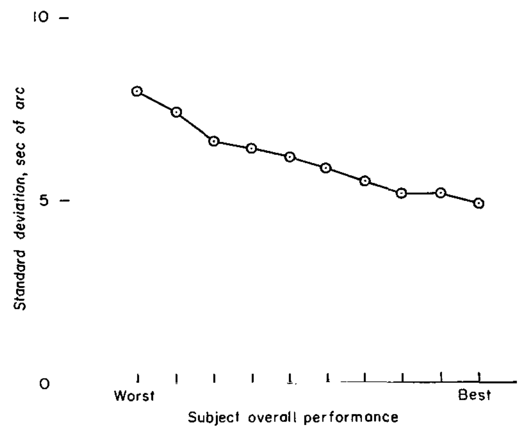

Figure 9.- Performance variability as a function of subject ability in experiment.

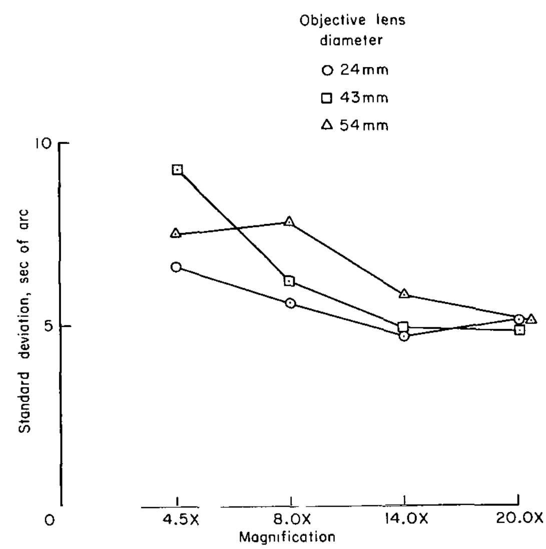

Figure 10.- Performance variability as a function of magnification and objective lens diameter.

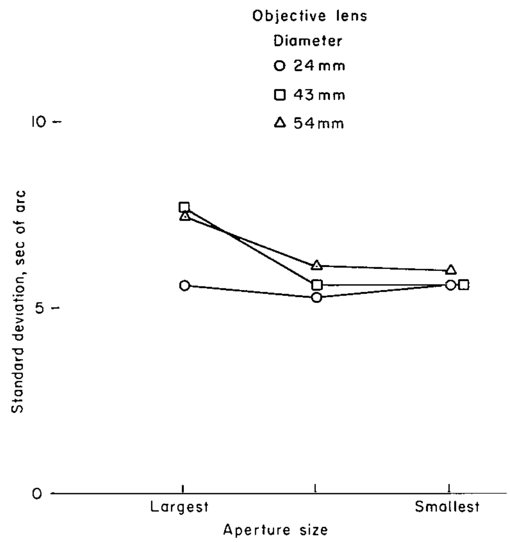

Figure 11.- Performance variability as a function of aperture and objective lens diameters.

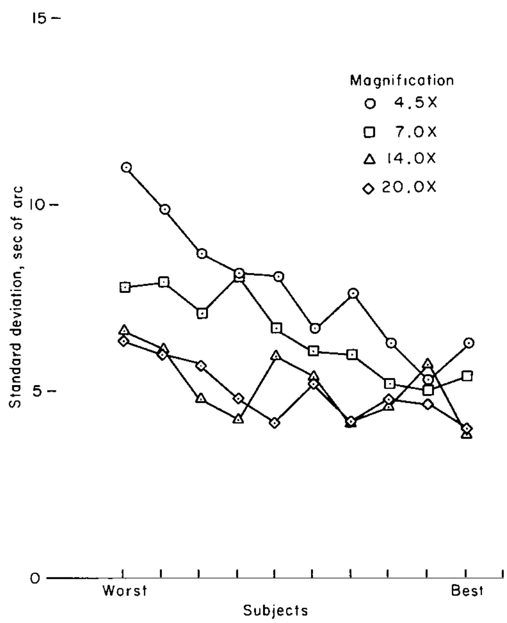

Figure 12.- Performance variability as a function of magnification and subject ability.

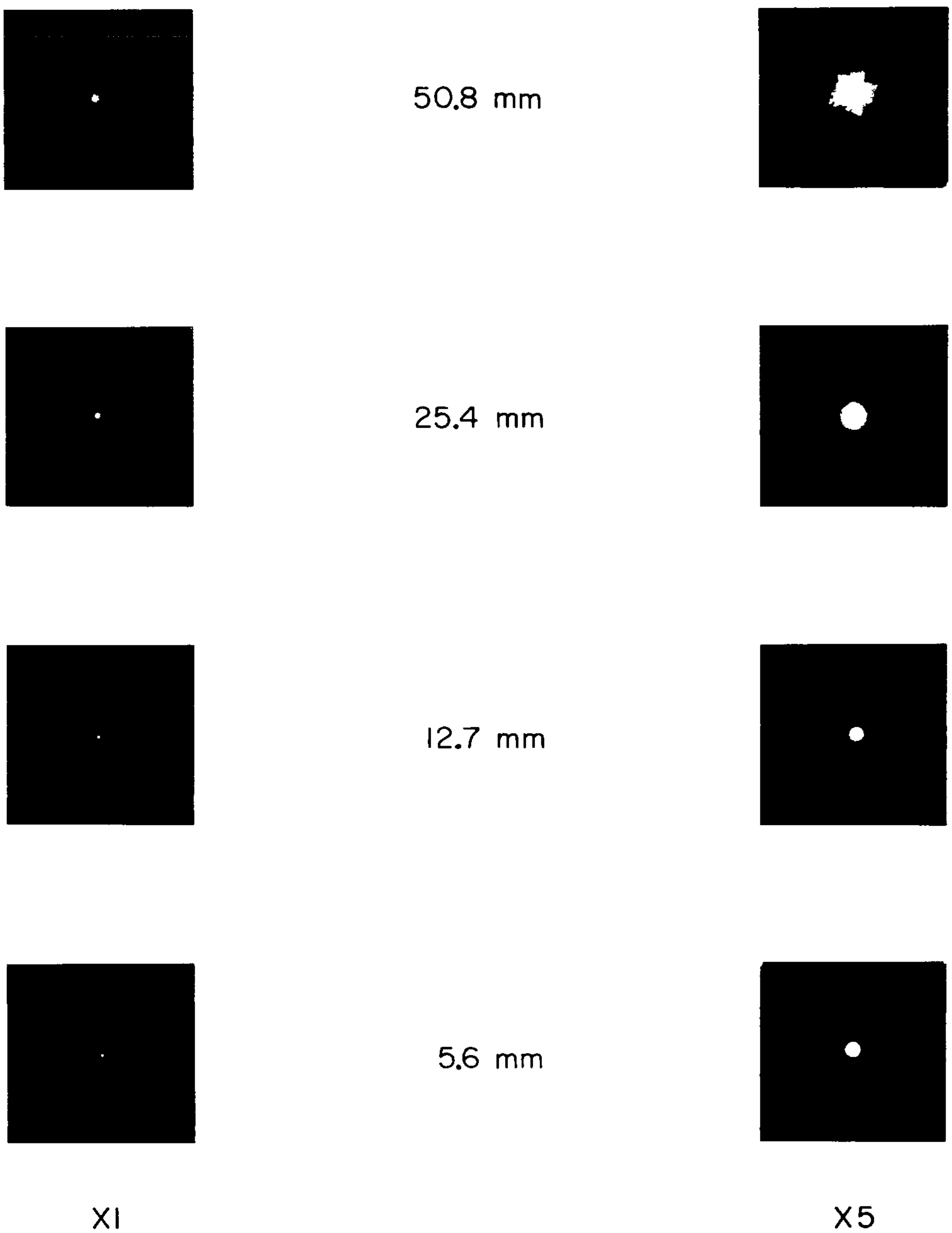

Figure 13.- Effect of different aperture diameters on the clarity of the in-focus image; objective lens diameter 54.0 mm, ocular focal length 12.5 mm.

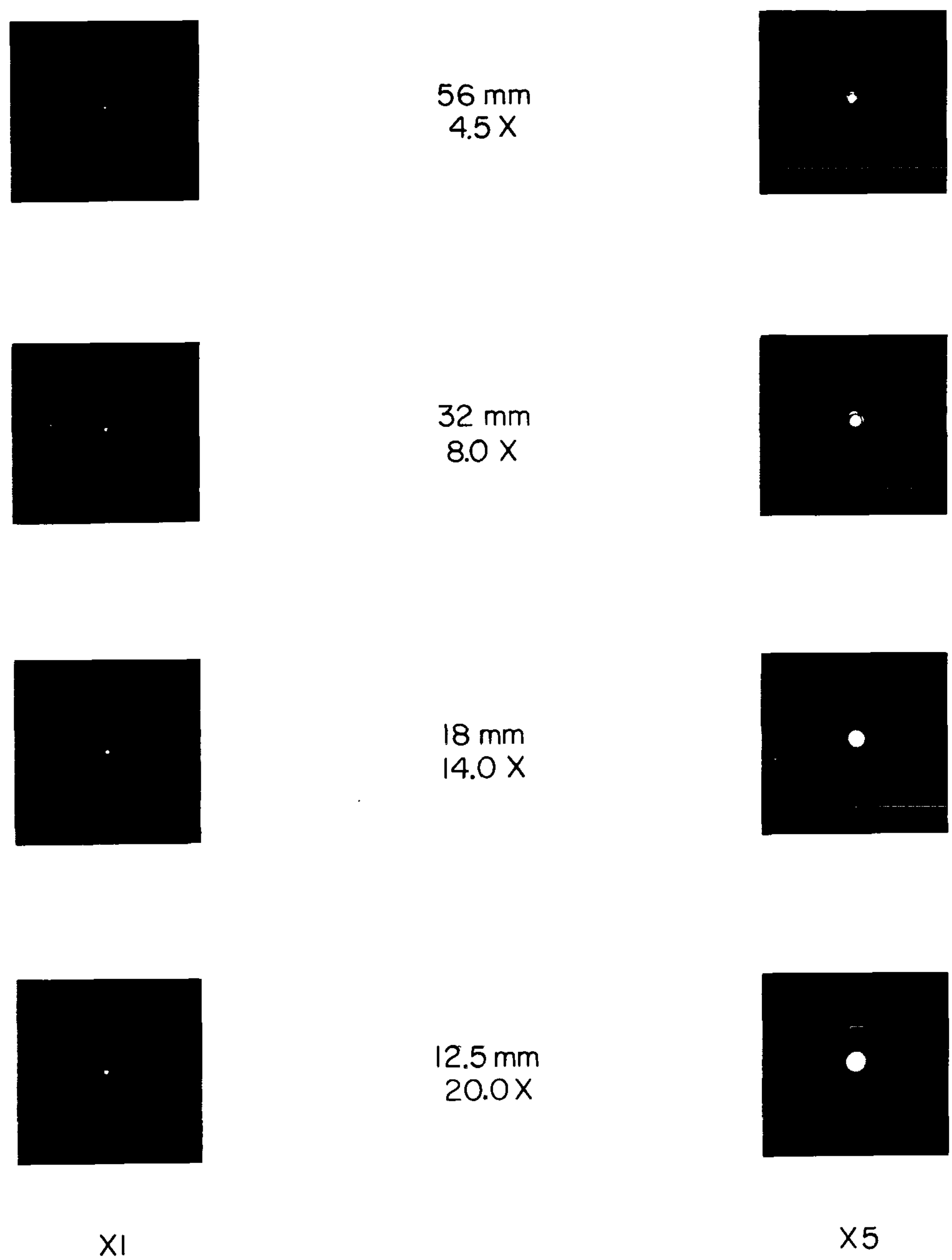

Figure 14.- Effect of different ocular focal lengths on the appearance of the in-focus diffraction patterns; magnification increasing downward, objective lens diameter 24.0 mm, aperture diameter 5.6 mm.

NASA-Langley, 1968 — 21 A-2998

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