THE EFFECTS OF HIGH LUMINANCE SOURCES UPON THE VISIBILITY OF POINT SOURCES*

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Many of the visual variables involved in celestial navigation will be greatly affected if the observer looks at or near the sun or other intense source. Greatly raised visual adaptation and possible damage to the visual system have been reported. The question was asked in the present investigation whether or not an observer could perceive a moving point source in close proximity to a source of high luminance. The correspondence between physical form and perceived shape was also studied. The variables investigated were: (1) glare-source shape (circle, square, triangle), (2) glare-source intensity (maximum = 4250 ft L), (3) point-source direction of movement in eight frontal-plane meridians, and (4) point-source direction within each meridian. Five highly trained observers viewed the stimulus configuration through an artificial pupil which provided a 10-1/2° field of view. The moving "star" was used as a test spot to determine the characteristics of the luminous field gradient produced by the glare source. Results indicated that: (1) Angular distance, from the edge of the glare source, at which the star disappeared or reappeared is directly related to the luminance of the glare source. (2) The star disappears and reappears at different distances depending upon what kind of edge geometry exists; e.g., the star can approach normal to a straight-line edge (square or triangle) or to a curved-line edge (circle). (3) Under relatively high luminance conditions the perceived shape of the glare source differed from its physical form. (4) The apparent size of the glare source increased as a function of its luminance, and (5) response variance tended to be larger under the higher luminance conditions; however, variance did not appear to be affected by either the shape of the glare source or the meridian of travel of the star. Several methods are proposed for utilizing these, and related findings in present navigational techniques. An electro-optical light shutter device is discussed which will provide adequate visual protection and which will make it possible to obtain navigational fixes upon highly luminous objects in space.

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INTRODUCTION

Several investigations have been performed which are related to the problem of sighting a space vehicle visually near the sun.[1,2] Measures of the minimal angle of resolution (MAR) for two small self-luminous objects against an unilluminated background have also been studied and have indicated that MAR tends to increase as a function of object luminance. One study[3] used two point sources against different background illuminations. The MAR was found to depend entirely upon contrast and not upon the absolute value of background luminance. The MAR associated with the highest contrast ratio in this study was found to be 4.0 minutes of arc (glare-source luminance = 3716 ft L).

These data are related to how the human observer perceives highly luminous objects in a dark field. As such they have definite importance to several aspects of navigation in space. It was felt that further work should be done to delineate more of the visual variables involved and how they interact with one another.

PROBLEM

The present experiment investigated the visibility of point sources (simulated stars) when they were either approaching or receding from high luminance sources in the apparent frontal plane. A secondary problem was that of investigating the differences between perceived shape and physical form of high luminance sources.

PROCEDURE

The radiation from an intense (4250 ft L) projection bulb was collimated, filtered (for nine intermediate glare intensities), and reflected into the observer's right eye by one of three different first surface mirrors. Figure 1

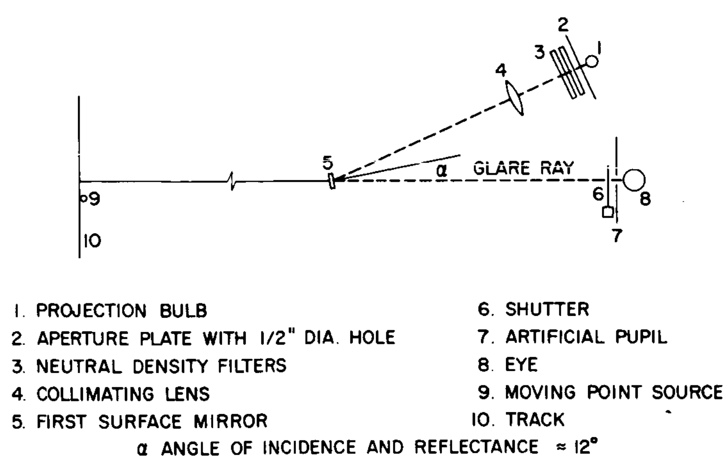

Fig. 1.- Schematic Diagram of Apparatus.

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is a schematic diagram of the optical system used. Circular, square, and triangular shapes were used, each having the same frontal area in order to equate total photic flux to the eye. When viewed at a standard distance all mirrors (glare sources) subtended wholly foveal visual angles. The maximum glare-source dimension subtended 1° 12' 00" arc. For this study the circular mirror visually simulated the sun with several restrictions, one of which was its angular dimensions and another its color temperature (3250° K). The sun can be characterized by the spectral radiative output of a 5800° K black body.[4-8] The apparent luminous intensity of the mirrors was considerably less (65%) than that of the sun for safety reasons; however, all mirrors appeared very white and bright as does the sun from orbital altitude. The square and triangular mirrors can be thought of as simulating specular reflecting man-made objects in space which reflect solar radiation into an observer's eyes.

The point source used to simulate, visually, a navigation referent-star was a 15-watt incandescent lamp within an enclosure having a small hole through which it shone directly into the observer's eye. The star had a luminance of 0.8 candle and subtended a visual angle of 7' 12" at mean viewing distance. It must be noted that although this simulation is only approximate, the star appeared very similar to a star of 0.3 magnitude, such as Rigel.

The star moved, in the frontal plane, on a track behind the glare source at a constant velocity of 5' 30" visual angle per second which has been shown to be suprathreshold for these viewing conditions.[9-11] This motion appeared to the observer as if the glare source were traveling in front of a stationary star. The track, upon which the star traveled, rotated about an axis which coincided with the visual axis. This made it possible to rotate the track (like a propeller) into any frontal-plane meridian. Eight meridians, each separated by 45° about the entire 360°, were investigated. Two directions of star motion were studied within each meridian since the star could travel both up and down the track.

A psychophysical method (limits)[12] was used to determine the point at which the observer perceived the star's disappearance behind the glare source as it traveled toward its edge (IN trial) and the point at which it once again reappeared from behind the glare source (OUT trial). Statistical analysis of results was based upon the means of IN - OUT trials for each side of the glare source within each meridian. Observer response variance was analyzed over all conditions.

Five highly trained male observers (mean age = 24.2 years) took part. All had 20:20 vision and all observed the stimulus arrangement through a 3-1/2-mm-diameter artificial pupil. This was used in order to control the amount of photic flux to the retina. Without it the natural pupillary fluctuations would likely be quite different among observers.[13] All observers were dark adapted for at least 10 minutes before testing.

A shutter opened to allow the observer to see the glare source and moving star. The shutter was open for 33% of the total trial time or approximately 10 seconds. Within this time the observer fixated the center of the glare source and attended to the approaching star. Previous studies had shown that an observer can voluntarily fixate an intense glare source within a circle having a diameter which subtends 45' of arc.[14] The instant the star disappeared the observer released a finger button. This response recorded the star's track position and closed the shutter. Twenty seconds later, when the shutter opened, the observer again fixated the glare source and tried to perceive the reappearance of the moving star at which time he again released his finger button. The direction of travel of the star was reversed 180° and the entire procedure was repeated for a total of 12 trials per meridian. The reader is referred to Ref. 15 for a more detailed account of the procedure used.

RESULTS

Some rather interesting results were obtained. (1) The distance, in visual angle, from the perceived edge of a glare source at which a star disappears (or reappears) is directly related to the luminance of the glare source. This appears to be a curvilinear function which accelerates rapidly at about 1000 ft L and again begins to decelerate at about 4000 ft L. Figure 2

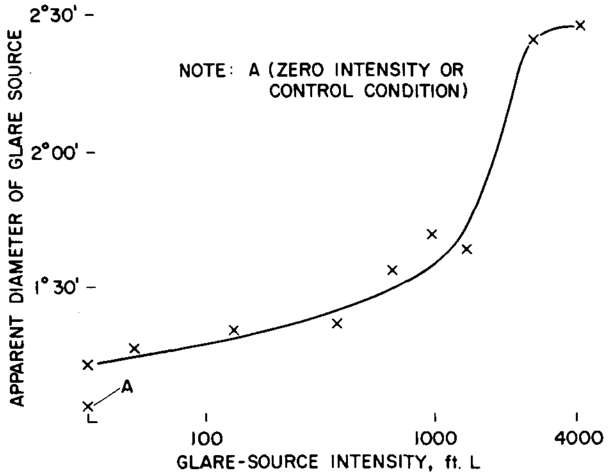
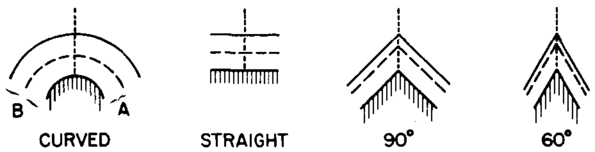


Fig. 2.- Effect of Glare-Source Intensity Upon Its Apparent Size.

illustrates this finding, which is somewhat larger than those obtained for two point sources.[3] (2) The star disappears and reappears at different apparent distances from the edge of the glare source, depending upon what kind of edge geometry exists. An example of a straight edge can be found on the sides of the square and triangular mirrors. The edge of the circular mirror provides an example of a curved edge. The star disappears and reappears farther from the curved edges than it does for straight line edges under equivalent luminance conditions. Figure 3 presents these data. (3) Under relatively high luminance viewing conditions the perceived shape of the glare source differed from the physical form of the mirror used. This is illustrated in Figs. 4, 5, and 6. (4) The apparent size of the glare source increased as a function of its luminance. This rather well-known phenomenon has been called irradiation.[16,17] This effect can also be seen in the previous three figures. (5) Response variance tended to be larger under the higher luminance conditions than under lower luminance conditions; however, variance did not appear to be significantly affected by either the shape of the glare source or the meridian of travel of the star.



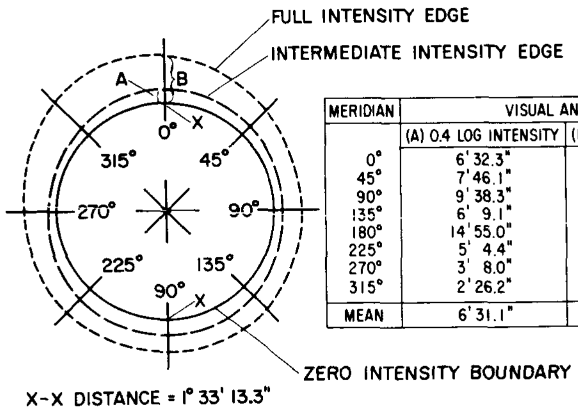
----- PATH OF POINT SOURCE
—— FULL INTENSITY
—— 0.4 LOG INTENSITY

EDGE GEOMETRY	VISUAL ANGLE	
	B	A
CURVED (16)*	12' 29.3"	6' 26.8"
90° (8)	8' 26.7"	5' 36.1"
60° (6)	8' 35.7"	6' 41.1"
STRAIGHT (14)	7' 33.8"	3' 31.8"

* INDICATES NUMBER OF SETS OF SIX IN AND SIX OUT TRIALS EACH VALUE IS BASED UPON

Fig. 3.- Effect of Glare-Source Edge Geometry Upon Point Source Disappearance and Reappearance Position.

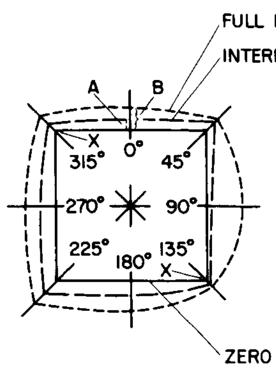
(CIRCLE)



MERIDIAN	VISUAL ANGLE	
	(A) 0.4 LOG INTENSITY	(B) FULL INTENSITY
0°	6' 32.3"	20' 35.9"
45°	7' 46.1"	13' 16.5"
90°	9' 38.3"	12' 39.2"
135°	6' 9.1"	12' 47.0"
180°	14' 55.0"	13' 8.0"
225°	5' 4.4"	12' 26.6"
270°	3' 8.0"	13' 8.0"
315°	2' 26.2"	20' 33.0"
MEAN	6' 31.1"	14' 29.5"

Fig. 4.- Effect of Glare-Source Luminance Upon Perceived Size and Shape.

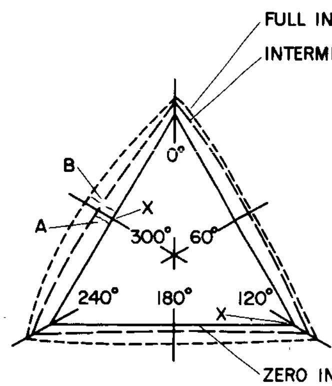
(SQUARE)



MERIDIAN	VISUAL ANGLE	
	(A) 0.4 LOG INTENSITY	(B) FULL INTENSITY
0°	5' 16.3"	8' 59.2"
45°	7' 1.8"	7' 57.4"
90°	0' 37.9"	12' 3.3"
135°	5' 51.5"	8' 50.0"
180°	4' 37.6"	11' 7.8"
225°	8' 31.4"	14' 9.2"
270°	3' 59.7"	9' 22.4"
315°	9' 49.1"	14' 18.3"
MEAN	5' 36.6"	10' 31.2"

Fig. 5.- Effect of Glare-Source Luminance Upon Perceived Size and Shape.

(TRIANGLE)



MERIDIAN	VISUAL ANGLE	
	(A) 0.4 LOG INTENSITY	(B) FULL INTENSITY
0°	6' 41.4"	6' 58.3"
60°	0' 2.6"	8' 0.8"
120°	6' 55.4"	10' 8.7"
180°	3' 7.7"	7' 15.7"
240°	9' 37.2"	11' 5.1"
300°	6' 44.2"	13' 34.8"
MEAN	5' 31.0"	9' 22.2"

Fig. 6.- Effect of Glare-Source Luminance Upon Perceived Size and Shape.

DISCUSSION

The above findings present data with which to approach a celestial navigation task analysis. Even though the celestial space environment was not accurately simulated, its gross visual aspects were adequately simulated for this purpose.

If a star is going to be chosen as a navigational referent with respect to either the perceived edge of the sun's photosphere, which is unlikely, or some man-made object having a high luminance (direct or reflected), optical filters will have to be used to reduce the photic flux to such a level that the physical edge of the referent can be accurately perceived.[18-20] Another approach would be to calculate the visual angle between the edge of the glare source and point of disappearance (or reappearance) of the star. This, however, requires knowledge of many visual parameters as well as requiring appropriate tables or calculators.

As has been suggested many times before, navigational sightings should be confined to a vision envelope which does not include any extremely bright sources aimed in the direction of the eye.[21-23] In the past this suggestion has been based primarily upon two factors: (1) fear of damage to the visual system or of temporary flashblindness, and (2) the raised visual threshold accompanying such a situation. Aside from these considerations the present study has shown that without adequate luminance attenuation the glare source will appear larger than it actually is, will appear quite rounded, and will cause an approaching (or receding) star to eclipse relatively far from its actual edge. These considerations prompt us to develop adequate filtering devices. One such device is discussed below.

The author feels that an electro-optical light shutter that is molecular in speed, nonabsorptive, not limited in area, linear, and operable with less than 100 volts peak signal is needed. Such a device has been proposed.[24] This optical shutter operates upon the principle of electrically induced birefringence within component layers of a multilayer interference filter. A further design parameter must be that only a given portion of the visual field must be filtered leaving the periphery unfiltered and thus usable for celestial navigation purposes. In order to accomplish this last requirement an appropriate head-position sensor must be developed with which to control the exact position, size, and shape of optical density upon the window. The magnitude of optical density could be a function of glare-source luminance. In this way any required glare-source luminance could be achieved for navigational use.

Regarding the findings that perceived shape differs from the physical form of the glare source it seems obvious that if navigation involves the visual identification of an object in space on the basis of its perceived shape, under high luminance levels, the actual object may differ quite remarkably from its reported frontal plane shape. Of course it is unlikely that there will be many perfectly flat specularly reflecting objects in space because much of the flat sheet materials used in the outer skin of space vehicles are bent or rolled into cylinders or conic forms. A specular reflection from such a surface would appear as an intense line with a very steep luminance gradient on either side (neglecting shadows).[25] Spherical specularly reflecting surfaces would appear as points.[26] Because there is a lack of any scattering atmosphere in space,[27] the physical edge of such vehicles would probably only be perceived as an "assumed line" where background stars become eclipsed.[23] The fact remains, however, that visual identification of highly luminous objects in space, on the basis of their shape, may lead to incorrect identification.

The response variance, which tended to be larger under higher luminance conditions, could be explained by several factors. Differences in response time as a function of glare-source luminance and/or inability to perceive the dim star within the veiling luminance surrounding the glare source (at the same place each trial) might be two factors. For equivalent luminance conditions, viewing a particular glare-source shape had no significant effect upon response variance.

SUMMARY

In view of the fact that the luminance levels used in the present investigation were well below those actually existing in space, caution must be exercised when extrapolating these findings. It is possible to state several conclusions based upon this research: (1) Celestial navigation and guidance techniques involving the human visual system should avoid visual fields that include high luminance sources, at least until adequate optical filtering devices are perfected. (2) If navigational sightings are performed using high luminance sources as reference objects of approximately 2000 ft L apparent luminous intensity or greater, one must expect rather large errors in estimating star eclipse angles (from the edge of the luminous source). (3) Under high luminance conditions one is likely to perceive size and shape characteristics of the glare source which may misrepresent the actual glare producing object.

Further work is needed in this and related areas in order to establish greater understanding of this complex phenomenon.

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