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SYSTEMS NOTE 67

VEILING GLARE FROM SPECTACLES AND VISORS IN AVIATION

by

B. A. J. CLARK

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SYSTEMS NOTE 67

VEILING GLARE FROM SPECTACLES AND VISORS IN AVIATION*

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B. A. J. CLARK

SUMMARY

Veiling glare from surface scratches, turbidity and fluorescence in spectacles and visors may have a significant effect on the vision of pilots. The problems of measuring the stray light produced by these items are indicated, and results of some actual measurements are presented in the form of a single index for each sample under representative conditions. Such an index may provide a way of avoiding premature replacement of expensive items, as well as indicating items which have become a flight safety hazard.

The techniques appear suitable for extension to aircraft transparencies, and to related fields such as the effects of veiling glare on the vision of motor vehicle drivers.

* Presented at a meeting of Working Party 61, Air Standardization Coordination Committee, Canberra, November 1978.

POSTAL ADDRESS: Chief Superintendent, Aeronautical Research Laboratories, Box 4331, P.O., Melbourne, Victoria, 3001, Australia.

DOCUMENT CONTROL DATA SHEET

Security classification of this page: Unclassified

1. Document Numbers (a) AR Number: AR-001-732 (b) Document Series and Number: Systems Note 67 (c) Report Number: ARL-Sys-Note-67	2. Security Classification (a) Complete document: Unclassified (b) Title in isolation: Unclassified (c) Summary in isolation: Unclassified

3. Title: VEILING GLARE FROM SPECTACLES AND VISORS IN AVIATION

4. Personal Author: B. A. J. Clark	5. Document Date: April, 1979
	6. Type of Report and Period Covered:
7. Corporate Author(s): Aeronautical Research Laboratories	8. Reference Numbers (a) Task: DST 78/112
9. Cost Code: 73 6640	(b) Sponsoring Agency: DSTO
10. Imprint: Aeronautical Research Laboratories, Melbourne	11. Computer Program(s) (Title(s) and language(s)): Nil

12. Release Limitations (of the document):
Approved for public release

12-0. Overseas:	N.O.		P.R.	1	A		B		C		D		E	

13. Announcement limitations (of the information on this page):
No limitation

14. Descriptors:		15. Cosati Codes
Optical properties	Windshields	0510
Optical measurement	Goggles	0616
Glare	Transparent panels	2006
Visual perception	Eyeglasses	

16. *ABSTRACT*

Veiling glare from surface scratches, turbidity and fluorescence in spectacles and visors may have a significant effect on the vision of pilots. The problems of measuring the stray light produced by these items are indicated, and results of some actual measurements are presented in the form of a single index for each sample under representative conditions. Such an index may provide a way of avoiding premature replacement of expensive items, as well as indicating items which have become a flight safety hazard.

The techniques appear suitable for extension to aircraft transparencies, and to related fields such as the effects of veiling glare on the vision of motor vehicle drivers.

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1. INTRODUCTION

Brightness discrimination is a fundamental aspect of vision. Luminance is a psychophysical correlate of brightness. Many experiments have shown that for an object of luminance L surrounded by a background of luminance L_b to be seen as a separate entity, the contrast $(L - L_b)/L_b$ must exceed some threshold magnitude, the value of which depends on several factors such as the state of adaptation of the eye, the shape and extent of the object, and colour differences between the object and background (Ref. 1). If the object is observed through a nominally transparent optical medium which scatters light to some extent, the 'veiling glare' corresponding to the scattered light has the effect of reducing contrast, regardless of whether the object is lighter than the background (positive contrast) or darker (negative contrast). However, the effects are much more important in the case of negative contrast and a small object. If the object is not thereby made invisible it will at least be harder to see or will be less noticeable. In an aircraft, pilots usually have to look through the windshield, windows or the canopy (collectively, the 'transparencies') to see external objects. Pilots may also be using visors, corrective spectacles, contact lenses, sunglasses and/or goggles. Stray light (which includes scattered light, light reflected from optical surfaces, component edges, mounts, etc. as well as fluorescent light) from all such items in use is additive but the optical quality of transparencies and ophthalmic lenses is generally so good that much of the time, veiling glare is unobtrusive. On occasions, however, veiling glare can be severe, as in trying to see into a shadow-filled valley through a hazy windshield which is illuminated by direct sunlight. This paper is directed at the problem of specifying the maximum allowable quantity of stray light for in-service components. In Australia, at least, there is at present apparently no standard method for the precise *in situ* measurement of stray light in transparencies, visors etc. so that these components are currently discarded only when some individual has judged their deterioration to have introduced a flight safety hazard. Apart from the point that this presumed criterion may be too lenient from an operational effectiveness aspect, visual judgments will inevitably lead to a situation in which some components are replaced prematurely with attendant unnecessary costs and others will be replaced too late with consequent increased hazard. The ultimate aim, not reached in this paper, is to devise a simple procedure for accurately designating the rejection point. This paper introduces the problem and describes a technique which might form the basis of such a procedure.

2. LITERATURE REVIEW

2.1 Stray Light from Optical Components

The adverse effect of windshield haze and surface dirt on visual target detection range was studied at least as long ago as 1943 (Luczak, cited in Ref. 2). Losses in range were shown to increase with viewing angle of incidence. Grether (Ref. 2) mentioned other previous work and pointed out that transparency haze contributed to 'glare' as well as loss of target contrast when looking near high intensity light sources such as the sun; usually both discomfort glare and disability glare would be present in that type of situation.

'Haze' is not well defined in the literature. Sometimes it appears to encompass all sources of stray light, viz. coarse and fine surface scratches and pits, stress-solvent crazing (Ref. 3), dirt and dust, minute water droplets formed by the action of rain repellent coatings (Ref. 4), multiple reflections from surfaces including lamination interfaces (Ref. 5), and inherent properties of transparency materials such as inclusions, turbidity and fluorescence. At other times its meaning is more restricted. There is sometimes an ambiguity between its use for windshields and the long-established usage of the term in meteorology (Ref. 6).

Studies of the optical properties of spectacle lenses, sunglasses and goggles are numerous but few deal with the problem of stray light. Even fewer adopt a quantitative approach and in general the limits specified for stray light are arbitrary values for haze measured on one of the commercial 'hazemeters' described in the following section (e.g. Ref. 7).

Stray light in human eyes has been studied far more carefully (e.g. Ref. 8). Briefly, the luminance of the stray light around a small source imaged on the retina falls off approximately as the square of angular distance from the source, the total amount of stray light being about 10 per cent of the incoming beam in young eyes and more in older eyes (much more in the case of cataract). The stray light has a spectral distribution not much different from the incoming beam, except when the incoming beam has an appreciable component of ultraviolet radiation (approx. 320 *nm* to 380 *nm*), in which case the stray light has an additional component of fluorescent light, mostly in the region 400 *nm* to 500 *nm*. Whiteside (Ref. 9) deduced that fluorescence of the crystalline lens at 10 000 *m* altitude should be twice as intense as at ground level and thought that this was the reason for a veiling glare observed in cockpits at high altitude. An experiment to test this hypothesis proved negative. It was later shown that the experiment was invalid because the yellow filters used to shield the eyes from ultraviolet radiation were themselves fluorescent (Ref. 10). Fluorescence in ophthalmic lens materials has been shown to decrease visual acuity in laboratory tests (Ref. 11), despite the low sensitivity of acuity tests to veiling glare (Ref. 12).

2.2 Existing Techniques of Measurement

North American practice for many years in the measurement of haze and luminous transmittance of transparent plastics is based on American National Standard K65.5 (Ref. 13). The test may be performed either with a Hardy-type recording spectrophotometer or, as a simplified procedure, with commercial hazemeters. Briefly, the latter test takes the form that light from a known source (e.g. CIE Source A or C) passes into an integrating sphere giving a photometric reading T_1. With the specimen in the beam, the total (direct plus diffuse) transmission gives a reading T_2. A light trap in the sphere, without and then with the specimen in place, gives respective readings T_3 for the instrumental stray light and T_4 for the instrument plus sample stray light. Then the total transmittance of the sample is

$$T_t = T_2/T_1\,,$$

the diffuse transmittance is

$$T_d = (T_4 - T_3\,(T_2/T_1))/T_1\,,$$

and the haze value is

$$\text{Haze, per cent} = T_d/T_t \times 100.$$

Haze values regarded as acceptable for eye protection filters and aircraft transparencies range from ½ per cent to 6 per cent (Refs 2, 3, 7, 14).

Bauer *et al.* (Ref. 14) devised a different procedure with the aim of relating the measurements more directly to the performance characteristics of the human eye. The luminance L_s of the stray light is proportional to the illuminance E at the light scattering sample, so that

$$L_s = l\,E\,,$$

where l is called the luminance coefficient. This coefficient has units which are more meaningful if left as $(cd/m^2)/lx$ rather than simplified to sr^{-1}. The value of the coefficient depends on the direction and spatial distribution of the incident light. If the luminous transmittance of the sample is T, the reduced luminance coefficient l^* is defined as

$$l^* = l/T\,,$$

a quantity of particular value in characterizing welding filters in terms of stray light effects on the apparent contrast of objects seen through the filter. Bauer *et al.* gave several photometric methods for measuring l^*, all of which use a small on-axis source of light with a dark surround, and by comparison with hazemeter measurements of actual samples, l^* of 0·2 $(cd/m^2)/lx$, the value specified in the German standard for welding filters, is about equivalent to a haze value of 0·16 per cent. The North American standards are much less stringent. Bauer's method has recently been proposed as part of new international standards for eye protection filters.

Allen (Ref. 15) used another approach in a study of how windshield surface damage and dirt affect vision in night driving. By analogy with a formula for ocular stray light ($L_s = 10\ E/\theta^2$ where L_s is the luminance of the ocular stray light at an angle θ from a source producing an illuminance E at the eye), Allen used $L_s = 10\ E/\theta^n$ for windshields and called L_s/E the veiling luminance factor. Measurements of L_s as a function of θ were made at night on a number of windshields illuminated by a vehicle headlight. The direct view of the headlight was obscured for a camera aimed through the windshield by an opaque spot subtending about 6°; the stray light aureole was photographed and the luminance of the stray light determined by densitometry. The exponent n in the above equation appeared to be about 2. For many of the in-service windshields tested, the stray light was comparable in magnitude with the intra ocular stray light given by the θ^2 formula.

Martin (Ref. 16) described a technique, used at least as early as 1922, for measuring 'glare' or stray light in optical instruments. The instrument under test is aimed at a uniform extended bright field and a photometric reading taken at the centre of the instrument's field of view. A black spot is then placed in the bright field so that the photometer measures only the stray light overlying the spot image. The second reading, expressed as a percentage of the first, is an arbitrary measure of the stray light. Methods of this sort are often termed 'black spot' methods although the spot is sometimes a dark cavity. Martin pointed out how the popularity of these methods arose from their relative simplicity and sensitivity: the large field gives a stray light signal that is much greater, and therefore easier to measure, than when small object sources are used. However, he developed a method in which both the object and measuring aperture were of small angular subtense and had independence of positioning in the object and image planes respectively. 'Glare spread functions' obtained by this method can be used to predict the distribution and luminance of the stray light for any luminance distribution in the object plane.

2.3 Discussion

Martin's method gives fundamental information about the stray light in optical instruments but it is a laboratory technique and presumably time consuming. All of the other methods described are more or less dependent on the geometry of the measuring arrangements and extension of the results to other arrangements is at best of uncertain value. Of course, these methods fulfil their respective purposes adequately, and ease of routine testing presumably takes precedence over esoteric considerations such as the errors introduced by finite detector apertures.

The problem at hand is how to measure the stray light in transparencies, visors and ophthalmic lenses used in aviation in a way which allows prediction of visual performance losses in practical situations. In turn, knowledge of the visual loss associated with stray light should then allow limits to be set for in-service deterioration. Particularly in the case of transparencies, a test is needed for field measurements with the component in situ. This need not be the same test as that used for visual performance prediction but it should preferably be relatable to visual performance, if possible.

The visibility of one aircraft seen from another is a matter of considerable importance in aviation. If, for reasons of poor meteorological visibility, aircraft have to operate under instrument flight rules, collision avoidance is provided by the air traffic control system. In visual meteorological conditions (VMC) by night, the usual flashing and fixed lights on aircraft are bright enough to give plenty of time for collision avoidance in most cases. In VMC by day, however, lights may be of little or even negative value and collision avoidance depends critically on how well aircrew can see other aircraft. If the sun is shining, the detection difficulty may be reduced by the glint of the other aircraft, but will be increased, possibly greatly so, by direct sunlight falling on the transparency through which the observation is being made. Martin's technique could, no doubt, be adapted to cope with such situations but the labour involved could be excessive because of the ranges of angles possible between the transparency, sun and target aircraft, quite apart from the variability of glint.

It seemed more promising to try a less complex approach: simply to set up a viewing situation which could be regarded as representative of actual conditions and to measure, at least for a few typical samples of transparencies, visors and lenses, the amount of stray light which may be found in practice. With these measurements, it would then be possible to use standard visual performance data to gain some idea of the visual losses associated with the observed amount of stray light.

3. A PRACTICAL TECHNIQUE

3.1 Arrangement of Apparatus

The technique should be reasonably representative of in-service conditions of illumination, viewing direction and so on. Observations in flight might appear worth pursuing because of the face validity thereby obtained, but the disadvantages of trying to make precise photometric measurements in an aircraft subject to vibration, attitude changes, lack of space and considerable operating expense dictate that the initial experiments at least ought to be done on the ground, and not even in an aircraft on the ground until some experience has been gained with a simpler arrangement.

The arrangement chosen is shown in Figure 1. A telephotometer with an external aperture stop was used to observe a black hole in a box. The observations were made outdoors, usually with the sun at about 45° from the telephotometer axis. This value of the angle was chosen because in temperate latitudes it is possible for much or all of each day (the exceptions mostly being near noon in summer) to attain this angle while keeping the photometer axis horizontal, simply by selecting an appropriate bearing angle for the photometer. The aperture stop with the sample close in front of it was meant to provide some similarity with the relative position of the eye and lens or visor in actual use. The proximity of sample and stop also prevented light from behind the photometer being reflected from the sample directly into the instrument and thereby giving erroneous readings. The aperture of the stop (an iris diaphragm) at its minimum opening was 10 mm, somewhat larger than the human pupil in daylight but this was considered to be unimportant. The stop was far enough from the objective lens of the telephotometer to prevent direct sunlight from falling on the lens, thus minimizing stray light in the photometer.

3.2 Theory

It is helpful if the black spot has a negligibly small luminance. Figure 2 shows the arrangement of the box with a black hole. An inclined surface within the box was intended to remove any adverse effect of a specular reflectance component from the surface visible through the hole. From a viewpoint within the box, a part of the horizon or its vicinity could be seen through the hole. The hole would thus have the same luminance as the horizon, here assumed constant at L_H and the intensity of the hole is thus

$$I = L_H \, r^2 .$$

The illuminance on the inclined surface

$$E = I \cos \theta / d^2$$

$$= L_H \, r^2 \cos \theta / d^2 .$$

Seen from outside the box, the inclined surface with diffuse reflectance R has a luminance

$$L_s \approx RE/\pi$$

$$\approx L_H \, (r^2 \, R \cos \theta / d^2).$$

In the actual box used, all internal surfaces were painted matt black ($R \approx 4\%$) and the factor in brackets had a numerical value of 0·000 051. If the luminance of the white surface surrounding the hole is comparable with the horizon luminance, the luminance of the white surface is 20 000 times that of the hole. This was considered satisfactory. (Actually the hole would have been slightly fainter if the inclined plane had been removed but this was found only after the box had been completed. If black gloss paint with a diffuse reflectance of 0·2 per cent had been used on the inclined plane, the hole would have been fainter by a factor of about 20. The box was adequate in its original form for the present experiments and no changes were made.)

The sequence of telephotometer measurements used in stray light measurement was:

(a) Measure the apparent luminance of the black hole, L_1. This gives the sum of the actual luminance of the hole and the instrument stray light.
(b) Measure the luminance L_2 of the white area surrounding the hole.
(c) Repeat (a) and (b) with the sample of unknown luminous direct transmittance T in front of the photometer aperture stop. This gives readings L_3 and L_4 respectively. In both of these measurements, scattering by the sample has added an apparent luminance increment $L_s = l\,E$ where l is the luminance coefficient and E the illuminance on the sample.
(d) Reverse the positions of photometer and black hole to allow E to be deduced from the luminance of the white surround if l is of interest.

Then,

$$L_3 = TL_1 + L_s$$

and

$$L_4 = TL_2 + L_s\,,$$

therefore

$$T = \frac{L_4 - L_3}{L_2 - L_1}$$

and

$$L_s = L_3 - TL_1\,.$$

L_s is an index of the performance of the sample, and L_s/E gives the luminance coefficient which is also an index of performance. Another index, S, can be defined by

$$S = \frac{L_s}{L_4 - L_3}\,;$$

it can be used in calculating the contrast loss for targets viewed through the sample. It can be expressed as a percentage but care must be taken not to confuse the values with hazemeter results as the two are quite different in derivation.

3.3 Practical Ground Trials

'Ground' here means not in an aircraft; in fact, the trials were carried out on top of a bituminous roof with an almost unobstructed view of the sky down to the skyline of distant buildings. The photometer (Spectra Pritchard Model 1980) was focused on the black hole which was about 2 m away. This distance was chosen so that the 1° field aperture of the photometer was about 15 per cent smaller than the viewed size of the black hole. Luminance measurements of the hole did not change reliably when smaller field apertures were selected. Similar trials with some tinted lenses in front of the photometer objective gave comparable results, so that at least the technique gave promise of adequate field angle independence of the measurements.

The samples available for test included a demonstration set of ophthalmic tinted lenses*, some obsolete but new wide field goggle lenses (ex USAF), a piece of an ex RAAF visor, some transparency materials and an old pair of polarizing lenses.

Measurements were taken during a variety of weather conditions (viz. cloudless sky, overcast sky, and with the photometer looking at 45° either towards or away from the sun). These measurements produced little that was unexpected and indicated that the method appeared worth pursuing.

3.4 Results

Table 1 shows the results for the case of a cloudless sky and the sun shining on the samples at 45°. Note that the test underestimates the amount of stray light for the samples of plastic sheet representing canopy materials because of the closeness of the samples to the dark surface of the photometer objective; in practice, canopies tend to be illuminated from both sides and some additional back-scattered light could be expected.

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* Kindly made available by the Clinic of the Victorian College of Optometry.

Some check on the measurements was available in the case of samples for which the luminous transmittance was known independently. The most accurately known value was $T = 12.1\%$ for the ex RAAF visor*. Measurements on six different days with the Pritchard photometer gave a mean for T of $13 \cdot 6\%$ with a standard deviation of $1 \cdot 5\%$. The accuracy of the photometer for readings of this type is believed to be better than these results indicate and some improvement in the accuracy of the transmittance results, and presumably in the stray light results, was achieved during the later days of the whole series of observations by careful attention to details, most of which appeared unimportant in the beginning. An example is the need for the observer to have a fixed position and stance during the measurements on a sample, even though considerable movement is necessary in between each measurement as the sample is placed in or out of the beam, as the photometer is re-aimed and the range and filter settings are changed, and as the photometer readings are observed under the hood usually found necessary to exclude daylight from the digital display. The accuracy of the stray light measurements is not known. Presumably it is worse than that of the transmittance measurements because the reproducibility was not quite as good. Much of the extra variation appears likely to have arisen from the difficulty, with the sample holder used, of ensuring precise realignment of the sample with the photometer. The surface density of surface damage on most of the samples varied visibly across their surfaces.

4. DISCUSSION

Consider a meniscus ophthalmic lens of perfectly clear glass with no surface defects. If light from a bright surround is reflected firstly from the rear surface and then from the front so as to overlie a small black target, the value of S would be about $0 \cdot 16\%$. If the lens were tinted and had a transmittance T, the multiply reflected light would be reduced by the factor T^2 so that in this case S would be $0 \cdot 16T\%$. This gives some idea of the smallest values that could be expected for S. The experimental technique and equipment used certainly had sufficient sensitivity to detect values of S well below $0 \cdot 1\%$. Only one of the samples listed in Table 1 had such a small value for stray light. The question now arises as to what effect a given value of S produces in terms of degradation of visual performance.

An example will serve to illustrate the method. The visual performance data are taken from the imperial unit nomograms given by Middleton (Ref. 6). For convenience, nominal values were chosen to begin with and were subsequently converted to *SI* units. Consider a pilot wearing a visor with $T = 13\%$ observing an oncoming aircraft with cross-sectional area of $1 \cdot 86\ m^2$. The aircraft has negative contrast of $0 \cdot 05$ against an overcast sky with luminance $263\ cd/m^2$ and the meteorological visibility V_2 is assumed to be $1524\ m$. The aircraft would normally be visible at a distance of $914\ m$. The apparent surround luminance is 13% of $263\ cd/m^2$, which is $34 \cdot 2\ cd/m^2$. From the stated contrast, the oncoming aircraft would have an apparent luminance of $32 \cdot 5\ cd/m^2$ in the absence of any stray light in the visor. However the visor does produce stray light and the effect of this is to lighten the oncoming aircraft by S times the surround luminance. (The surround is darkened also, but only by an imperceptibly small amount.) For the purpose of this example, assume that the visor and canopy together have $S = 2\%$, an unusually small value judging by the results in Table 1. The apparent luminance of the aircraft would thus be $32 \cdot 5 + 0 \cdot 02 \times 34 \cdot 2$ which is $33 \cdot 2\ cd/m^2$, and the apparent contrast is therefore $-0 \cdot 03$. The threshold distance now becomes $704\ m$.

This example is certainly not an extreme case. It does illustrate the importance of minimizing stray light in the interests of minimizing degradation of visual performance. The rejection values for S cannot be decided on a vision basis only: clearly, cost-benefit studies would be needed. In the meantime it is also apparent that work in this field should be extended to include measurements in aircraft and the development of a simple field test method for visors and transparencies in service. It may well be that some relationship can be found between hazemeter and S values, especially if the hazemeters have a light source approximating *CIE* Illuminant D_{6500} and thereby take acount of any fluorescence likely to be encountered in practice.

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* Kindly measured on a Cary Model 14R spectrophotometer and computed for Illuminand C by Dr Lewis Freeman at Materials Research Laboratories, Maribyrnong, Victoria.

5. CONCLUSIONS

Stray light in optical and ophthalmic media used in aviation can have a severely detrimental effect on visual performance in conditions where targets of low negative contrast are observed by natural light. Standard hazemeter techniques for measuring stray light do not give results that can be readily applied in terms of visual performance loss. A 'black spot' photometric technique used in representative natural light conditions was developed to give results which can be applied in visual performance calculations. Samples of ophthalmic tinted lenses, visors, goggles and aircraft transparency materials were tested by this method and an example of the use of these results showed how the threshold detection distance of an approaching aircraft could be severely reduced by an apparently innocuously small amount of stray light. Extension of the measurements to actual aircraft situations appears warranted. For discrete samples, the variability of natural lighting conditions should be overcome by suitable laboratory techniques and ultimately this should lead to the development of a simple field method for monitoring the condition of in-service aircraft transparencies and aircrew visors and sunglasses. The rejection value set for stray light in such a method would need to be determined by cost-benefits studies.

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TABLE 1
Stray Light Measurements

Sample	S %	Usage
Clear glass spectacle lens	0·8	Demonstration lens set, surfaces appeared almost as new
Green CR39 lens	1·5	
Brown glass lens	3·2	
Tinted lens set:		
$T = 84\%$	1·6	
78	2·1	
43	3·5	
15	0·1	
Polarizing sunglass lens	51·6	Scratched beyond reasonable usage
Goggle lenses:		
green	26·1	New but obsolete
amber	12·5	
clear	6·8	
Neutral tint visor	30·4	Discarded by pilot
Methyl methacrylate sheet	3·3	Equivalent by visual comparison to about two months of use as aircraft canopy
Polycarbonate sheet	12·3	

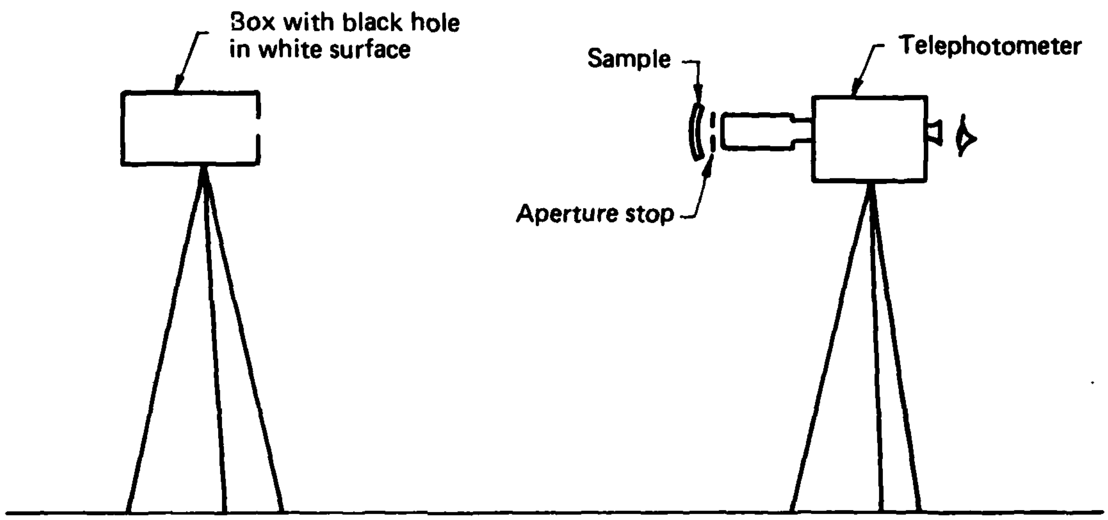

FIG. 1 ARRANGEMENT FOR STRAY LIGHT MEASUREMENT

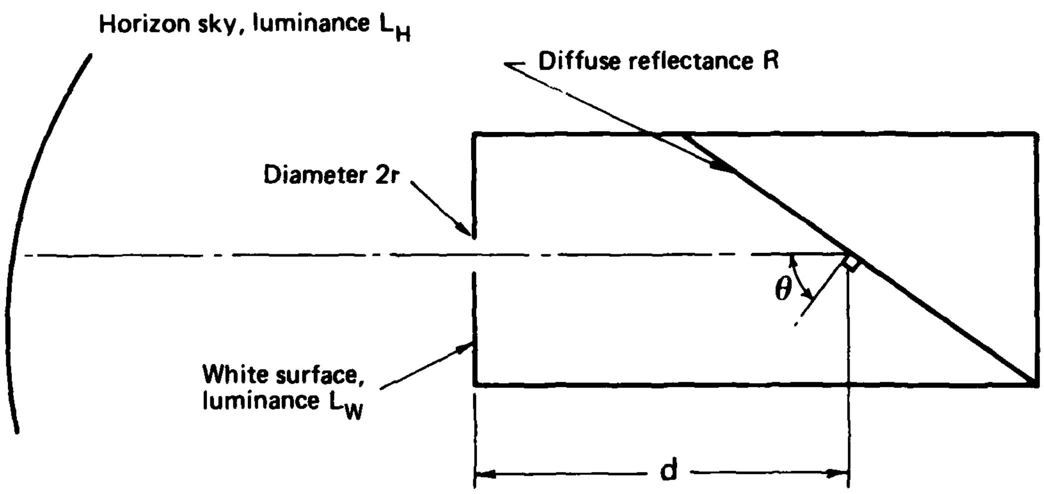

FIG. 2 BOX WITH 'BLACK HOLE'.

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