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20 January 1936

NRL Report No. H-1230

FR-1230

NAVY DEPARTMENT  
BUREAU OF ENGINEERING

Report on

Airplane Camouflage. Preliminary Report on  
Reduction of Visibility by  
Artificial Illumination.

NAVAL RESEARCH LABORATORY  
ANACOSTIA STATION  
Washington, D.C.

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Declass by Auth  
of NRL Memo 2028-507  
Ser 3368 on  
15 May 1959 GH Fowler  
RDC NRCE

No. of Pages: Text - 7 Plates - 6

Authorization: BuAero.let. Aer-E-22-EP(F39-5) of 8/1/34.

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A B S T R A C T

Measurements were made on winter days at Washington of the brightness of the sky and of Navy gray and white surfaces illuminated by a 4 kilowatt searchlight. From the measurements it is estimated that to make the shadow areas of surfaces of an airplane aloft approach the sky in brightness

(Navy gray must be increased in brightness by 700 to 1000  
foot candles.)

(White paint must be increased in brightness by 500 to 800  
foot candles.)

This requires an illumination of

(2100 to 3000 foot candles.)  
(750 to 1200 foot candles.)

which requires

(50 to 75 kilowatts) for each 100 square feet of illuminated area.  
(15 to 25 kilowatts)

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CHAPTER I

INTRODUCTION

References: (a) BuAero.let.Aer-E-22-EP(F39-5) of 8/1/34.  
(b) OpNav.let. Op-22-B(SC)A21 Serial 1467 of 11/9/35.  
(c) BuAero.let.Aer-E-252-RL(F39-5) of 11/23/35.

AUTHORIZATION

1. This problem was authorized by reference (a). References (b) and (c) are also pertinent.

2. The suggestion has been made, references (b) and (c), that the visibility of an airplane in the daytime viewed against a sky background might be reduced by illuminating with artificial lights on the plane those areas which are in shadow and hence usually darker than the sky background. Estimates were requested based on any reasonable assumptions of the amount of illumination necessary. It was realized that the suggestion is an old one; it is mentioned in reports of the World War, but as far as is known, no attempt has been made to put it into practice.

SCOPE OF THE PRESENT REPORT

3. As described in the following paragraphs, measurements have been made of the brightness of the sky in the daytime in sunny and cloudy weather of various surfaces in shadow with and without artificial illumination. From these data estimates are made of the airplane lighting installation which indicate that at least a one kilowatt light, or the equivalent, for each four square feet is necessary.

4. Probably first thoughts in connection with the scheme are somewhat as follows: An airplane is at a distance of a few miles from an observer at sea level and at an altitude of several thousand feet. It is assumed to appear to the observer as a small dark object against the sky. Suppose that there were lights properly disposed on the plane to illuminate the dark portions of the plane. The pilot turns on the lights and slowly increases their intensity by turning a handle. To the observer viewing the airplane from below the plane becomes less dark and its contrast with the sky background becomes less. When the plane becomes as bright as the sky background it vanishes from the view of the observer. Conceivably, the pilot could be provided with a little optical gadget which would enable him to tell when he had adjusted the intensity of the illumination to the correct value.

5. These ideas are theoretically sound, the picture is enticing, and although obvious practical difficulties immediately come to mind, it seemed of value to examine the ideas with care to estimate how much artificial illumination might be required to produce appreciable effects.

6. In this report the correctness of the assumption that the plane appear as a dark object against the sky is not discussed. Occasionally, of course, a Navy gray plane appears bright sky.

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## CHAPTER II

## EXPERIMENTS

(1) Measurements of Brightness of Sky and Various Surfaces.

7. Measurements were made of the brightness of a cloudless sky and of a sky covered with clouds on mid-winter days at this Laboratory. The sky brightnesses in foot-candles are given in Table 1 for various compass directions and altitudes above the horizon. The measurements were made with a Macbeth Illuminometer, Leeds and Northrup Company. It is seen from Table 1 that for the sun at an altitude of about  $30^\circ$  the brightness of the sky in regions not too close to the horizon was around 1000 foot-candles in both clear and cloudy weather. This is of course a very rough average statement; heavy clouds are darker and thin clouds are brighter than 1000 foot-candles. Such a case is shown in the data of the last column of Table 1, for when the data were taken the clouds to the east were heavy and dark, and to the west and overhead were thinner and much lighter.

Table 1

## Brightness of Sky in Foot Candles at Washington

<u>Direction</u>	<u>Altitude</u>	<u>Dec. 19, 1935</u> <u>Clear, 1 P.M.</u>	<u>Dec. 18, 1935</u> <u>Cloudy, 10:30 A.M.</u>
North	$5^\circ$	1220 foot candles	420 foot candles
	$30^\circ$	900	950
	$60^\circ$	830	1230
East	$5^\circ$	1030	380
	$30^\circ$	960	810
	$60^\circ$	760	570
South	$5^\circ$	1800	500
	$30^\circ$	near sun, greater than 3000	1280
	$60^\circ$	2200	1150
West	$5^\circ$	1600	670
	$30^\circ$	1540	1020
	$60^\circ$	1200	1300
Zenith		700	1300

8. The brightness of a Navy gray surface held vertical on the roof of the Laboratory was about 250 foot-candles in cloudy weather during the middle hours of a winter day; and was around 300 foot-candles in clear weather, the surface being in shadow. The brightness of white paper -- white blotting paper was used -- was about 460 and 500 foot-candles under similar conditions. The effects and numerical values are shown in the right-hand pictures of Plates 2 and 4.



9. The brightness of the underneath side of a horizontal Navy gray surface held about 10 feet above the roof of the Laboratory was about 80 and 100 foot-candles during the middle hours of a winter day in cloudy and clear weather, respectively. The brightness of a white blotting paper surface under respectively similar conditions was 150 and 200 foot-candles. The effects and numerical values are shown in the right-hand pictures of Plates 3 and 5.

10. From the foregoing data for altitudes of the sun not above  $30^\circ$  the following conclusions emerge:

To match the average brightness of the daylight sky there must be added a brightness of approximately

- Rule (a) 700 foot candles on the side of a vertical Navy gray surface in shadow,
- Rule (b) 500 foot candles on the side of a vertical white paper surface in shadow,
- Rule (c) 1000 foot candles on the underneath side of a horizontal Navy gray surface,
- Rule (d) 800 foot candles on the underneath side of a horizontal white paper surface.

These conclusions may be condensed into the rough working statement,

- Rule (e) The shadow areas of a Navy gray and a white painted airplane aloft in the daytime must be increased in brightness by 700 to 1000 foot candles and by 500 to 800 foot candles, respectively, to match the brightness of the average sky for solar altitudes not above  $30^\circ$ .

For solar altitudes above  $30^\circ$ , as in bright tropical weather, probably greater numbers of foot-candles than those just mentioned are necessary.

The reflectivity of a Navy gray surface was found by measurement to be about  $1/3$  or 30 to 35 percent, and of white paper or a white painted surface to be about  $2/3$  or 60 to 70 percent.

The illumination supplied by a source of light at any place is by definition the brightness in foot candles of a perfectly reflecting white surface at that place. Such a white surface is said to have a diffuse reflectivity of 1 or 100 percent. The brightness of any other surface at the place due to the illuminant is, then, the illumination multiplied by the reflectivity of the surface.



Rule (f) Therefore, referring to Rule (e) in order to brighten a Navy gray surface by 700 to 1000 foot candles, the illuminant must provide 3 times these numbers or 2100 to 3000 foot candles. Similarly, to brighten a white painted surface by 500 to 800 foot candles the illuminant must provide  $3/2$  times these numbers or 750 to 1200 foot candles.

(2) Experiments with Searchlight Illumination

11. To test these conclusions various surfaces were illuminated with a 24 inch carbon arc searchlight taking 100 amperes at 40 volts or 4 kilowatts. The arrangements are shown in Plate 1. Photographs of Navy gray and white blotting paper illuminated by the searchlight in clear and cloudy weather are shown in Plates 2, 3 and 4, and of a white wall, none too clean, in Plate 6. The measured brightnesses of the sky and the surfaces are marked on the photographs. The surfaces were in all cases about 10 feet from the searchlight. In the vertical positions, Plates 2 and 4, the surfaces were normal to the beam, the illuminated area being about 1.2 feet in radius or 4 square feet. In the horizontal positions, Plates 3 and 5, the surfaces were at an angle of  $30^\circ$  to the beam, the illuminated area being about 8 square feet; in this case, the surfaces were supported above the searchlight, and the searchlight beam directed up on to them at an angle of  $30^\circ$  to the horizontal. The dark segment in the circular beam of the searchlight, visible in most of the Plates and particularly in Plate 1, was the shadow of the carbon supports of the searchlight.

12. Qualitatively, it is seen from the Plates that the 4 kilowatt searchlight illuminated 4 square feet of a vertical surface of Navy gray and of white blotting paper sufficiently to make them brighter than the winter sky (Plates 2 and 4, left hand pictures); that it was sufficient to illuminate 8 square feet of a horizontal white paper to equal the sky brightness (Plates 3 and 5, lower left hand pictures); and that it was not sufficient to illuminate 8 square feet of a horizontal Navy gray surface to equal the sky brightness.

13. Quantitatively, the following calculation may be made: The surfaces were about 10 feet from the searchlight. At this distance the brightness of the beam was about 1800 foot candles over 4 square feet, which means that the brightness of a perfectly white surface normal to the beam would be 1800 foot candles and at  $30^\circ$  to the beam would be  $1800 \cos 60^\circ = 900$  foot candles. Hence the Navy gray surface normal to the beam should be brightened  $1/3 \times 1800 = 600$  foot candles and at  $30^\circ$  to the beam  $1/3 \times 900 = 300$  foot candles; similarly, the white paper should be brightened  $2/3 \times 1800 = 1200$  foot candles, and  $2/3 \times 900 = 600$  foot candles, respectively. These values are in rough agreement with the observed values given in Plates 2 to 5; the observed values are not very accurate, being open to errors of 10 or 15 percent, due to strong wind, unsteadiness of arc searchlight and variations of daylight, distances and angles. Referring to the experiment of Plate 6, the illuminated area of the wall was 20 square feet; hence the searchlight should have added  $1200 \times (4/20) = 240$  foot candles, which agrees well enough with the observed value 200 foot candles.

(3) Efficiency of Projection of Illumination

14. Engineering tables give the efficiencies of the open air continuous current carbon arc and of the gas filled tungsten lamp as 0.92 and 0.66 watts per spherical candle, respectively.

15. Therefore, the 4 kilowatt carbon arc should yield  $4000 \div 0.92 = 4400$  foot candles spread over a spherical surface of 1 foot radius or 12.6 square feet.

16. If this luminosity were compressed without loss, as by perfect reflectors and lenses, into 4 square feet, it should amount to an illumination of

$$4400 \times 12.6 \div 4 = 13600 \text{ foot candles.}$$

17. In the case of the 4 kilowatt searchlight of the present experiments the concave reflector occupied 1/4 of the total sphere; the diameter of the reflector was 23 inches and the focal length 10 inches. Therefore, 3/4 of the light was not used, being absorbed by the housing, and the number 13600 must be reduced to  $13600 \div 4 = 3400$  foot candles.

18. Of this only about 0.6 got into the beam because of interception of light by the carbon supports, etc. Hence the luminosity of the beam is approximately

$$0.6 \times 3400 = 2000 \text{ foot candles.}$$

This agrees well enough with the observed value 1800 foot candles.

19. The calculation brings out the well known fact that in the 4 kilowatt 24 inch Navy searchlight more than 3/4 of the light produced at the carbons is immediately lost because of finite size of reflector and unavoidable obstructions.

20. The gas filled tungsten lamp is slightly more efficient than the carbon arc, and reflectors or projection systems in special cases of flood lighting and projected illumination can undoubtedly be made which are more efficient than that of the 24 inch searchlight, but a projecting efficiency greater than 50 percent would be difficult to obtain. The general conclusion may be stated:

Rule (g) Illumination projectors using gas filled tungsten lamps can probably not be made to yield a luminosity greater than 2000 foot candles over each 2 square feet of area for each kilowatt of electrical energy put into the lamps.

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CHAPTER III

CONCLUSIONS AND DISCUSSION

(1) Conclusions

21. The conclusions embodied in Rules (e), (f) and (g) may be summed briefly as follows:

To make the shadow areas of surfaces of an airplane aloft approach the sky in brightness

- A (Navy gray must be increased in brightness by 700 to 1000 foot candles)  
(White paint must be increased in brightness by 500 to 800 foot candles)

This requires an illumination of

- B (2100 to 3000 foot candles)  
(750 to 1200 foot candles)

which requires

- C (1 to 1.5 kilowatts) for each 2 square feet  
(0.3 to 0.5 kilowatts)

or

- D (50 to 75 kilowatts) for each 100 square feet.  
(15 to 25 kilowatts)

of illuminated area.

(2) Discussion

22. The conclusions just given are, if anything, underestimates. For brighter conditions, as in summer and in the tropics, when the entire scale of outdoor brightness may be five times that of winter days at Washington, greater values than those given would be necessary. A lighting installation on a plane must satisfy conditions A to D to be appreciably effective, if it falls short of these by a factor of 2 it will probably yield negligible and disappointing results.

23. It has been suggested that conditions sometimes exist, as for example when the plane is above haze, that so much light is reflected from below up on to the plane that the shadow areas on the plane are not very dark and may therefore need only a little added artificial light to eliminate them. The answer to the suggestion is that in all cases if the added artificial light is to have an appreciable effect the amount added must be greater than at least 1/3 of the light which is already there.

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24. The lighting installation on the plane probably need not spread the light uniformly with great exactness, any inequalities of illumination would disappear with distance. The exact tint of the surfaces and of the lights would appear to be unimportant as long as the surfaces were somewhere near neutral and the lights somewhere near white.

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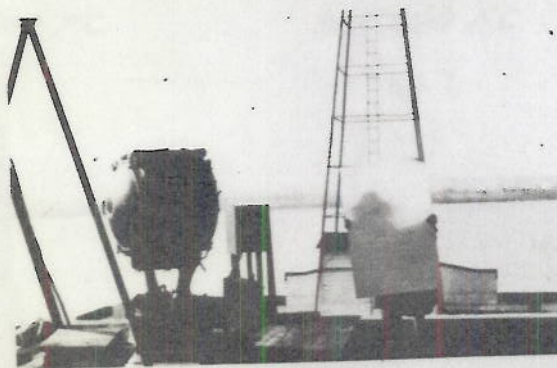


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Cloudy Day



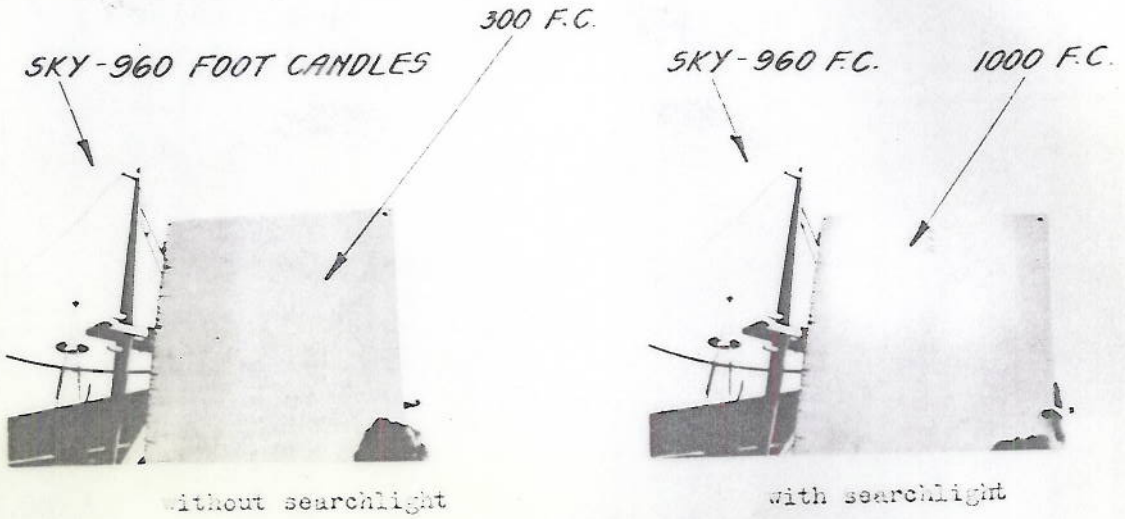
Sunny Day

Four kilowatt, 24 inch, carbon arc searchlight  
shining on vertical Navy gray surface.

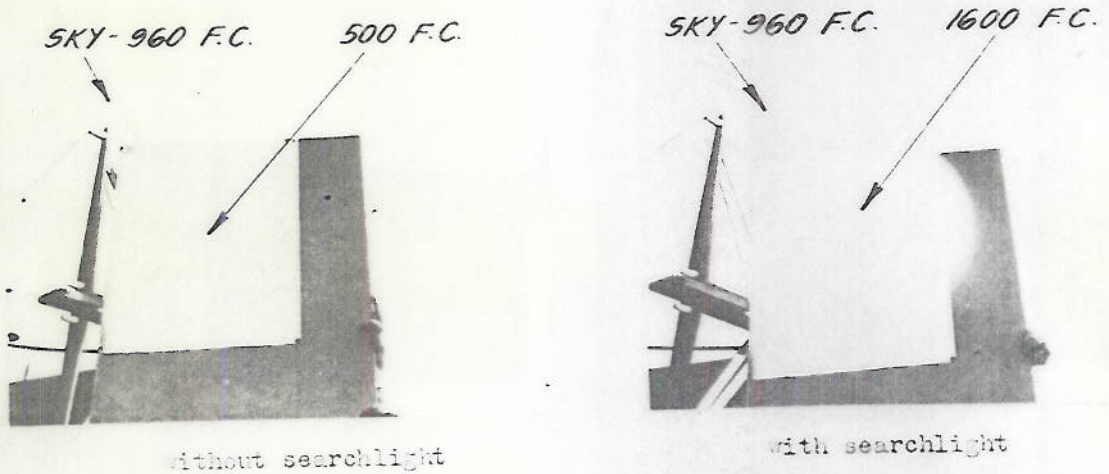
Plate 1

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Navy Gray. Clear Sky.



White Paper. Clear Sky.

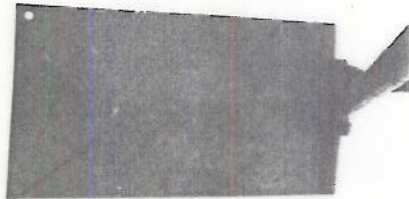
Vertical surface in shadow illuminated by a 4 kilowatt searchlight at distance of 10 feet December 19, 1935, 1 p.m., clear, sunny day. Surfaces normal to beam.

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SKY-800 FOOT CANDLES

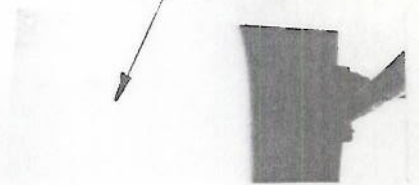
SKY-800 F.C.

560 F.C.



without searchlight

100 F.C.

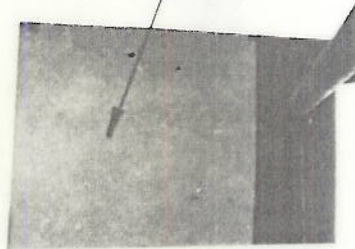


with searchlight

Navy Gray. Clear Sky.

SKY-800 F.C.

200 F.C.



without searchlight

SKY-800 F.C.

900 F.C.



with searchlight

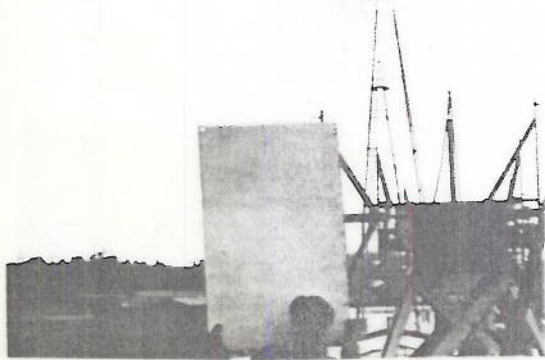
White Paper. Clear Sky.

Underneath side of horizontal surface illuminated by a 4 kilowatt searchlight at distance of 10 feet December 19, 1935, 2 p.m., clear, sunny day. Surfaces at 60° to direction of beam.

Plate 3

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without searchlight



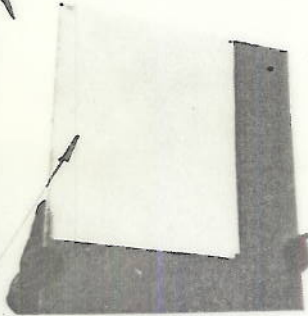
with searchlight

Navy Gray. Cloudy Sky.

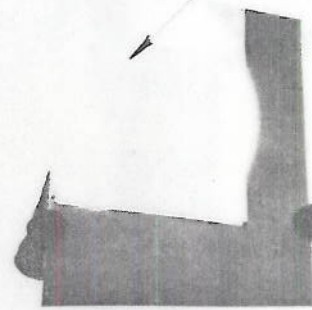
SKY-900 FOOT CANDLES

SKY-900 F.C.

1400 F.C.



without searchlight



with searchlight

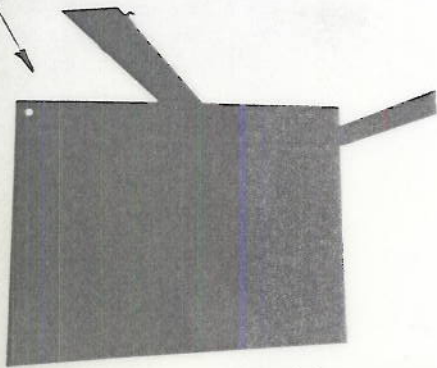
460 F.C.

White Paper. Cloudy Sky.

Vertical surface illuminated by a 4 kilowatt searchlight at distance of 12 feet. December 17, 1935, 11 a.m., uniformly cloudy day. Surfaces normal to beam.

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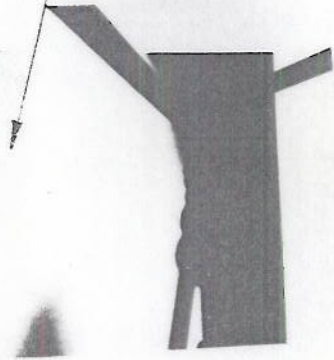
SKY-830 FOOT CANDLES



without searchlight

SKY-830 F.C.

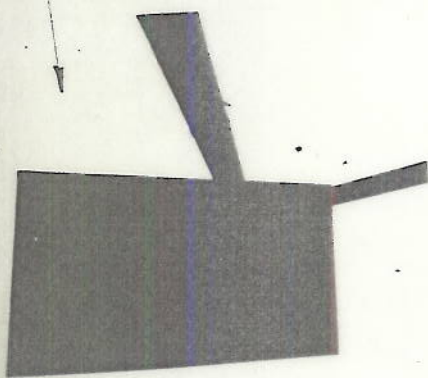
550 F.C. NAVY GRAY



with searchlight

Navy Gray. Cloudy Sky.

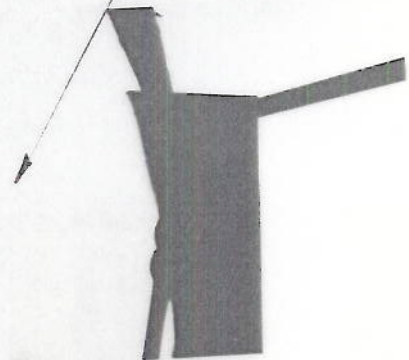
SKY-830 F.C.



without searchlight

SKY-830 F.C.

1030 F.C.



with searchlight

White Paper. Cloudy Sky.

Underneath side of horizontal surface illuminated by a 4 kilowatt searchlight at distance of 10 feet, December 19, 1935, 10 a.m., uniformly cloudy day. Surfaces at 60° to direction of beam.

Plate 5

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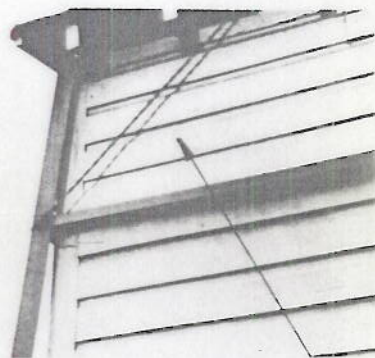
SKY-1000 FOOT CANDLES



without searchlight

200 F.C.

SKY-1000 F.C.



with searchlight

400 F.C.

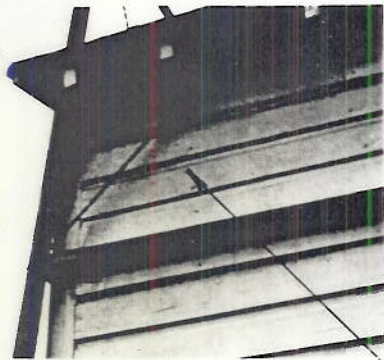
Vertical surface, painted white, illuminated by a 4 kilowatt searchlight at distance of 30 feet; illuminated area 20 square feet, December 17, 1935. 2 p.m., uniformly cloudy day.

Plate 6

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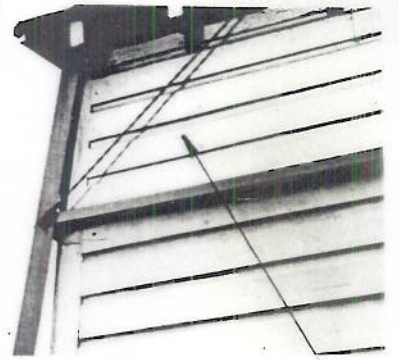
SKY-1000 FOOT CANDLES



without searchlight

200 FC

SKY-1000 F.C.



with searchlight

400 FC

Vertical surface, painted white, illuminated by a 4 kilowatt searchlight at distance of 50 feet; illuminated area 20 square feet, December 17, 1935. 2 p.m., uniformly cloudy day.

Plate 6

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