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THE EFFECTS OF IRRADIATION AND STAR MAGNITUDE ON SEXTANT SIGHTING PERFORMANCE

by Robert J. Randle and Emmett C. Lampkin

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SUMMARY

A hand-held sextant may provide a practical and economical method of acquiring navigational information in space flight during an emergency or to supplement other navigation measurements. If this mode is chosen for space flight, it is mandatory that the limits of human performance with the sextant be established. The present study was designed to investigate variables which may affect sighting accuracy.

Male college students with good visual acuity (Snellen 20/20 or better) and normal color vision were trained to make angle measurements with a marine sextant. The sextant was gimbal mounted and angle readings were recorded with a digital shaft encoder mounted on the shaft of the sextant vernier knob. In measuring the angular subtense of a simulated planetary disk, increases in disk brightness were associated with increases in the measured subtense. Changing the magnitude of the reference star did not significantly affect performance ($p < 0.10$).

INTRODUCTION

In marine navigation the sextant has been used for acquiring accurate angular data for deriving 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. In considering the use of a hand-held sextant 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 considerably simplified. 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 the latest in a series (refs. 2, 3, 4) conducted at Ames Research Center to explore the feasibility of using a conventional marine sextant for acquiring backup or emergency navigation data in space and in other tasks that require angle measurements. The sextant was installed in a controlled laboratory setting with an optical simulation of targets. The sextant vernier (fine setting) knob was fitted with a digital shaft encoder which remotely displayed the measured angle 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. This equipment is described in detail elsewhere (see ref. 3).

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

> Irradiation is a well-known phenomenon which makes a bright target appear larger than it actually is. Bright planetary surfaces used as targets in measuring the angle between the limb of the planet and a reference star may contribute to inaccurate measurements due to irradiation. (a) What is the extent of this effect in terms of sextant sighting accuracy? (b) Does the effect also depend upon the brightness of the reference star?

EXPERIMENTAL PROCEDURE

Sighting Task

The phenomenon of irradiation refers to changes in the apparent location of contours and apparent size under different illumination of target and background. The Dictionary of Visual Science (ref. 5) gives the following definition of irradiation: "A phenomenon in which bright areas or objects appear enlarged against a dark background, as demonstrated in the overestimation of the size of stars, ..." Of course, the background need not be totally dark in order for irradiation to be produced.

In order to quantify the irradiation effect, it was necessary to make sextant measurements of the apparent angular subtense of a disk whose brightness varied in known discrete steps. One kind of target configuration which could be affected by irradiation would be a reference star osculated on the limb of a planetary disk when the angle between these two was being measured. Also, the irradiation effect could be enhanced when a dimmer star is used as the reference and it comes close or tangent to the boundary of the bright planetary disk. To investigate this possibility star magnitude was also varied.

The subject's task was as follows: The planetary disk and the reference star appeared in the sextant telescope. The star was offset a few minutes of arc from either the upper right limb or the lower left limb. The subject rotated the sextant vernier knob to bring the star image to the limb and oscillated the star to achieve a more accurate star-limb tangency. When he was satisfied that this had been achieved, he pressed a button that automatically recorded the angle to which the sextant had been set. He then backed the star away from the limb and repeated the process. When he had completed eight of these sightings, he moved the star image to the opposite limb and again took eight sightings.

For each subject the star always moved in the same direction, i.e., toward the limb from the extradisk position. This was done in order to circumvent gear backlash errors in the sextant. This effect was minimized

when a subject went past, or overshot the limb by requiring him to back the star image away and start the sighting over.

The eight sightings on each limb were averaged. By subtracting the mean for the upper from the mean for the lower, the apparent angular subtense was computed.

Equipment

A simulated star and planetary disk, both of whose brightness could be varied, were used as targets. The simulated star was produced by means of a parabolic mirror at whose focal point was placed a grain-of-wheat lamp enclosed within a metal capsule. The capsule had a 0.0005-inch-diameter aperture pointing at the mirror. Both the mirror and the point light source were supported by a metal tube. Star magnitudes were varied by adjusting the voltage across the point source of light until the star was just visible to the dark adapted experimenter. While adjusting the voltage, the experimenter viewed the star through a neutral density filter of an appropriate log value. A sixth magnitude star was used as the reference point. The method used to determine star values from the sixth magnitude point is discussed below.

A star of first magnitude (+1.0) is 100 times the intensity of a sixth magnitude star.[1] Thus, there are 2.0 log units of brightness difference between a star of magnitude +6 and a star of magnitude +1:

$$\log 2.5119^5 = 0.40002 \times 5 = 2.0010$$

If the sixth magnitude star is just visible, that is, lies on the foveal absolute visual threshold, then a star of first magnitude will be just visible through a log 2.0 neutral density filter. For the second and third magnitudes the filter log values are 1.6 and 1.2, respectively.

Before setting the intensity of the simulated star, the experimenter dark adapted for 10 minutes (subjects adapted to the same level). Since star magnitude presentations were randomized over days, only one magnitude was set up each day.

The planetary disk was simulated by placing a metal plate with a circular aperture at the focal plane of a large lens system taken from an aerial camera. The system had a 24-inch focal length with an f/4.5 lens. (See fig. 1.) Behind the focal plane and the circular aperture was the light box for illuminating the disk. This was separated from the exit aperture by an opal glass diffusion screen to achieve a uniform distribution of light over the entire simulated planetary disk.

[1]A unit interval between these values represents a change in intensity by a factor of 2.5119 (the fifth root of 100). A fifth magnitude star is 2.5119^1 times as intense as a sixth magnitude star; a third is 2.5119^3 times as intense as a sixth, etc. (see ref. 6).

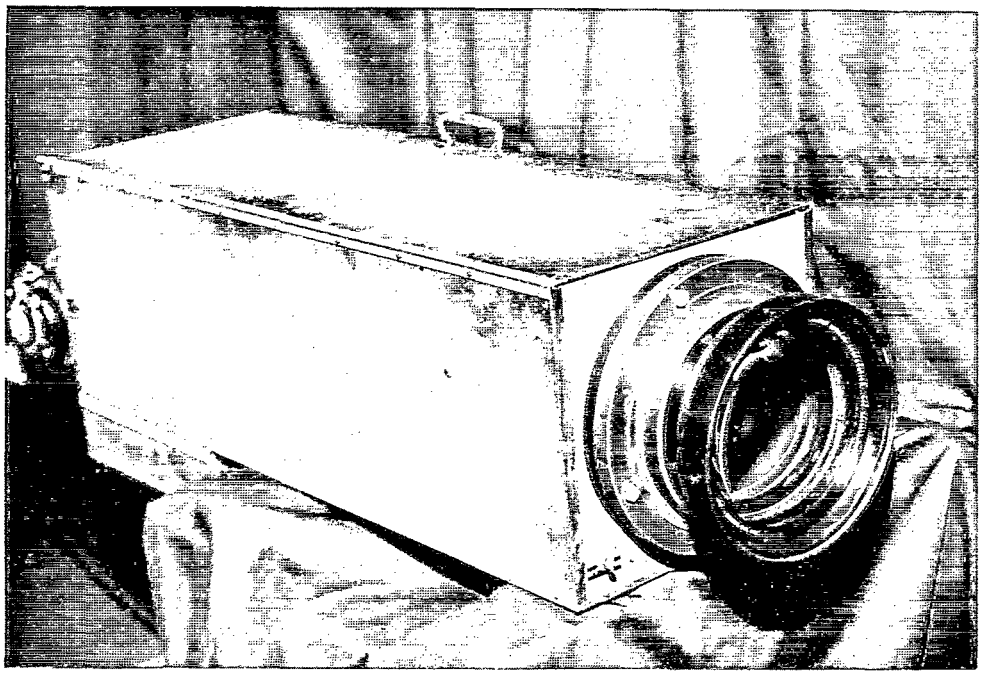

Figure 1.- Box containing lens system, aperture, and light source for simulating a planetary disk.

Brightness was varied by interchanging incandescent lamps of varying wattage in the light box behind the focal plane of the lens system. (See fig. 2.) Fine tuning to the desired brightness level was accomplished by adjusting the

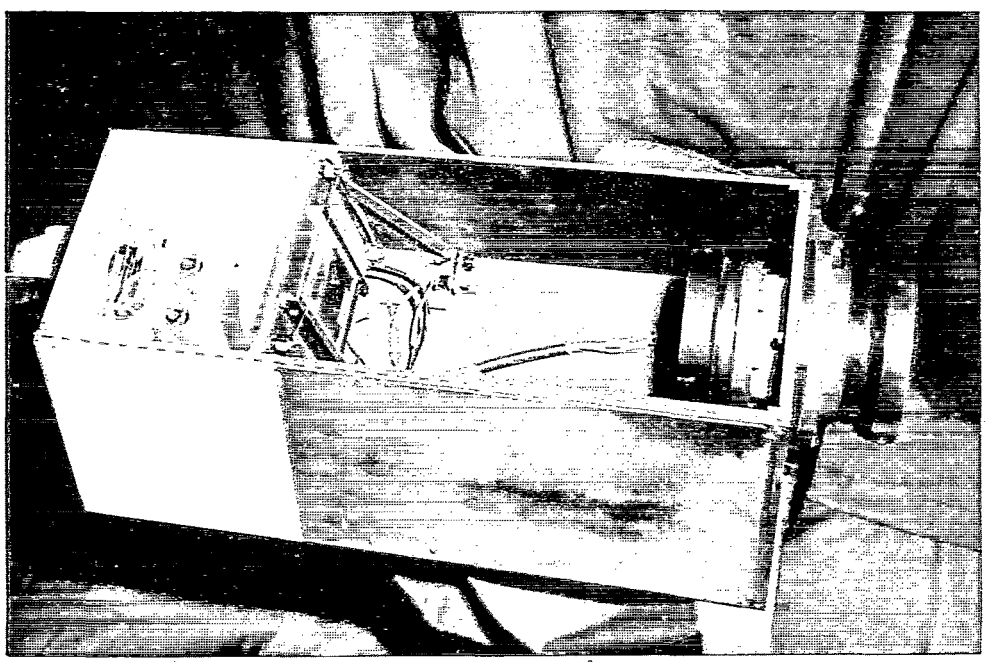

Figure 2.- Interior of the disk simulator showing aperture mounting and incandescent light sources for illuminating the aperture.

voltage across the lamps until the exact value was read on a Pritchard photometer which was bore-sighted on the center of the circular aperture. Voltage adjustments were only necessary over a small range (120 ±10 V). To prevent serial effects in sighting performance due to monotonic changes in the values of the experimental variables, brightnesses were randomized over sighting sessions with a different serial order for each subject.

The angular diameter of the simulated planetary disk was held constant at 60 minutes of arc. This diameter was measured with a Wild T1 theodolite to within ±10 arc seconds accuracy. In a pilot study, in which disk diameter was a variable, it was found that disk size did not affect performance.

The optical axis of the disk was alined along the telescope, or optic axis of the sextant. In this way when the sextant (2) was oscillated about its optical axis, the subject saw the star (1) moving back and forth in an arc-like manner while the planetary disk (3) remained stationary. The rays from both the star and planetary disk were collimated to eliminate parallax as a source of error (fig. 3).

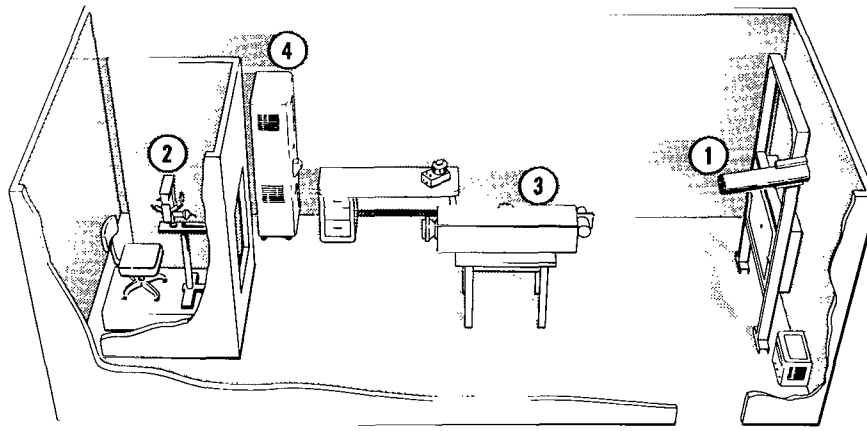

Figure 3.- Layout of the experimental room for irradiance study.

The sextant used was the Plath micrometer marine sextant with the six power (6×) monocular. The sextant was gimbal-mounted and the measured angle was detected by a digital shaft encoder and recorded on a printer (4) . The encoder is described in reference 3 and shown in figure 4. The subject's head was held steady by using a dental bite mold and plate, adjusted for comfortable monocular (right eye) viewing.

Experimental Design

In order to assess the effects of both disk brightness and star magnitude, a factorial design was employed. Six disk brightnesses were used: 1.6, 160, 500, 1600, 5000, and 9000 foot-lamberts (or: 0.2, 2.3, 2.7, 3.2, 3.7, and

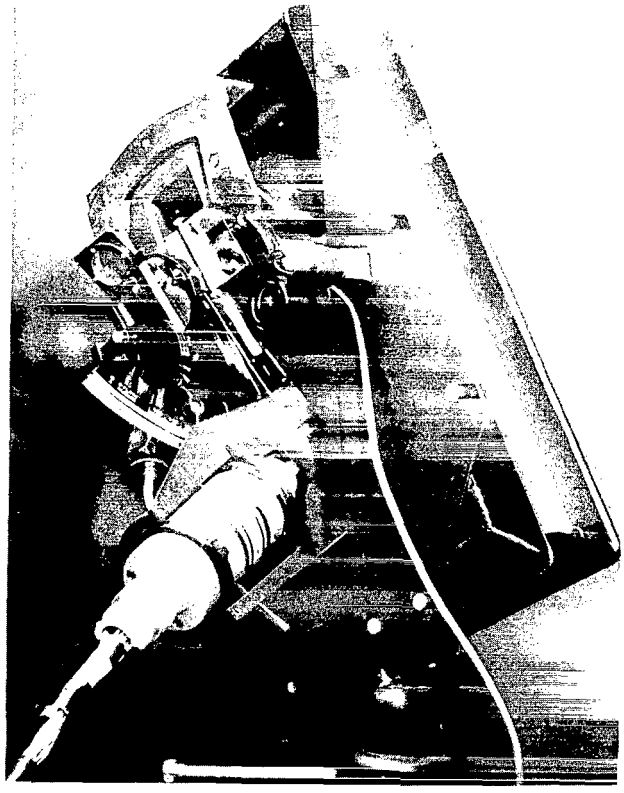

Figure 4.- The gimbal mounted sextant showing the digital shaft encoder attached to the vernier knob.

3.9 log units, respectively). Three star magnitudes were used: +1, +2, and +3. Ten male subjects took part. The design, therefore, was a 10 × 6 × 3 factorial (10 subjects × 6 treatments (brightness) × 3 treatments (magnitudes)). (See ref. 7, p. 243). Each subject participated in three sessions a day until he completed the 18 conditions.

Subject Population and Training

The subjects were undergraduate male students from nearby colleges. Their visual acuity was rated as 20/20 or better, using the Bausch and Lomb Master Orthorater. Color perception was normal as measured by the Ishihara test for color blindness.

All 10 subjects received training prior to sighting under the study conditions. Previous unpublished studies associated with this study had shown that a stable performance level was reached after 4 or 5 days practice, with 3 spaced-sessions per day, 16 sightings per session. All subjects, therefore, trained for 5 days. The training task was to measure the angle between two simulated stars by superimposing their images in the sextant telescope's field of view.

RESULTS AND DISCUSSION

An analysis of variance was used to evaluate both the main effects of the independent variables and any interactions that may have occurred between them. The results in figure 5 show only that independent variable for which there was a statistically significant change in the dependent variable.

For evaluating the statistical significance of the results the 0.05 level of probability was selected as the criterion.

The criterion variable was the measured angular subtense of the luminous disk. The numbers in the analysis of variance summary table are derived from the sextant measured angular subtense in seconds of arc. Table 1 shows the results of the analysis of variance. The brightness of the disk was found to be a significant variable, the magnitude of the reference star was not. Over a range of 3.7 log units of brightness (9000 ft-L) there is an increase in the sextant measured disk subtense of 50 seconds of arc. (See fig. 5.) Except

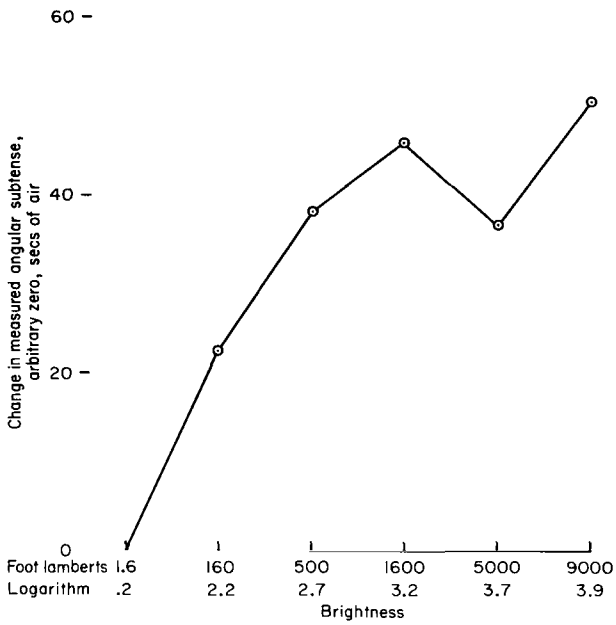

Figure 5.- Increase in disk angular subtense measured by sextant as a function of disk brightness.

for one point (cf. data point for 5000 ft-L) the increase in apparent disk size is monotonic with increasing brightness.

It is not known why irradiation decreased at the 5000 foot-lambert level. There may be disturbances at this level that were not due solely to irradiation but which were attributable to changing techniques and criteria of task accomplishment.

The effects of irradiation are considerable in terms of error in sextant measurement. The accuracy required for space flight will allow only a few arc seconds of error, whereas the present findings have shown errors as large as 50 seconds of arc. In the region of brightness comparable to that of the moon seen from outside the earth's atmosphere, about 900 foot-lamberts (ref. 8), the error is almost 40 seconds of arc. According to figure 5, a 2.5 log unit neutral density filter would reduce this to about zero. The temptation to use a bright, high contrast planetary disk as a target in navigation sightings apparently should be avoided.

This experiment did not show a significant effect due to star magnitude, at least for those magnitudes used. However, the $p < 0.10$ value indicates there may be some effects which were not fully detected by this design.

RÉSUMÉ

A study was conducted to examine the effects of (1) high target brightness and (2) star magnitude on the accuracy of angles measured with a standard marine sextant. The results were as follows:

1. As simulated planetary disk brightness increased, the sextant measured angular subtense of the disk also increased significantly.

2. Star magnitude did not affect the results due to irradiation although the data were approaching significance ($p < 0.10$).

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., 94035, March 5, 1968
127-51-06-03-00-21

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TABLE I.- ANALYSIS OF VARIANCE FOR EFFECTS OF IRRADIANCE ON THE ANGULAR SIZE OF THE LUMINOUS DISK AS MEASURED BY THE SEXTANT

Source of variance	Degrees of freedom	Sum of squares	Mean square	F ratio	Probability
Magnitude	2	6799.42	3399.71	2.72	n.s.
Brightness	5	52100.39	10420.08	8.33	<0.001
Subjects	9	195701.39	21744.60		
M × B	10	10948.03	1094.80	1.11	n.s.
M × S	18	22464.35	1248.02		
B × S	45	56311.28	1251.36		
M × B × S	90	88803.82	986.71		

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