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DISCOMFORT GLARE: AN IMPROVED DYNAMIC ROADWAY LIGHTING SIMULATION

by

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INTRODUCTION

Efficient Roadway Lighting should give a degree of safety and driving comfort for night traffic not inferior to those experienced in day time under otherwise comparable conditions, so that the traffic capacity of the road at night is as much as possible equal to that planned for the day time.

With the advent of high speed road vehicles, the necessity for improving visibility on the roads increased. A unique characteristic of the visual task imposed on the motorist is that a break in visual performance is not possible as long as he is driving the car. In addition to the task of receiving and processing visual information the motorist must concentrate on the actual driving of his vehicle.

The task of driving gets more difficult during the night time. The principal purpose of roadway lighting is to ease the complexity of this driving task and to create a night-time environment conducive to quick, accurate and comfortable seeing for the motorist. Adequate visibility at night results from lighting (both fixed and vehicular) which provides adequate luminance contrast with good uniformity together with reasonable freedom from glare. The discussions in this report deal with one aspect of visibility from fixed roadway lighting, namely glare.

Glare in roadway lighting.

When the field of vision of an observer contains a light source whose luminance in the direction of the observer is appreciably greater than that of the other part of his field of vision this light source will give rise to glare. The glare produced increases with increased glare source luminance, apparent size and number and with decreasing luminance of the background and with decreasing angle between the direction of observation and direction to the light source. There are two types of glare effect, they are:

1. Disability glare.
2. Discomfort glare.

Disability glare.

Glare which results in a reduction of visual performance is known as "disability glare." It is sometimes also referred to as "blinding glare" or "veiling glare". In the German literature the term "physiologische Blendung" (physiological glare) is used on the grounds that this is a purely physiological (that is peripheral) reaction, which can be measured by purely physiological methods.

Discomfort glare.

Discomfort glare is the negative subjective reaction to too-bright lights, as contrasted with disability glare which is a visual performance loss. Discomfort glare can definitely be observed in cases where disability glare can hardly be measured. Thus, in an artificially lighted street where a measurable effect of glare on the visual performance is practically absent discomfort glare can still be inadmissibly high. Discomfort glare is referred to in the German literature as "psychologische Blendung" (psychological glare), on the grounds that the sensations involved are largely or wholly of a psychological (that is, in the central nervous system) nature.

Discomfort glare as a design criterion:

While both forms of glare reactions are caused by the same light, many factors involved in roadway lighting such as source size, displacement angle of the source, illuminance at the eye, adaptation level, surrounding luminance exposure time and motion do not affect both forms of glare in the same manner, nor to the same degree. The only two factors common to both forms of glare are illuminance at the eye and the angle of entrance in to the eye.

Even these factors have varying effects on the two forms of glare.

It is generally true that even though disability glare is negligible, the discomfort glare can be appreciable. Conversly, if the discomfort glare is acceptable, hardly any effect on visual performance may be expected. Thus, discomfort glare frequently serves the protective function of preventing disability glare, or worse, because it generally occurs at lower luminances and because people avoid situations which produce discomfort and thus, avoid disability. Clearly, such a conclusion is of extreme importance for the proper design of street lighting installations: it means that one might be able to restrict one's attention to discomfort glare. Hence, further discussions in this report will be confined to the discomfort glare aspect of roadway lighting.

Research on Discomfort glare in Road Lighting.

European roadway lighting has included the estimation and prevention of discomfort glare for some years. This is based on a predictive system called, "Glaremark". Unfortunately, North American tests have failed to show the adaptability or validity of Glaremark (Keck and Odle 1975). Therefore in order to provide a basis for a North American system research is underway at Kansas State University. Discomfort glare research related to roadways has been supported by the Illuminating Engineering Research Institute (IERI) off and on for a number of years. The first study was an extensive experiment based upon the pilot work of Putnam and his coworkers (Bennett 1977). A multiple regression model has been developed for predicting glare sensitivity as a function of glare source size, position and background luminance for a single glare source (Bennett, 1977). This study enabled prediction of an average response for a single, static glare source. Later probit analysis (Bennett and Rubison, 1979) enabled predication of an arbitrary percentile rather than just the average.

Further research extended this work to a number of static sources rather than a single source (Bennett 1980). Based upon a suggestion by Glenn Fry as to how to accommodate varying number of sources, Merle Keck of the Roadway Lighting Committee, Research Sub-committee produced the "cumulative Brightness Evaluation (CBE)" system for using in roadway lighting designs using these research results.

Further unpublished field tests were conducted by Vincent P. Gallagher in Philadelphia (Gallagher & Keck 1981). The site was located in Philadelphia and consisted of a glare street served by luminaires mounted on opposite spaced poles 110.5 ft apart. Each pole was capable of carrying two luminaires and each luminaire could be switched independently. One type of luminaire was used for all the configurations. Two spacing--110.5 ft. opposite and 221 ft. opposite and seven light levels--maximum about four times minimum, were used. Twenty four subjects were used who rode through each of the 10 configurations and scored each system in terms of brightness of pavement, visibility discomfort glare, uniformly of pavement brightness and overall quality. Ranking for the ten configurations was based on the 'glaremark' and 'CBE' values computed by Merle Keck using photometric data and field data. Also, the ranking for the 10 configuration was done by observer rating. However, the glaremark and North American CBE systems were equally unpredictive.

Based upon the idea of Fry's, a dynamic roadway lighting simulator for discomfort glare research was designed and built at Kansas State University during the first part of 1982 (Anantha, Dubbert and Bennett 1982) An experiment was conducted using this simulator in the summer, 1982 (Bennett 1983). Seventy-four subjects were run each for three hours. In the experiment the conditions simulated included:

1) Car speeds of 30 mph and 60 mph.

2) Spacing of 4 MH (Mounting Height) and 8 MH.

3) One side lighting and two side staggered lighting.

4) Number of lights of 26, 10, 2, and 1.

5) A dynamic condition and a static condition.

Linear regression equations were fitted to each subject's luminance-criterion selection for each experimental condition. Each equation was used to estimate a luminance value for the "BCD" (Border line between Comfort and Discomfort) criterion.

Results showed that the static condition was less uncomfortable than the dynamic conditions. Correspondingly, the smaller BCD value for 60 mph than for 30 mph showed that the annoyance value was greater for the higher speed. Spacing was the statistically significant variable. Observers were less sensitive to the 8 MH conditions than the standard 4 MH conditions. No difference was found between lighting on one or both sides and number of lights. Finally, no fatigue effect was found over three hours.

The results show, in general, that the Fry simulator approach was a useful way to study discomfort glare from fixed roadway lighting. The main advantage is that it is much less expensive than field lighting tests and is much more flexible.

However, this Fry simulator needed further improvements which were compromised in the interest of expediency in meeting the needs of road light specialists. Therefore, a newly-engineered simulator was built to get a simulation closer to actual roadway lighting.

This report deals with the major improvements and achievements of this new simulator. Also a change of direction for the research was planned. Rather than a "parametric study" a predictive - systems - validation approach was planned. This leads to the second major aspect of this report i.e. the Predictions of Discomfort glare by the two predictive systems, Glaremark and

CBE and prediction of Discomfort glare from the subjects actual rating.

PROBLEM

The objective of this report is to build a new simulator, an improved version of Fry simulator with the following improvements/developments.

1) Observer position to be made more realistic by providing a car seat, steering wheel, etc.
2) Variation of luminous area of the luminaire as a function of viewing angle.
3) Use of different types of luminaires.
4) Create a Roadway Lighting simulation which would appeal to the observer close to the real world condition.

With the help of this simulator a predictive-systems-validation study will be conducted. The prediction of glare by observers rating will be compared with that of the prediction of glare by the predictive systems — CBE and Glaremark for the four different types of luminaire.

PRINCIPLES OF DYNAMIC SIMULATION

The basic concept of the simulation is: a disk is rotated in front of a light source. The disk has a clear spiral which increases in width as it spirals outward. The disk is opaque except for the clear spiral track. An occluder with a narrow open sector occludes most of the disk. As the disk rotates behind the occluder, the observer sees a series of 'roadway lights' from the large first light above him to the ever more closely-spaced small lights near the horizon. The basic concept is further developed in this new simulator.

The new concept is: Two disks rotate in opposite direction (in proportion to the vehicle speed) behind an occluder. The disks are opaque except for clear double-spiral tracks on each of them as shown in Figure 1. The occluder is opaque except for the two narrow sectors. Both the disks and the occluder are in front of the light source. On the several places where the two sectors and the double-spirals on each disk intersect a series of roadlights occur. These appear to move toward and above the driver, getting larger. Further discussions will expand this concept and translate the roadway lighting conditions to simulation parameters.

Real World Conditions vs Simulation Parameters

The first step is to establish the relationships between the road-lighting conditions and the simulation parameters. Table 1 establishes such relationships.

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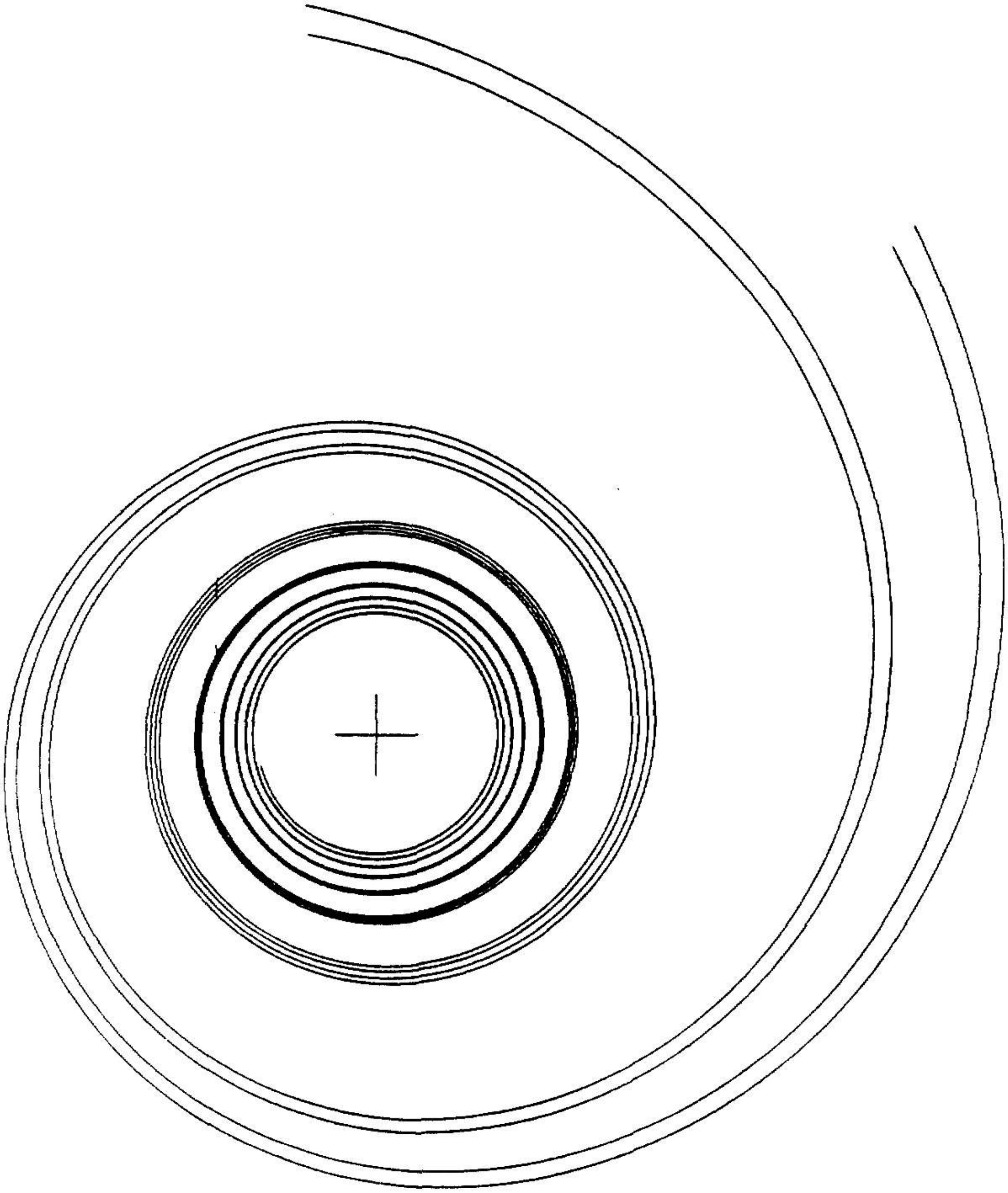
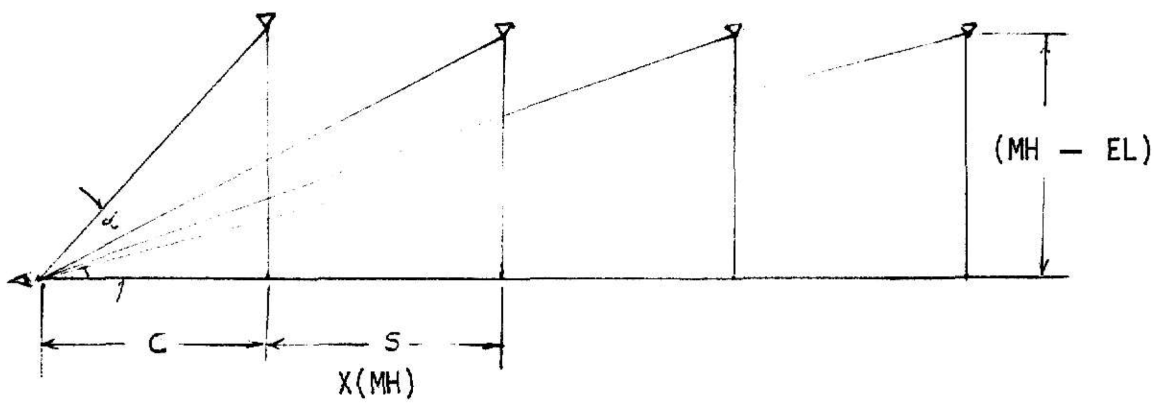


FIGURE 1: DOUBLE SPIRAL TRACK

TABLE 1. Real World Conditions and Simulation Parameters.

REAL WORLD CONDITION	SIMULATION PARAMETER
1) Speed of the car, M mph	1) Rotational speed of the disk, m rpm
2) Angular distance from the observer's line of sight to the road light (varying between α and β)	2) Angular distance from the observer's line of sight to the spiral segment (varying between α and β)
3) Distance from the motorist to the light pole, D	3) Spiral segment radius, r
4) Horizontal dimension of luminaire, W	4) Width of the narrow open section in the opaque mask, w
5) Vertical dimension of luminaire, H	5) Width of the spiral (in the radial direction), h
6) Lateral displacement of the light pole from the line of sight, L	6) Angular position of open sector on mask from the vertical, λ

Design Calulations for the Simulator



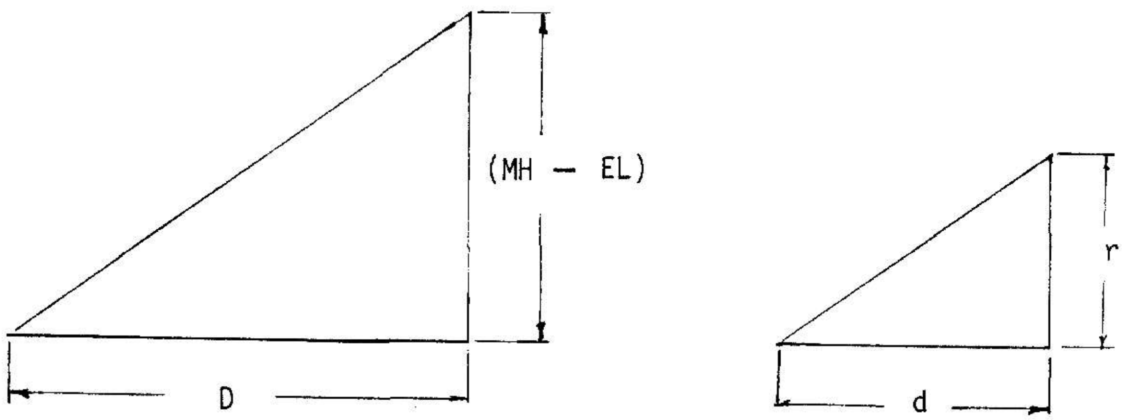
Let (MH) be the mounting height of the luminaire

(EL) be the eye level of the motorist from the road

α be the windshield cut-off angle

and C be the corresponding distance of the pole to the motorist at cut-off angle.

The spacing (S) between two adjacent light poles can be expressed as a multiple of mounting height (MH). Let this spacing be X(MH). Let d be the viewing distance of the simulation spiral. The instantaneous radius r of this spiral can be calculated from the similar triangles shown below, where D is the instantaneous distance (in the real world) of the light pole from the motorist.



$$\frac{(MH - EL)}{D} = r/d$$

$$r = \frac{(MH - EL)\, d}{D} \tag{1}$$

A distance of S or X(MH) corresponds to one revolution (i.e., 2π radians) of the spiral. Therefore, a distance of D corresponding to an angular rotation of θ radians is given by

$$\frac{X\,(MH)}{2\pi} = D/\theta$$

$$D = X(MH)\ .\ \theta/2\pi \tag{2}$$

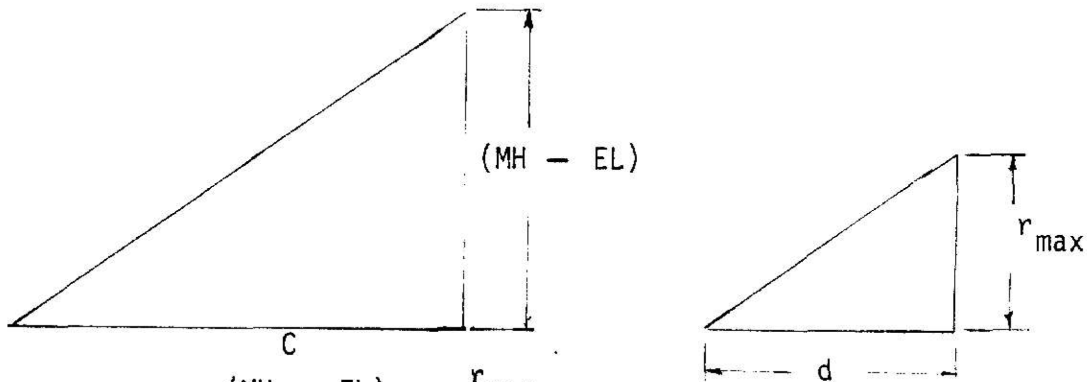
Substituting for D in equation (1),

$$r = \frac{(MH - EL)\, d}{X(MH)}\ .\ 2\pi/\theta \tag{3}$$

From equation (2).

$$\theta = \frac{2\pi}{X(MH)} \cdot D \tag{4}$$

The limits for the value of θ have to be fixed. Considering the one extreme condition, when the closest luminaire is just about to be cutoff from view by the windshield, the maximum radius r_{max} of the spiral can be obtained from the similar triangles



Now $$\tan\alpha = \frac{(MH - EL)}{C} = \frac{r_{max}}{d}$$

$$r_{max} = d\tan\alpha \tag{5}$$

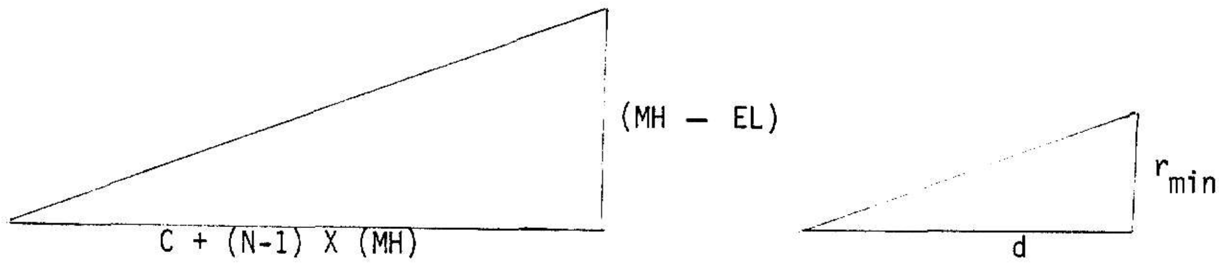
$$C = \frac{(MH - EL)}{\tan\alpha} \tag{6}$$

From equation (4)

$$\theta_{max} = \frac{2\pi}{X(MH)} \cdot C$$

$$= \frac{2\pi}{X(MH)} \cdot \frac{(MH - EL)}{\tan\alpha} \tag{7}$$

The other limiting value θ_{min} is obtained, considering the luminaire farthest away from the motorist. If the motorist is able to see a total of N luminaires, then the distance of the luminaire farthest away from the motorist is C + (N-1) S i.e., C + (N-1) X(MH).



From these similar triangles,

$$\frac{r_{min}}{d} = \frac{(MH - EL)}{C + (N-1)\ X(MH)}$$

$$r_{min} = \frac{d.(MH - EL)}{C + (N-1)\ X(MH)} \tag{8}$$

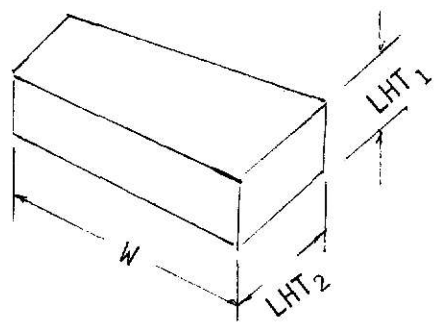
From equation (4),

$$\theta_{min} = \frac{2\pi}{X(MH)} \cdot [C + (N-1)\ X(MH)] \tag{9}$$

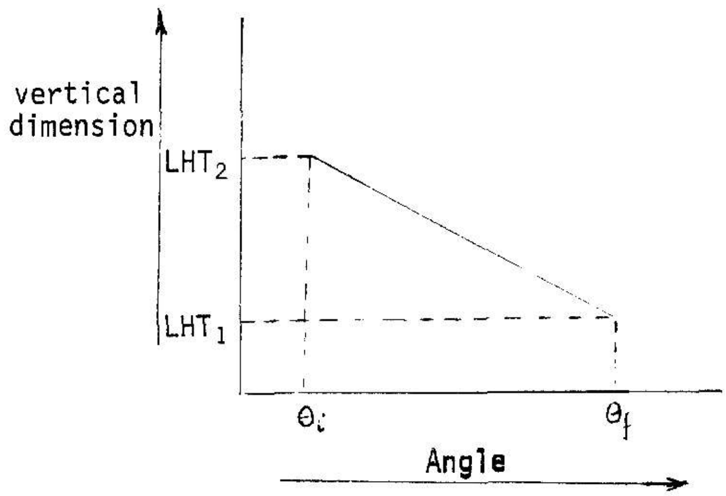
Thus, equation (3) establishes the radius of the spiral and equations (7) and (9) establish the limits for the rotational angle θ through which the spiral has to be plotted. The vertical dimensions of the luminaire has to be simulated by plotting another concentric spiral. This will give rise to a spiral track, the width (in the radial direction) of which will correspond to the vertical dimension of the luminaire. The radius of this outer spiral is given by

$$r_1 = \frac{(MH - EL + H)\ d}{X\ (MH)} \cdot 2\pi/\theta \tag{10}$$

where H is the vertical dimension of the luminaire. Equation (10) accounts only for the distance effect in computing the vertical dimension of the luminaire. However, the luminous area of the luminaire is not perpendicular to the line of sight. Therefore, the luminous area varies as a function of the vertical angle as the observer moves. In order to incorporate the luminous area as a function of vertical angle in equation (10) the vertical dimension (H) of the luminaire is assumed to vary linearly as the angle changes. It can be computed as follows.



The figure shows the width LHT_2 and the vertical height (LHT_1) of the luminaire. The following linear relation is assumed.



At θ_i = cut off angle (α), $H = LHT_2$

θ_f = 2π x number of Revolutions, $H = LHT_1$

As θ varies from the cutoff angle to 2π (rev) the vertical dimension of the luminaire varies from LHT_2 to LHT_1, as per the following equation

$$H = m\theta + b \qquad (11)$$

where m is the slope of line A and b is the intercept of line A in the above figure.

Now the values of m and b can be evaluated as

$$\text{Slope } m = \frac{LHT_2 - LHT_1}{\theta_i - \theta_f} \qquad (12)$$

Substituting in equation (11) we get

$$H = \frac{(LHT_2 - LHT_1)}{\theta_i \quad \theta_f} \theta + b \qquad (13)$$

When $H = LHT_2;\ \theta = \theta_i$

Substituting these values in equation (13)

$$LHT_2 = \frac{(LHT_2 - LHT_1)}{\theta_i \quad \theta_f} \cdot \theta_i + b$$

$$b = LHT_2 - \frac{(LHT_2 - LHT_1)}{(\theta_i - \theta_f)} \cdot \theta_i \qquad (14)$$

Substituting the values of M and b from equations (12) and (14) respectively in equation (11) we get

$$H = \frac{(LHT_2 - LHT_1)}{(\theta_i - \theta_f)} + \theta + LHT_2 - \frac{(LHT_2 - LHT_1)}{(\theta_i - \theta_f)} \theta_i$$

$$H = \frac{(LHT_2 - LHT_1)}{\theta_i - \theta_f} (\theta - \theta_i) + LHT_2 \qquad (15)$$

The difference between r_1 and r (the instantaneous radii of the outer and inner spirals) gives the width of the spiral in the radial direction, which corresponds to the vertical dimension of the luminaire

The instantaneous width h of the spiral = $r_1 - r$

$$= \frac{(MH - EL + H)\ d}{X(MH)} \cdot 2\pi/\theta - \frac{(MH - EL)}{X(MH)} \cdot 2\pi\theta$$

$$h = \frac{H \cdot d}{X\ (MH)} \cdot 2\pi/\theta \qquad (16)$$

The horizontal dimension W of the luminaire is simulated by the narrow opening in the mask, by maintaining the angle subtended by the width w of the opening at any point the same as that subtended by the corresponding luminaire on the road. This is done by considering the two sets of similar triangles shown in Figure 2 from the lower set of similar triangles,

$$\frac{PQ}{OQ} = \frac{XY}{OY}$$

$$\frac{OQ}{OY} = \frac{PQ}{XY} = \frac{r}{(MH - EL)} = d/D \text{ from equation (1)}$$

From the upper set of similar traingles,

$$\frac{RQ}{OQ} = \frac{ZY}{OY}$$

$$w = RQ = ZY \cdot \frac{OQ}{OY} = W \cdot d/D$$

$$w = \frac{(W.d)}{D}$$

Thus, the width of the narrow opening in the mask is linearly related and inversely proportional to the distance D of the motorist from the light pole. At the windshield cut-off angle point, this width W_c = W.d/C. At the other end, corresponding to the farthest luminaire, it will be

$$W \cdot \frac{d}{C + (N - 1)\ X\ (MH)} .$$

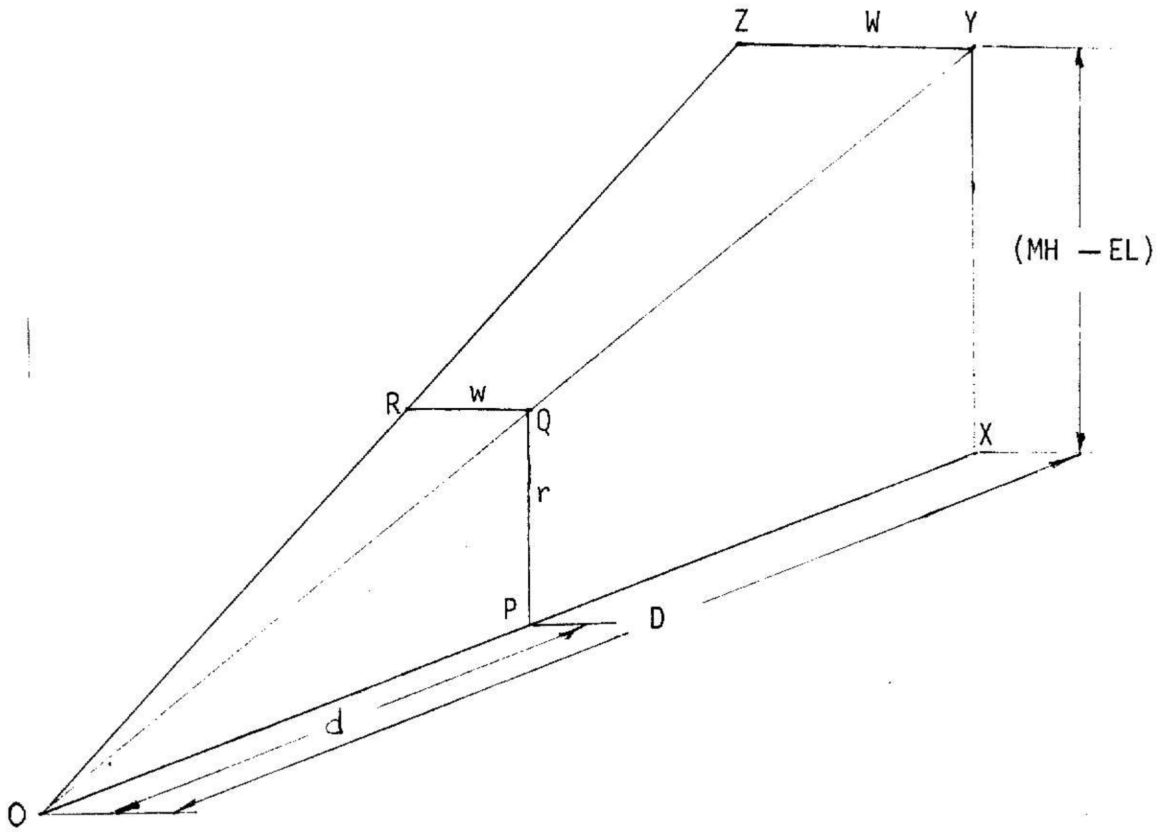
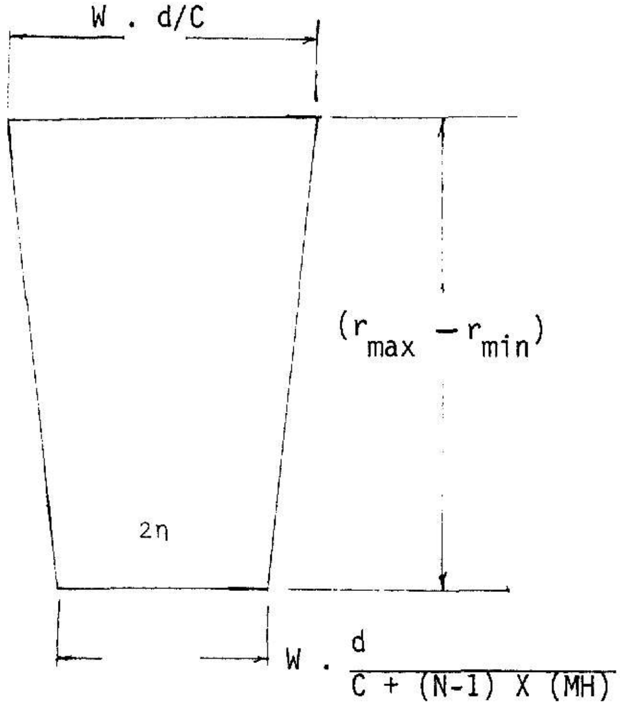


FIGURE 2: GEOMETRY FOR LUMINAIRE WIDTH SIMULATION

Thus the slit diverges from the center of the disk to the outer radius, as shown below



If the angular width of this opening is 2η,

$$\text{then } \tan \eta = \frac{1/2\ [W \cdot d/C - W \cdot \frac{d}{C + (N-1) X (MH)}]}{r_{max} - r_{min}}$$

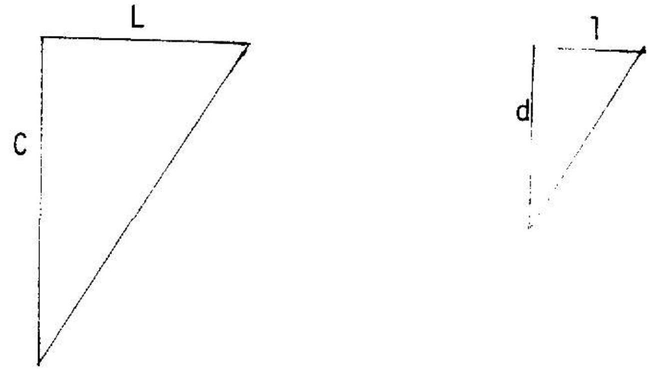
$$= \frac{1/2\ W \cdot d\ [1/C - \frac{1}{C + (N-1) X (MH)}]}{d(\tan \alpha - \frac{(MH - EL)}{C + (N-1) X (MH)})}$$

$$= \frac{1/2\ W\ [\frac{C + (N-1) X (MH) - C}{C[C + (N-1) X (MH)]}]}{\frac{\tan \alpha \cdot [C + (N-1) X (MH)] - (MH - EL)}{[C + (N-1) X (MH)]}}$$

$$= \frac{W\ [(N-1) X (MH)]}{2C\ \{\tan \alpha \cdot [C + (N-1) X (MH)] - (MH - EL)\}}$$

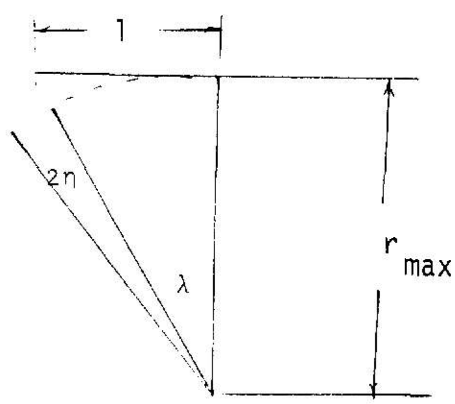
$$\text{Angular width, } 2\eta = 2\tan^{-1}\frac{W[(n-1)\ X\ (MH)]}{2C\{\tan\alpha\ .\ [C + (N-1)\ X\ (MH)] - (MH-EL)\}}$$

This slit in the mask will be positioned vertically only when the row of lights are along the line of sight. However, this is not generally the case. If the lights are on one side of the road and laterally displaced from the line of sight by a distance L and if it is assumed that the light which is farthest away from the motorist is on the line of sight, then the following consideration is valid.



$$l = L/C\ .\ d$$

Thus, the slit in the mask must be laterally offset by the amount at the miximun radius, corresponding to the windshield cut-off point.



If λ is the angle by which this slit must be tilted from the vertical position, then

$$\tan \lambda = \frac{1}{r_{max}} = \frac{L \cdot d/C}{d \cdot \tan \alpha}$$

$$= \frac{L}{C \tan \alpha}$$

$$= \frac{L}{\frac{(MH - EL)}{\tan \alpha} \cdot \tan \alpha}$$

$$= \frac{L}{(MH - EL)}$$

The angle λ by which the narrow opening in the mask must be tilted from the vertical is given by

$$\lambda = \tan^{-1} \frac{L}{(MH - EL)}$$

Finally the rotational speed of the disk simulating the speed of the car is calculated, considering the fact that one revolution of the spiral corresponds to a distance travelled of one spacing between the poles. In other words, X(MH)'/min corresponds to 1 rpm of the spiral. Therefore, the rotational speed of the spiral, to simulate a driving speed of M mph (i.e., 88 M'/min) is $\frac{88}{X(MH)}$ rpm.

$$\text{RPM of the disk, } m = \frac{88\ M}{X(MH)}$$

where M is the speed of the car in mph and MH is the mounting height of the luminaire in feet.

SUMMARY OF DYNAMIC SIMULATION

The development of the new simulator for roadway lighting can be summarized as follows.

At the suggestion of Merle Keck, Billy Lee Shelby provided data and carried out computer studies for four types of roadway lighting systems as listed below.

Cobra head (Horizontal luminaire)

HPS (High Pressure Sodium) long-cut off

HPS cut off and

Post Top

The luminaire systems are discussed in detail in the method section. Keeping the road width and mounting height constant for each type of luminaire the spacing was varied to get an average pavement luminance of one candela per meter square in all cases except the Post-Top, which was based on an average luminance of 0.5 candela per meter square.

The road description and the other details used in the roadway lighting design are listed below:

Number of Roadway	1
Number of lanes per roadway	4
Width of each lane	3.75 M
Width of roadway	15.00 M
Cut off angle (α)	20^{0}
Eye level of the motorist (EL)	4ft
Number of luminaires seen by the motorist (N)	8
Viewing distance of the observer in the simulator (d)	42"

The mounting height and the spacing used for each type of luminaire is given in Table 2.

Knowing the above details a computer program was written to get a double-spiral track for each type of luminaire. The photonegatives of the spiral plots with a clear spiral track were glued to the plexiglass disks. Two disks

TABLE 2: MOUNTING HEIGHT AND SPACING FOR EACH TYPE OF LUMINAIRE

TYPE OF LUMINAIRE	MOUNTING HEIGHT	SPACING
COBRAHEAD	32'	164'
HPS (HIGH PRESSURE SODIUM)CUT-OFF	32'	197'
HPS LONG CUT-OFF	26'	197'
POST TOP	32'	200'

each having a double-spiral were rotated at m rpm in the opposite direction behind an occluder which had two graduated sectors tilted at an angle λ to the vertical. Both the disks and the occluder were mounted in front of a light source. The observer was positioned in a car seat with a viewing distance of d from the disk. The lighted spiral track segments where the sector and the double-spiral on each disk intersect simulated the road lights as seen by a motorist on an artificially lighted roadway as shown in figure 3.

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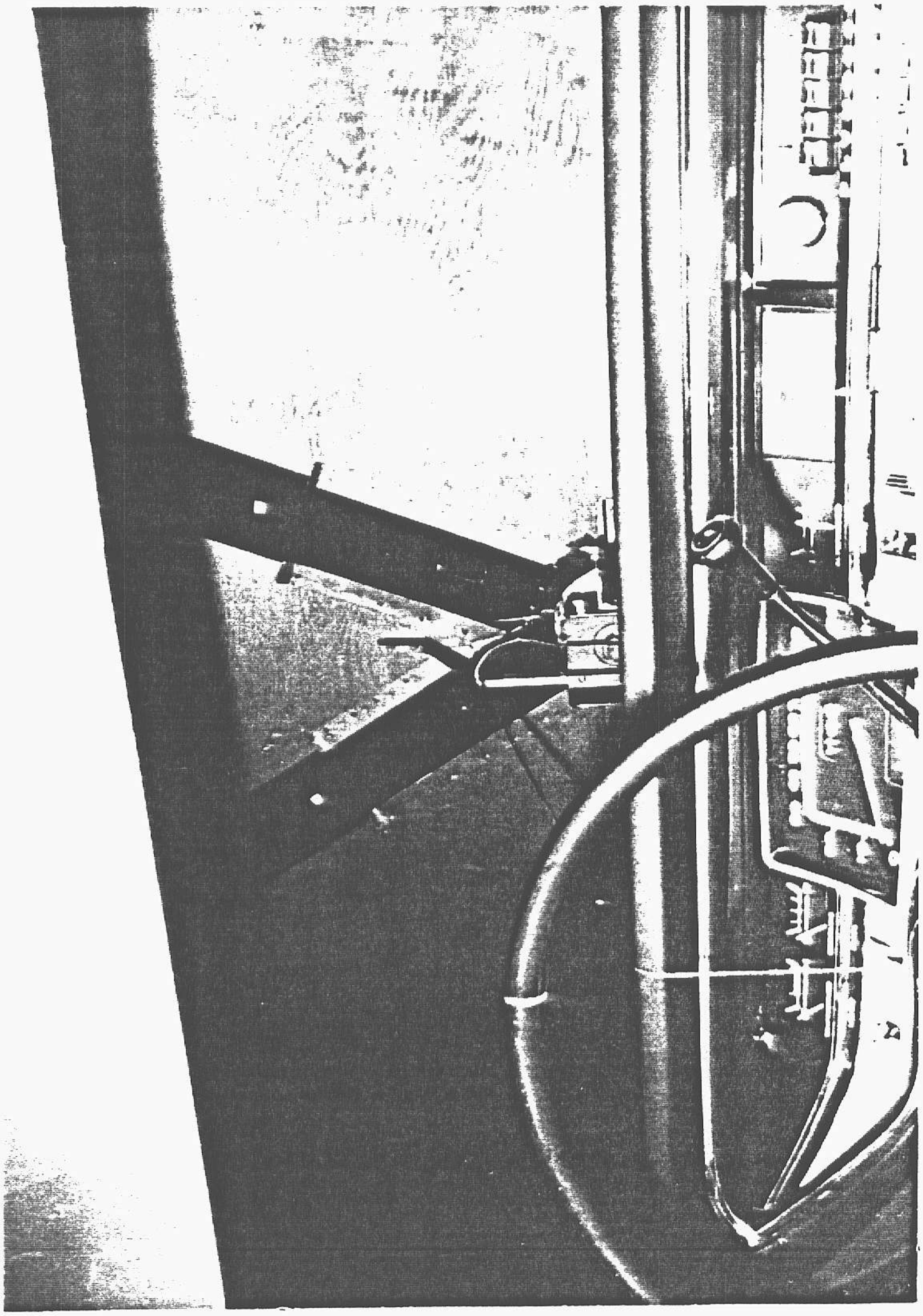

FIGURE 3: SIMULATED ROAD LIGHTS AS SEEN IN THE SIMULATOR

GLAREMARK AND CBE COMPUTATION

Discomfort glare can be quantified by using the empirical model called Glaremark (reported in CIE publication No. 31, 1976; Van Bommel and de Boer 1980) and "Cumulative Brightness Evaluation (CBE)" (Bennett, 1979). The subjective apprasals of the concept Discomfort Glare would be scaled similar to the physical scale produced using the Glaremark and CBE system. Further discussions deal with the computational details of the CBE and Glaremark values.

Calculation of Glaremark

In this empirical model the observer position along or across the roadway is not a criterion and thus it makes no difference to Glaremark if the observer is in lane 1 or lane 6 or whether he is moving dynamically or is static. The calculation of Glaremark is done using the following formula.

$$SLI = 13.84 - 3.31 \log I\text{-}80 + 1.3 (\log I\text{-}80/I\text{-}88)^{1/2} - 0.08 \log I\text{-}80/I\text{-}88 + 1.29 \log F \quad (17)$$

$$GM = SLI + 0.97 \log \bar{L} + 4.41 \log h^1 - 1.46 \log P \quad (18)$$

where the following definitions apply:

I-80 - luminance intensity at 80^0 in Co plane.

Co plane - Plane perpendicular to the plane of the central vertical axis of the luminaire (i.e., 90^0 horizontal).

I-88 - Luminance intensity at 88^0 in the Co plane.

F - Flashed area of the luminaire as viewed from 76^0.

SLI - Specific Luminance Intensity of the Luminaire.

$\bar{L}$ - Average roadway luminance.

h^1 - Height of the luminaire above the road minus the observer height.

P - A quantity based on the number of luminaires per km.

Values of I-80 and I-88 can be found from the photometric data of the luminaire. Similarly the other values can be obtained or calculated from the knowledge of the real world roadway lighting parameters.

Calculation of CBE

CBE is an observer-oriented system and the percentage of tolerable CBE will vary depending on the lane in which the observer is located and his position along that lane. The equation as developed by Merle Keck based on a suggestion by Dr. Glenn Fry using findings at Kansas State University is as follows:

$$CBE = \frac{(B_1^{1.67})S_1}{e^{0.08 A_1}} + \frac{(B_2^{1.67})S_2}{e^{0.08 A_2}} + \cdot \cdot \cdot \cdot \cdot \cdot \qquad (19)$$

where

B (in fL) is the brightness of the glare source
S (in steradians) is the source size
A (in degrees) is the source angle off the line of sight

CBE is the mean borderline between comfort and discomfort (BCD) - discomfort glare criterion. The prediction of glare for the four different types of luminaire will be calculated using the equations (18) and (19) and the same will be compared with the subjects prediction of glare.

METHOD

Simulator

The major features of the new simulator are described under these headings

Observer position

Disk System

Mounting and Driving System for Disks

Luminaire System

Cooling System

Opaque mask with graduated sectors

Control Panel

Observer Position: Figure 4 shows the simulator with the observer behind the wheel. An automobile drivers compartment was installed in the lab. The viewing distance of the observer from the disk was 42". Background luminance was provided by a light source which was located on the top of the car facing the graduated sectors. The background luminance could be adjusted to 1.00 cd/ m^2 or 0.5 cd/m^2 depending on the type of luminaire. The open sides of the car including the window were covered with black cloth so that the observer does not see any outside light. Dash lights were provided. The intensity of the dash light varied from 0.02 fL to 0.06 fL with an average of 0.04 fL. This seating arrangement was quite comfortable and appealed to the observer that he was driving the car during the night time(Figure 5).

Disk Systems: A computer program was written to plot the double spiral for each type of luminaire for opposite side lighting except for post-top luminaire. Types of luminaire used in the simulation were as follows:

Cobrahead: Figure 6 shows a typical cobrahead luminaire. Figures 7 and 8 gives the isofootcandle lines of horizontal illumination and the

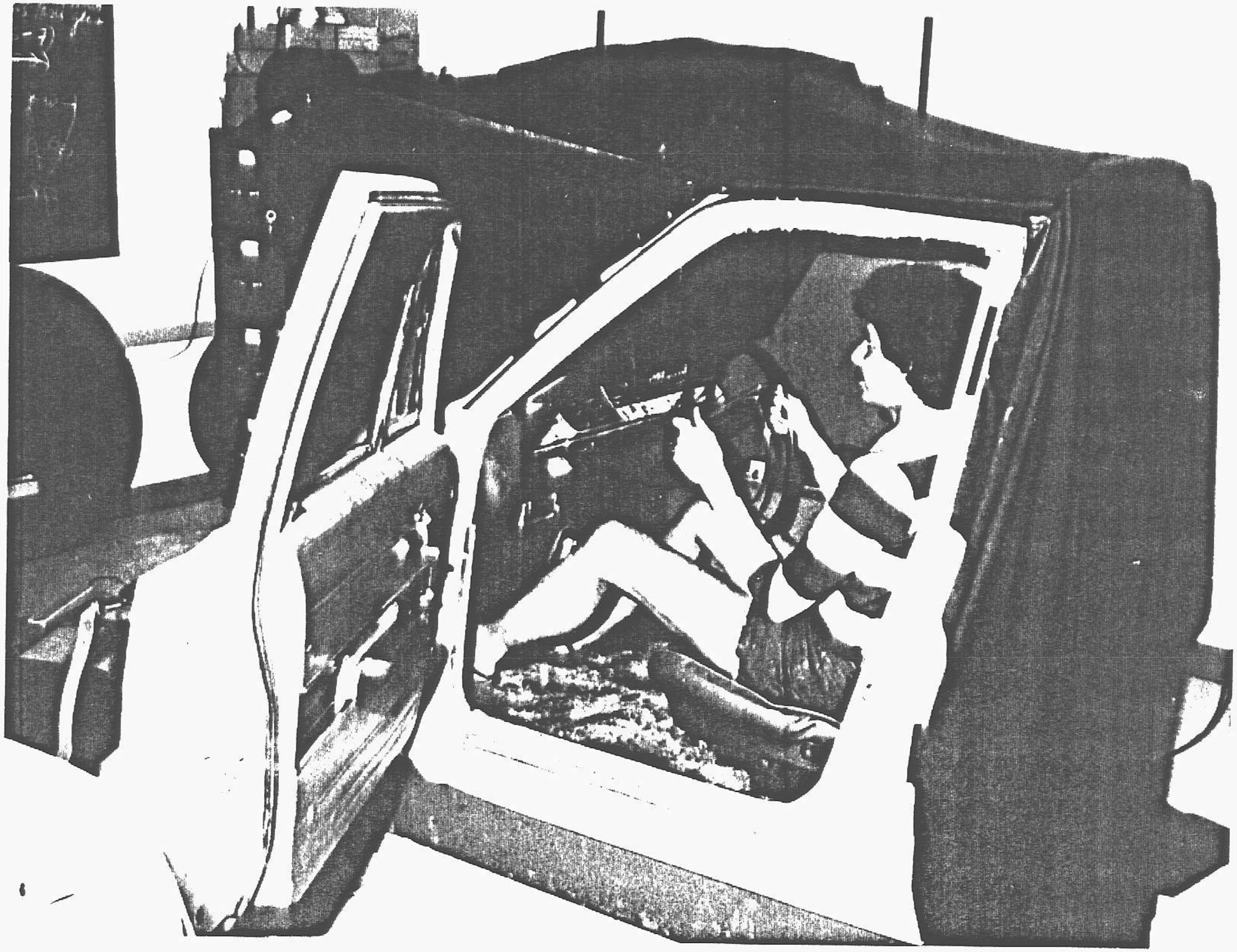

FIGURE 4: DRIVER BEHIND THE WHEEL IN THE SIMULATOR

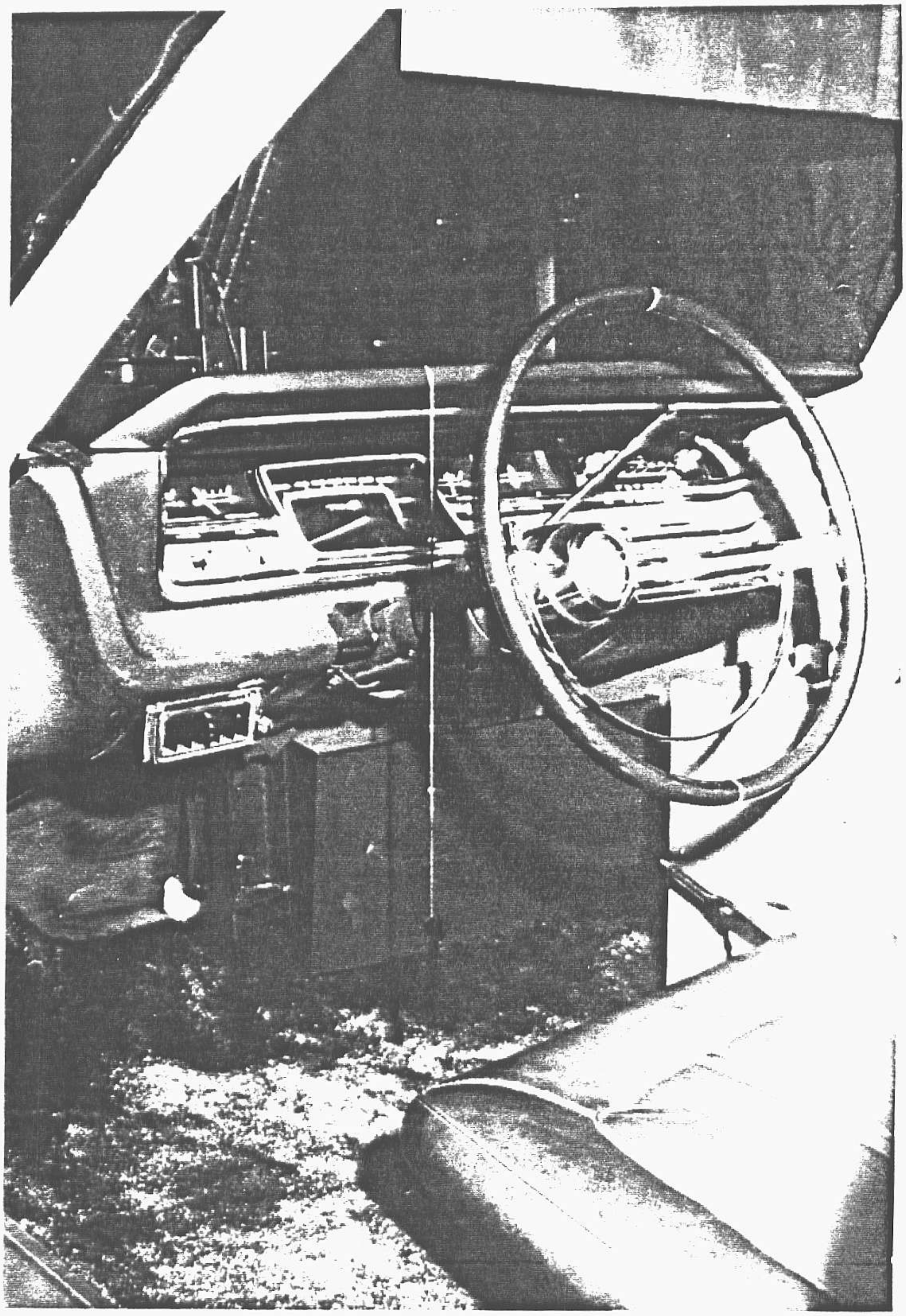

FIGURE 5: DRIVERS COMPARTMENT IN THE SIMULATOR

Horizontal Luminaire

High Pressure Sodium—200 to 400 Watts, Mercury Vapor—400 Watts,
Metal Halide—400 Watts
SERIES: 25 and 26

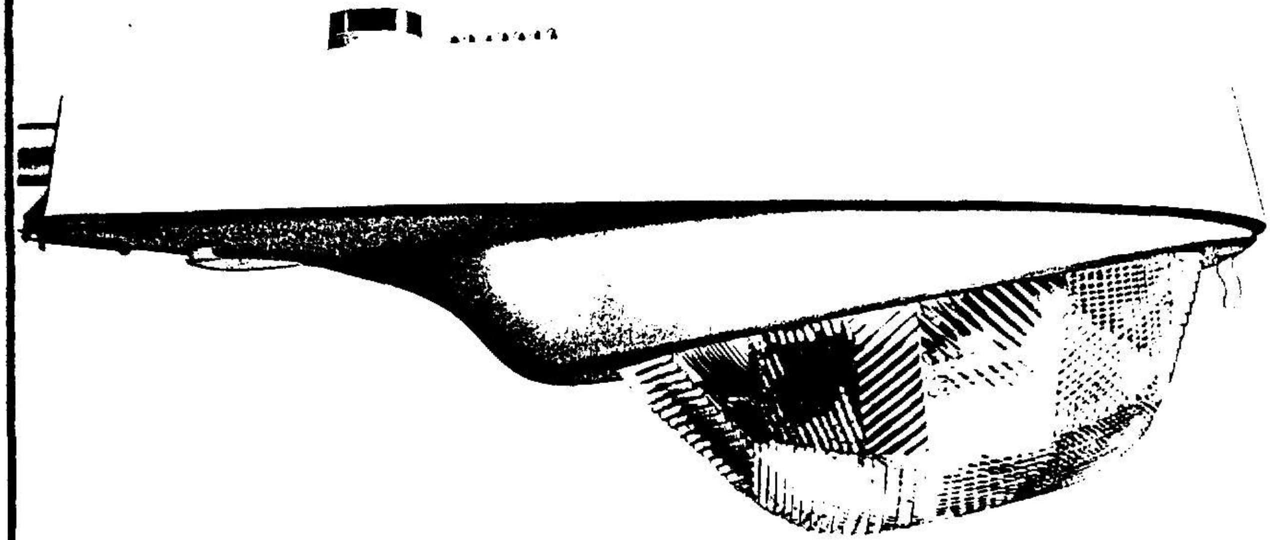

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FIGURE 6: Typical Cobrahead Luminaire

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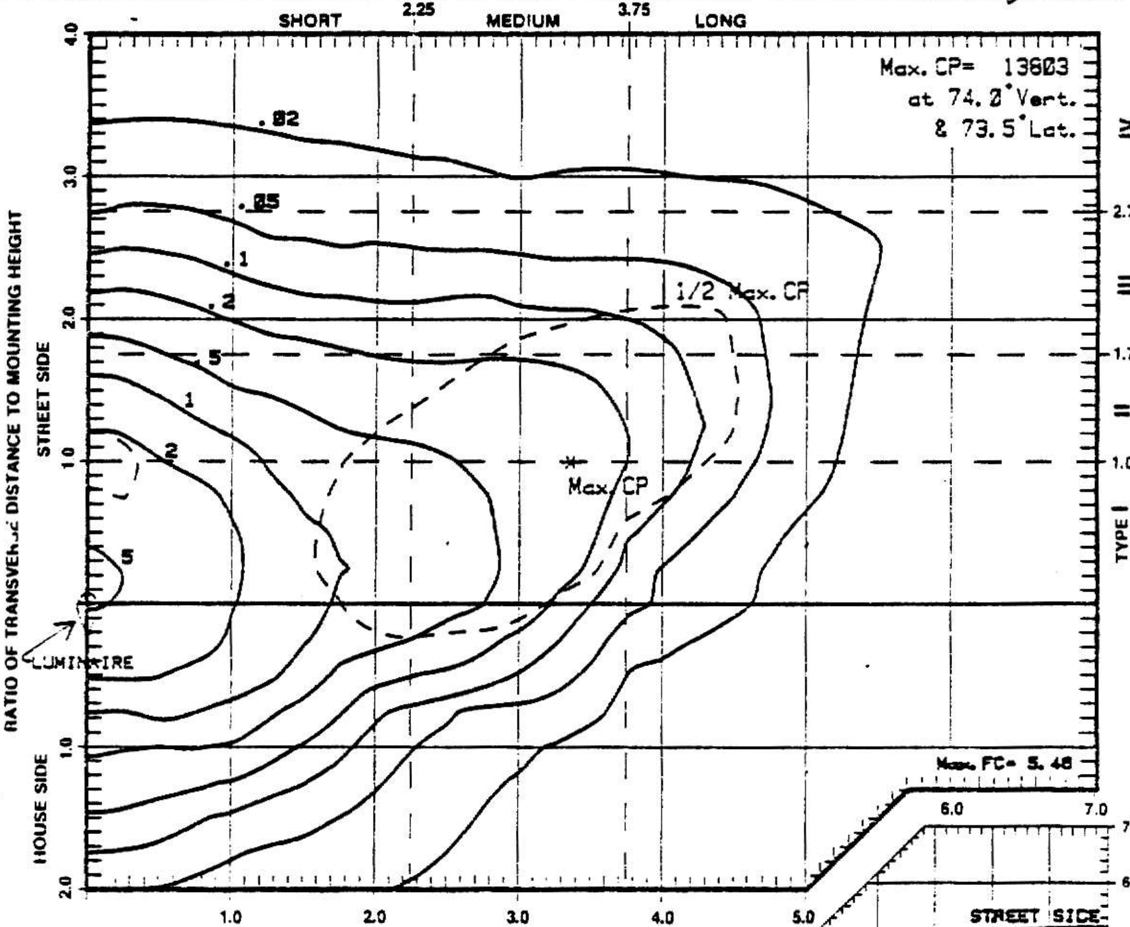
(601) 342-1545

PHOTOMETRIC REPORT

LUMINAIRE: ITT. 400 HORIZONTAL IES TYPE: III-MED -SEMICUTOFF LAMP: (1) 250w HPS #LU250 E-18 DESCRIPTION: LAMP POS. 2-9/16"X 7" SOCKET POS. A-3 (W/SPACER) (REF. 25-37)	REPORT # P0023 DATE: 4-75 TEST BY: JDW TEST DIST: 25' APRVD:



ISOFOOTCANDLE LINES OF HORIZONTAL ILLUMINATION

Footcandle data is based on a luminaire mounted at 30 feet. For another mounting height multiply the footcandle values by a factor from this table

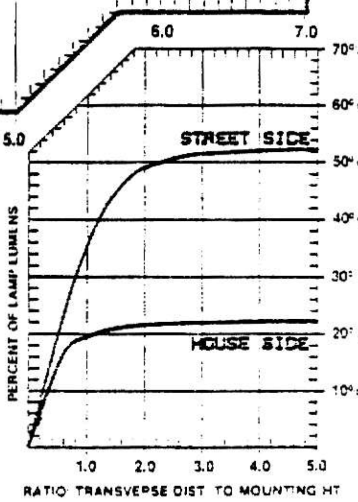
MOUNTING HEIGHT	25	28	30	32	35
FACTOR	1.44	1.15	1.00	.88	.74

This report is based on published IES Testing Procedures. Significance is limited to the degree that the tested sample is representative and that test conditions are duplicated. Voltage and characteristics of lamps and ballasts seriously affect field performance.

Values of footcandles, lumens, and isocandela are based on a lamp operated at 27500 lumens. If data is desired for a different lumen rating, multiply these values by the different lumen rating, then divide by 27500.

FLUX DISTRIBUTION

	Lumens	% Lamp
Downward Street side	14514	52.9
Downward House side	6157	22.4
Total Downward	20671	75.2
Total Upward	287	1.0
Total Flux	20958	76.2



COEFFICIENT OF UTILIZATION

FIGURE 7: ISOFOOTCANDLE LINES OF HORIZONTAL ILLUMINATION (COBRAHEAD)

CANDLEPOWER TABLE

STREET SIDE

LATERAL ANGLE

		.0	5.0	15.0	25.0	35.0	45.0	55.0	65.0	73.5	75.0	85.0
	100.0	236.	246.	208.	217.	220.	218.	261.	306.	323.	326.	343.
	95.0	285.	288.	269.	274.	286.	290.	328.	350.	359.	355.	378.
	90.0	309.	316.	307.	316.	332.	358.	417.	505.	440.	437.	430.
	85.0	376.	377.	390.	442.	400.	453.	608.	799.	604.	703.	549.
V	80.0	535.	533.	557.	747.	678.	745.	2410.	4627.	2504.	2205.	976.
E	75.0	691.	698.	711.	890.	1103.	1719.	3981.	11761.	13787.	12333.	3675.
R	74.0	718.	740.	830.	944.	1203.	2093.	5591.	11101.	13803.	13347.	8519.
T	70.0	1074.	1209.	1323.	1225.	1695.	2952.	5272.	10536.	12292.	12578.	13068.
I	65.0	2324.	2634.	2504.	2699.	2900.	4517.	5872.	8413.	8984.	9474.	10822.
C	60.0	5031.	4913.	4533.	4264.	4313.	5586.	5509.	6330.	7138.	7416.	7567.
A	55.0	6836.	7012.	6391.	5382.	5378.	5962.	5725.	5672.	6093.	6216.	6068.
L	50.0	6795.	6701.	6207.	6130.	5945.	6460.	6922.	6285.	5795.	5807.	5582.
	45.0	7522.	7452.	7526.	6354.	6007.	6791.	6844.	6359.	5799.	5856.	5725.
A	40.0	7098.	7171.	7277.	6514.	5599.	6595.	6334.	5774.	5677.	5685.	5746.
N	35.0	6407.	6460.	6992.	6591.	5268.	5533.	6003.	5562.	5358.	5419.	5542.
G	30.0	6652.	6755.	6820.	6040.	5125.	5231.	5611.	5415.	5329.	5354.	5407.
L	25.0	5468.	5717.	5529.	5431.	5501.	5207.	5039.	5072.	5056.	5101.	4966.
E	20.0	5248.	5272.	5419.	5599.	5644.	5260.	4864.	4843.	4880.	4921.	4712.
	15.0	5407.	5439.	5472.	5558.	5599.	5460.	5244.	5138.	4909.	4900.	4770.
	10.0	5256.	5309.	5406.	5431.	5603.	5628.	5505.	5317.	5235.	5244.	5089.
	5.0	5170.	5215.	5268.	5329.	5387.	5452.	5419.	5387.	5337.	5350.	5227.
	.0	4733.	4733.	4733.	4733.	4733.	4733.	4733.	4733.	4733.	4733.	4733.

FIGURE 8: CANDLEPOWER TABLE (COBRAHEAD)

candle power table respectively for this luninaire.

HPS Cut-Off: Figure 9 shows a typical HPS cut-off luminaire. Figures 10 and 11 gives the isofootcandle lines of horizontal illumination and the candle power table respectively for this luminaire.

HPS Long Cut-Off: Figure 12 shows a typical HPS long-cut-off luminaire. Figures 13 and 14 gives the isofootcandle lines of horizontal illumination and the candle power table respectively for this luminaire.

Post-Top: It is a cylindrical type of luminaire with the top diameter as 12" and the bottom diameter as 9.5" with a height of 6.5". Figures 15 and 16 gives the isofootcandle lines of horizontal illumination and the candle power table respectively for this luminaire.

In case of post-top luminaire one side lighting was used as this is the typical application of such lighting. A single spiral track was plotted for this. A typical program for a double spiral track with complete details of programming is shown in Appendix. For each spiral track corresponding to a particular type of luminaire two photo negatives of size 3' x 3' were developed as shown in the Figure 17. These photonegatives were glued to 3/8" plexiglass disks of 3' diameter with an acrylic adhesive which dried clear not affecting the clear spiral track. Thus, two disks having the same double-spiral track, offset from one another by 52^{0} and rotated in the opposite direction simulated roadway lights for a particular luminaire with opposite side lighting. As there is friction between the two disks when they are rotated in the opposite direction, felt pieces were glued to one side of one disk rubbing against the other disk to reduce friction and allow smooth rotation. The opaque part of the disk was painted with a heat resistant black paint leaving the spiral track clear. This prevented the transmission of light from the clear spiral track segment of one disk through the dark part of the other disk at the intersection of the open sector as shown by

HPS Cutoff Luminaire

High Pressure Sodium—70 to 400 Watts
Series: 53/54 & 153/154

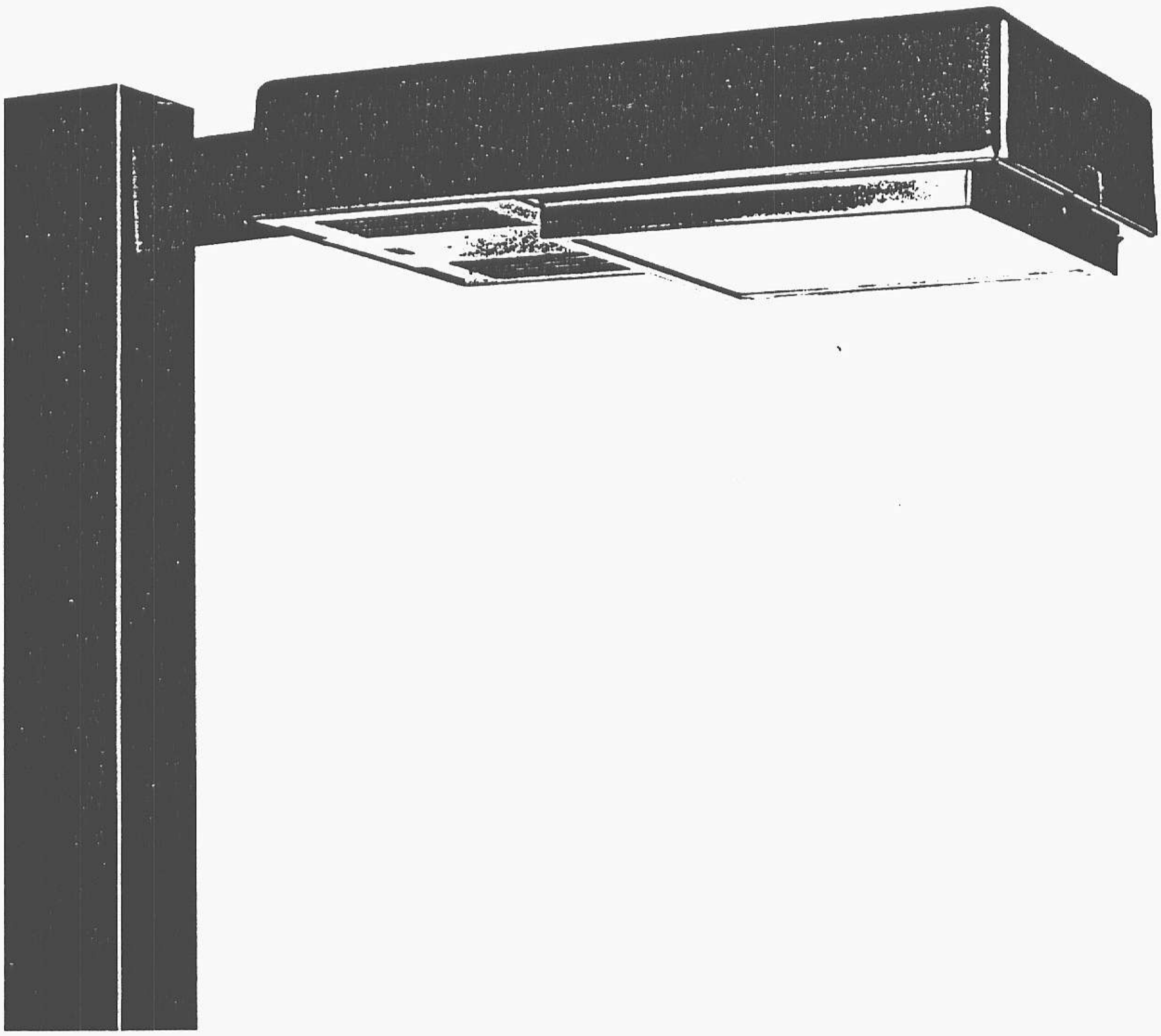


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FIGURE 9: Typical HPS cut-off Luminaire

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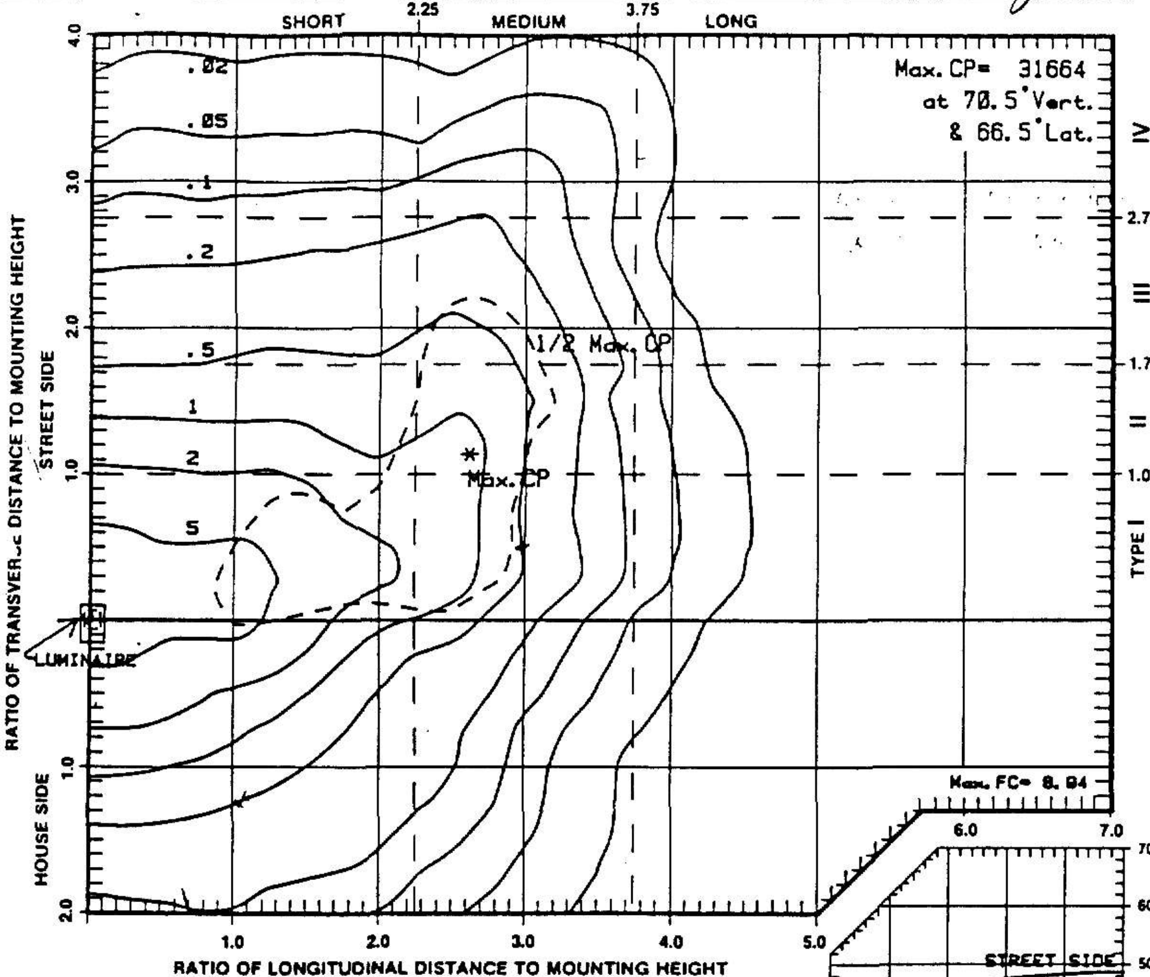
(601) 342-1545

PHOTOMETRIC REPORT

LUMINAIRE: DEV. 400 CUTOFF	REPORT # P2389
IES TYPE: III- MED - CUTOFF	DATE: 10-79
LAMP: (1) 400w HPS #LU400/BU E-18	TEST BY: BGH
DESCRIPTION: REFLECTOR #2 MAIN BEAM AREA	TEST DIST: 25'
BUFFED SOCKET B-2	APRVD:



ISOFOOTCANDLE LINES OF HORIZONTAL ILLUMINATION

Footcandle data is based on a luminaire mounted at 30 feet. For another mounting height, multiply the footcandle values by a factor from this table

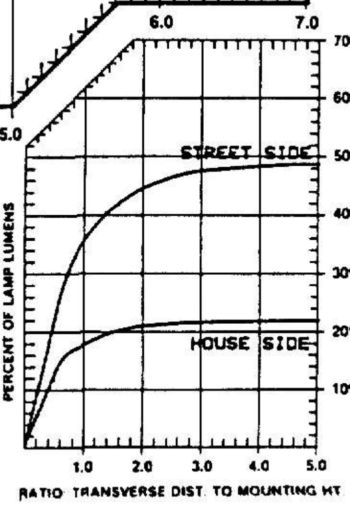
MOUNTING HEIGHT	25	28	30	32	35
FACTOR	1.44	1.15	1.00	.88	.74

This report is based on published IES Testing Procedures. Significance is limited to the degree that the tested sample is representative and that test conditions are duplicated. Voltage and characteristics of lamps and ballasts seriously affect field performance

Values of footcandles, lumens, and isocandela are based on a lamp operated at 50000 lumens. If data is desired for a different lumen rating, multiply these values by the different lumen rating, then divide by 50000.

FLUX DISTRIBUTION

	Lumens	% Lamp
Downward Street side	24223	48.4
Downward House side	10809	21.6
Total Downward	35032	70.1
Total Upward		
Total Flux		



COEFFICIENT OF UTILIZATION

FIGURE 10: Isofootcandle lines of Horizontal Illumination (HPS cut-off)

CANDLEPOWER TABLE

	STREET SIDE	LATERAL ANGLE										
		.0	5.0	15.0	25.0	35.0	45.0	55.0	65.0	66.5	75.0	85.0
	90.0	0.	43.	43.	0.	86.	43.	86.	86.	43.	86.	86.
	87.5	0.	43.	86.	43.	86.	86.	86.	86.	86.	86.	86.
	85.0	86.	86.	86.	86.	86.	86.	86.	86.	86.	86.	86.
V	82.5	86.	86.	86.	86.	86.	214.	171.	214.	171.	171.	257.
E	80.0	171.	171.	214.	342.	385.	1284.	513.	556.	471.	513.	770.
R	77.5	428.	556.	642.	1113.	1626.	9328.	1968.	1797.	1669.	2097.	1797.
T	75.0	1027.	1284.	1412.	2225.	3637.	12109.	12024.	9456.	6461.	5135.	4193.
I	72.5	1712.	2225.	2311.	3380.	5776.	10783.	25245.	25459.	18528.	9713.	9841.
C	70.5	2482.	2738.	2867.	3979.	6547.	9585.	18014.	31107.	31664.	20111.	14719.
A	70.0	2567.	2824.	3038.	4065.	6547.	9328.	16089.	28497.	31364.	24775.	16046.
L	67.5	2995.	3166.	3509.	4364.	6504.	9028.	10312.	18955.	23149.	28925.	25117.
	65.0	3252.	3295.	3765.	4664.	6761.	8429.	10826.	14848.	16688.	22849.	22293.
A	62.5	3338.	3466.	3808.	4578.	6162.	8344.	12708.	15490.	15361.	21822.	21009.
N	60.0	3509.	3594.	3851.	4536.	5691.	8857.	13821.	16902.	17158.	19982.	22079.
G	55.0	4022.	4151.	4407.	5177.	6418.	9242.	15490.	20410.	20795.	20410.	19897.
L	45.0	5563.	5563.	5862.	6589.	7574.	8900.	11895.	15361.	16474.	19640.	18271.
E	35.0	7189.	7146.	7360.	7574.	7959.	8472.	8943.	9414.	9542.	10612.	9884.
	25.0	8558.	8643.	8643.	8814.	8601.	8472.	8558.	8515.	8558.	8472.	7745.
	15.0	8900.	8814.	8900.	8772.	8772.	8558.	8344.	8044.	8002.	7574.	7231.
	5.0	7959.	7873.	7959.	7873.	7830.	7745.	7702.	7531.	7531.	7488.	7317.
	.0	7089.	7089.	7089.	7089.	7089.	7089.	7089.	7089.	7089.	7089.	7089.

FIGURE 11: CANDLEPOWER TABLE (HPS CUT-OFF)

HPS Luminaire

High Pressure Sodium—70 to 400 Watts
SERIES: 53/54 and 153/154

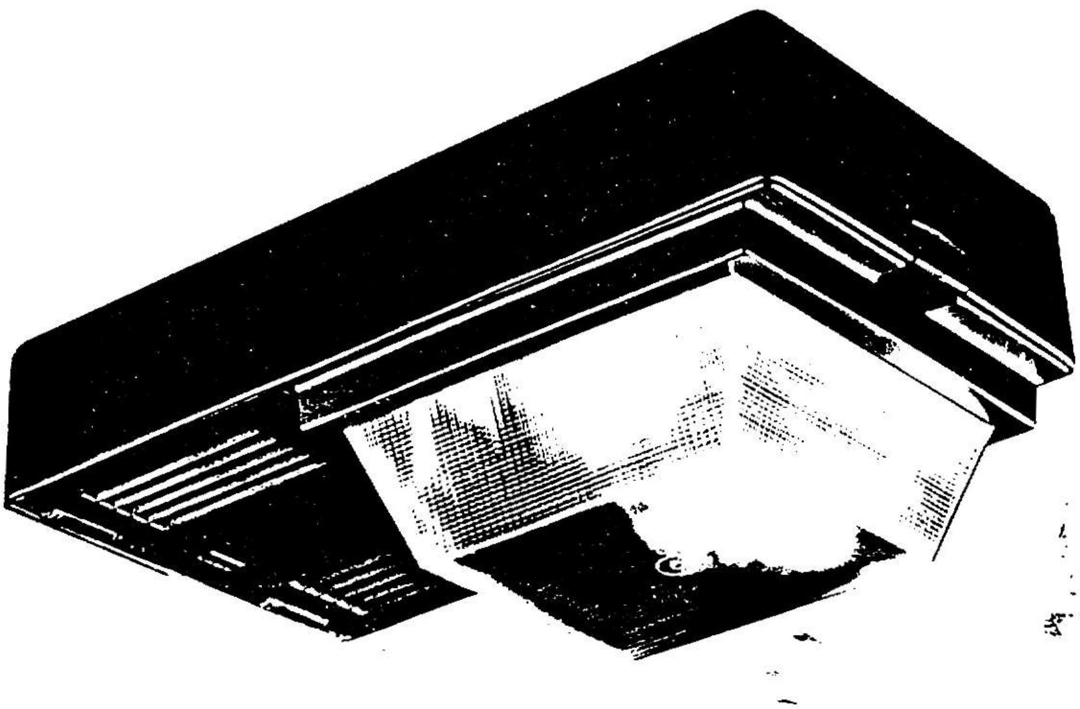


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FIGURE 12: Typical HPS long cut-off luminaire

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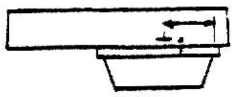
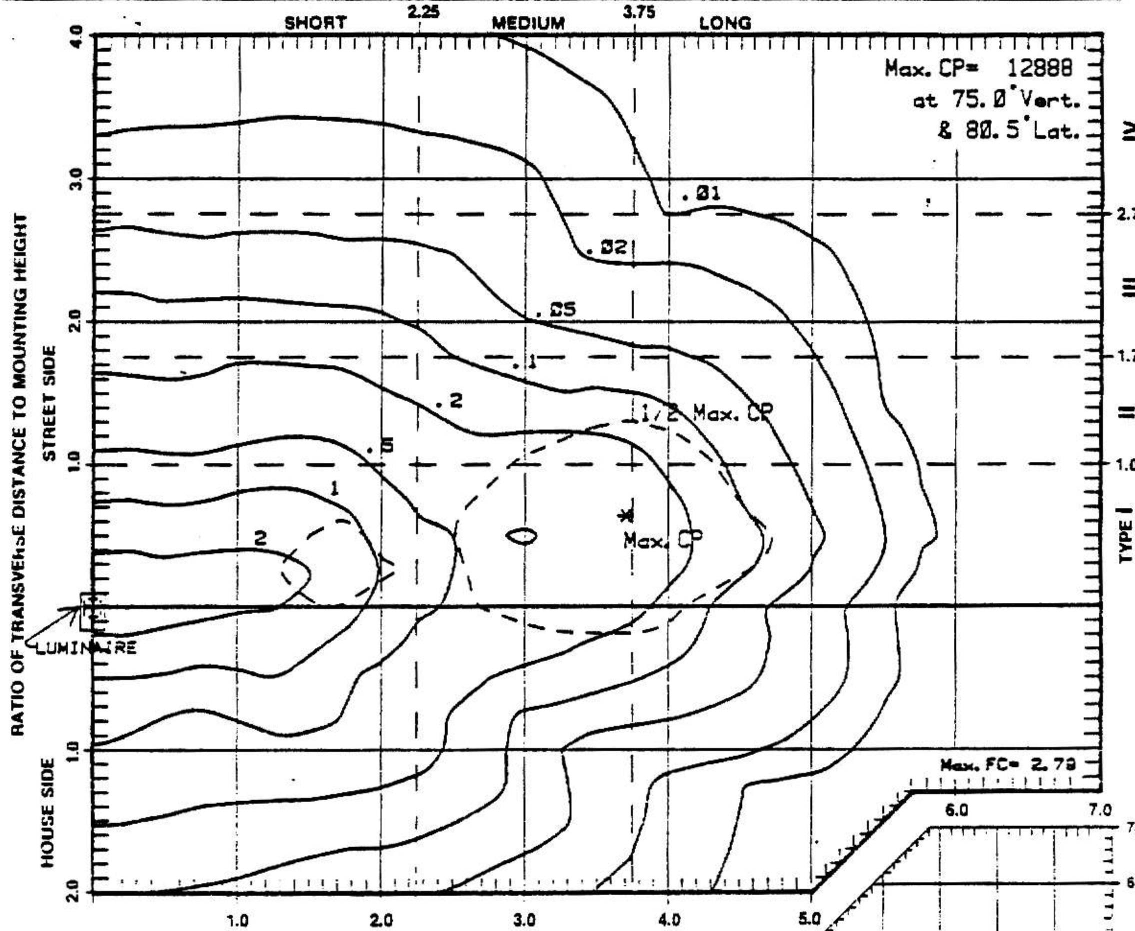
(601) 342-1545

PHOTOMETRIC REPORT



LUMINAIRE: ITT. 150 HPS
IES TYPE: II -LONG -CUTOFF
LAMP: (1) 150w HPS #LU150/55 BT25
DESCRIPTION: LAMP POSITION 1.00"x8.00"
PRISMATIC REFRACTOR, METALIZED REFLECTOR

REPORT # P2109
DATE: 2-79
TEST BY: BGH
TEST DIST: 25'
APRVD:



ISOFOOTCANDLE LINES OF HORIZONTAL ILLUMINATION

Footcandle data is based on a luminaire mounted at 25 feet. For another mounting height, multiply the footcandle values by a factor from this table

MOUNTING HEIGHT	20	22	25	28	30
FACTOR	1.56	1.29	1.00	.80	.70

This report is based on published IES Testing Procedures. Significance is limited to the degree that the tested sample is representative and that test conditions are duplicated. Voltage and characteristics of lamps and ballasts seriously affect field performance.

Values of footcandles, lumens and isocandela are based on a lamp operated at [illegible] lumens. If data is desired for a different lumen rating, multiply these values by the different [illegible]

FLUX DISTRIBUTION

	Lumens	% Lamp
Downward Street side	7292	44.3
Downward House side	4814	25.1
Total Downward	11106	69.4
Total Upward	0	.0
Total	11106	69.4

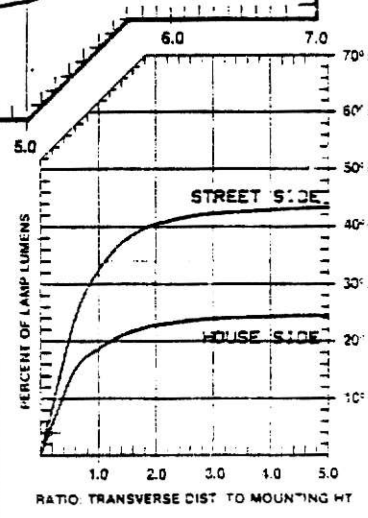


FIGURE 13: ISOFOOTCANDLE LINES OF HORIZONTAL ILLUMINATION (HPS LONG CUT-OFF)

	STREET SIDE	LATERAL ANGLE										
		0.0	5.0	15.0	25.0	35.0	45.0	55.0	65.0	75.0	80.5	85.0
	90.0	190.	227.	247.	266.	293.	304.	388.	375.	322.	297.	260.
	87.5	272.	330.	322.	367.	368.	453.	406.	445.	359.	322.	265.
	85.0	404.	476.	454.	470.	491.	526.	524.	540.	470.	412.	388.
	82.5	467.	549.	516.	549.	536.	582.	561.	627.	705.	656.	623.
V	80.0	561.	590.	569.	631.	646.	639.	623.	1262.	1085.	1303.	1431.
E	77.5	553.	557.	593.	685.	821.	1043.	751.	2503.	5296.	6430.	6183.
R	75.5	520.	507.	590.	714.	903.	1267.	1134.	2766.	9643.	12610.	11960.
T	75.0	520.	499.	583.	726.	924.	1340.	1196.	2966.	9779.	12586.	11672.
I	74.5	503.	503.	582.	742.	940.	1444.	1485.	3213.	9601.	12732.	11317.
C	72.5	511.	549.	594.	804.	1052.	1674.	1689.	3155.	9247.	11620.	10468.
A	70.0	627.	666.	672.	907.	1213.	1806.	2512.	3563.	6640.	7620.	6999.
L	67.5	775.	812.	779.	1039.	1307.	2042.	2710.	3745.	5326.	5943.	5758.
	65.0	891.	907.	833.	1115.	1468.	2066.	3283.	4495.	5296.	6054.	6092.
A	62.5	957.	936.	920.	1076.	1584.	2116.	3621.	5428.	6401.	7193.	7114.
N	60.0	907.	870.	874.	993.	1505.	2178.	3559.	5426.	7618.	8154.	7976.
G	55.0	817.	866.	863.	990.	1320.	1930.	3423.	4751.	6830.	7292.	6995.
L	45.0	1039.	1130.	1142.	1262.	1336.	1611.	2508.	3510.	4106.	4248.	3677.
E	35.0	1237.	1345.	1316.	1452.	1584.	1736.	2103.	2429.	2891.	2854.	2693.
	25.0	1361.	1452.	1452.	1551.	1670.	1648.	1992.	2066.	2194.	2198.	2141.
	15.0	1699.	1736.	1736.	1794.	1815.	1872.	1943.	1976.	2009.	1988.	1943.
	5.0	1823.	1815.	1827.	1819.	1831.	1819.	1827.	1794.	1798.	1782.	1765.
	0.0	1727.	1727.	1727.	1727.	1727.	1727.	1727.	1727.	1727.	1727.	1727.

FIGURE 14: CANDLEPOWER TABLE (HPS LONG CUT-OFF)

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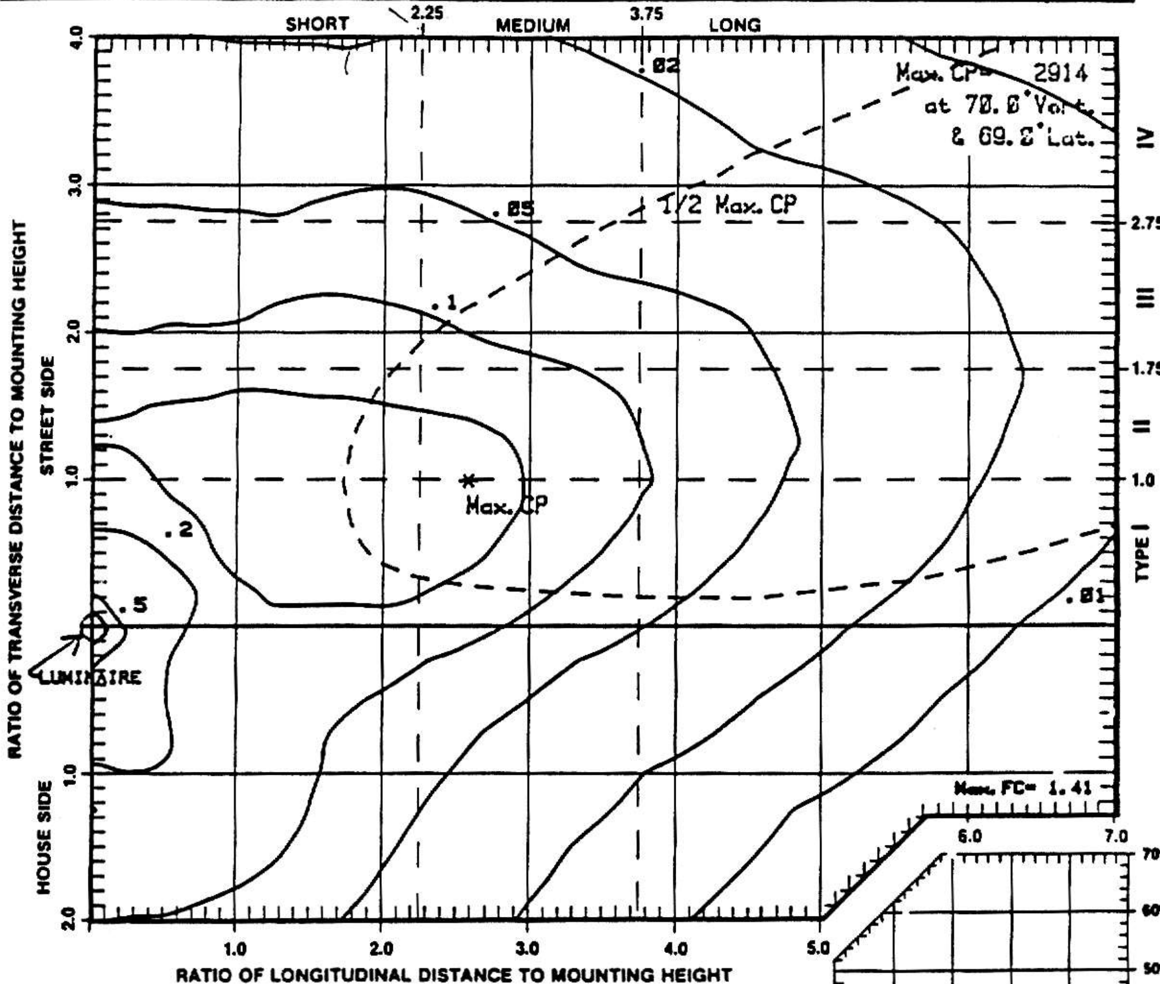
SOUTHAVEN, MISSISSIPPI 38671
(601) 342-1545

PHOTOMETRIC REPORT

LUMINAIRE: DEV. POST TOP
IES TYPE: IV -MED -NONCUTOFF
LAMP: (1) 175w M-V #H39KB-175 BT28
DESCRIPTION: TYPE III ACRYLIC REFRACTOR
LAMP TILTED 15 DEG.

REPORT # P2835
DATE: 3-80
TEST BY: WWP
TEST DIST: 25'
APRVD:



ISOFOOTCANDLE LINES OF HORIZONTAL ILLUMINATION

Footcandle data is based on a luminaire mounted at 20 feet. For another mounting height, multiply the footcandle values by a factor from this table:

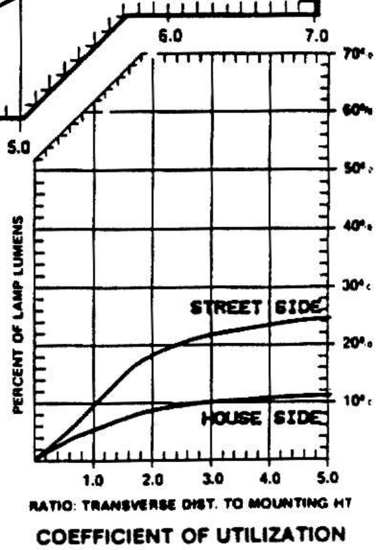
MOUNTING HEIGHT	15	18	20	22	25
FACTOR	1.78	1.23	1.00	.83	.64

This report is based on published IES Testing Procedures. Significance is limited to the degree that the tested sample is representative and that test conditions are duplicated. Voltage and characteristics of lamps and ballasts seriously affect field performance.

Values of footcandles, lumens, and isocandela are based on a lamp operated at 7900 lumens. If data is desired for a different lumen rating, multiply these values by the different lumen rating, then divide by 7900.

FLUX DISTRIBUTION

	Lumens	% Lamp
Downward Street side	2203	27.9
Downward House side	949	12.0
Total Downward	3152	39.9
Total Upward		
Total Flux		



COEFFICIENT OF UTILIZATION

FIGURE 15: Isofootcandle line of Horizontal Illumination (Post Top)

CANDLEPOWER TABLE

STREET SIDE		LATERAL ANGLE										
		0.0	5.0	15.0	25.0	35.0	45.0	55.0	65.0	69.0	75.0	85.0
	90.0	269.	276.	276.	319.	417.	512.	575.	602.	765.	746.	470.
	87.5	335.	346.	335.	394.	552.	664.	752.	1051.	1025.	1008.	621.
V	85.0	427	427.	424.	506.	736.	680.	1005.	1432.	1521.	1442.	910.
E	82.5	512.	512.	519.	611.	920.	1077.	1261.	1597.	2142.	2175.	1337.
R	80.0	552.	555.	562.	664.	1022.	1215.	1452.	2395.	[illegible]	2556.	1646.
T	77.5	578.	572.	568.	690.	1061.	1258.	1537.	2575.	2628.	2717.	1715.
I	75.0	578.	575.	598.	690.	1064.	1275.	1587.	2641.	2723.	2700.	1642.
C	72.5	572.	562.	591.	673.	1035.	1301.	1665.	2723.	2838.	2556.	1534.
A	70.0	558.	552.	585.	657.	999.	1275.	1708.	2726.	2914.	2487.	1429.
L	67.5	539.	512.	568.	624.	933.	1199.	1646.	2510.	2703.	2280.	1265.
	65.0	480.	453.	522.	558.	851.	1031.	1462.	1961.	2096.	1928.	1077.
A	62.5	440.	427.	483.	555.	821.	1045.	1265.	1485.	1541.	1465.	826.
N	60.0	453.	457.	503.	598.	854.	1025.	1163.	1140.	1100.	1054.	604.
G	55.0	460.	430.	509.	585.	713.	706.	775.	664.	641.	572.	365.
L	45.0	145.	145.	148.	151.	171.	164.	181.	177.	167.	177.	161.
E	35.0	138.	138.	138.	138.	145.	141.	145.	145.	148.	141.	135.
	25.0	131.	131.	135.	135.	135.	131.	138.	135.	138.	138.	131.
	15.0	125.	122.	122.	125.	128.	128.	128.	128.	125.	128.	131.
	5.0	374.	437.	368.	404.	273.	269.	200.	223.	214.	191.	217.
	0.0	564.	564.	564.	564.	564.	564.	564.	564.	564.	564.	564.

FIGURE 16: CANDLEPOWER TABLE (POST TOP)

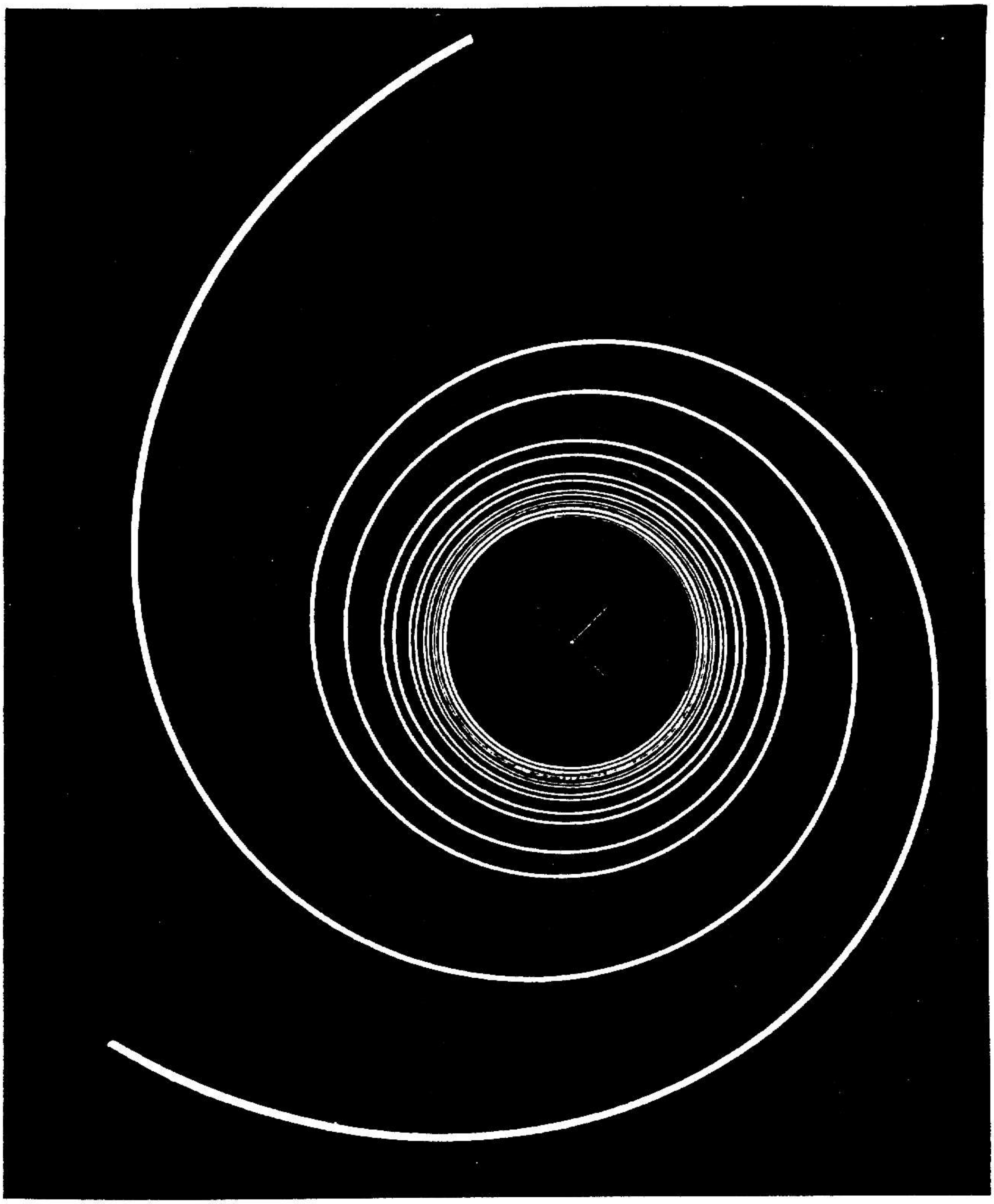


FIGURE 17: Photonegatives of Double Spiral Plot

the red spots in Figure 18. Thus only the intersecting double spiral segments at the open sectors were lighted which simulated the roadway lights as shown by the black spots in Figure 18. A piece of felt painted with high heat reflectant aluminum paint was glued to the opaque part of the side of the disk facing the luminaire. This helped in reflecting the heat falling on the disks from the luminaire and in keeping the disks cool. A 0.5" diameter hole was drilled at the center of the disk for mounting purposes. Two holes of 0.25" diameter were drilled on a radius of 2.5" to locate the disk. Figure 19 shows the two disks mounted for simulating roadway lights for a particular type of luminaire.

Mounting and Driving System for Disks: Figure 20 gives the details of the mounting system. Each of the two disks were mounted on the two pins projecting on the faces of the two aluminum hubs each of 4" diameter. The hub on the right hand side is movable where as the hub to the left is fixed. These hubs are mounted on two different shafts. There are grease inlets provided on the hubs for lubrication. The two hubs are screwed to the two sprockets which connect it to the drive system. The drive is transmitted from the chains to the sprockets which rotate the hubs and in turn rotate the disks. The drive system is designed and built in such a way that the two hubs rotate in the opposite direction. Figures 21 and 22 give the details of the drive system. The motor unit used is a 12 volt DC motor rated at 8 Amps maximum, approximately 40 rpm. The motor has a worm gear reduction to provide low rpm with high torque. The motor is tiltable and the gear (1) can be engaged to the gear (3) which provide a high range of speed (no speed reduction) or to gear (1) which provide a low range of speed (speed reduction 2:1). The drive is transmitted by the gears which finally rotate the

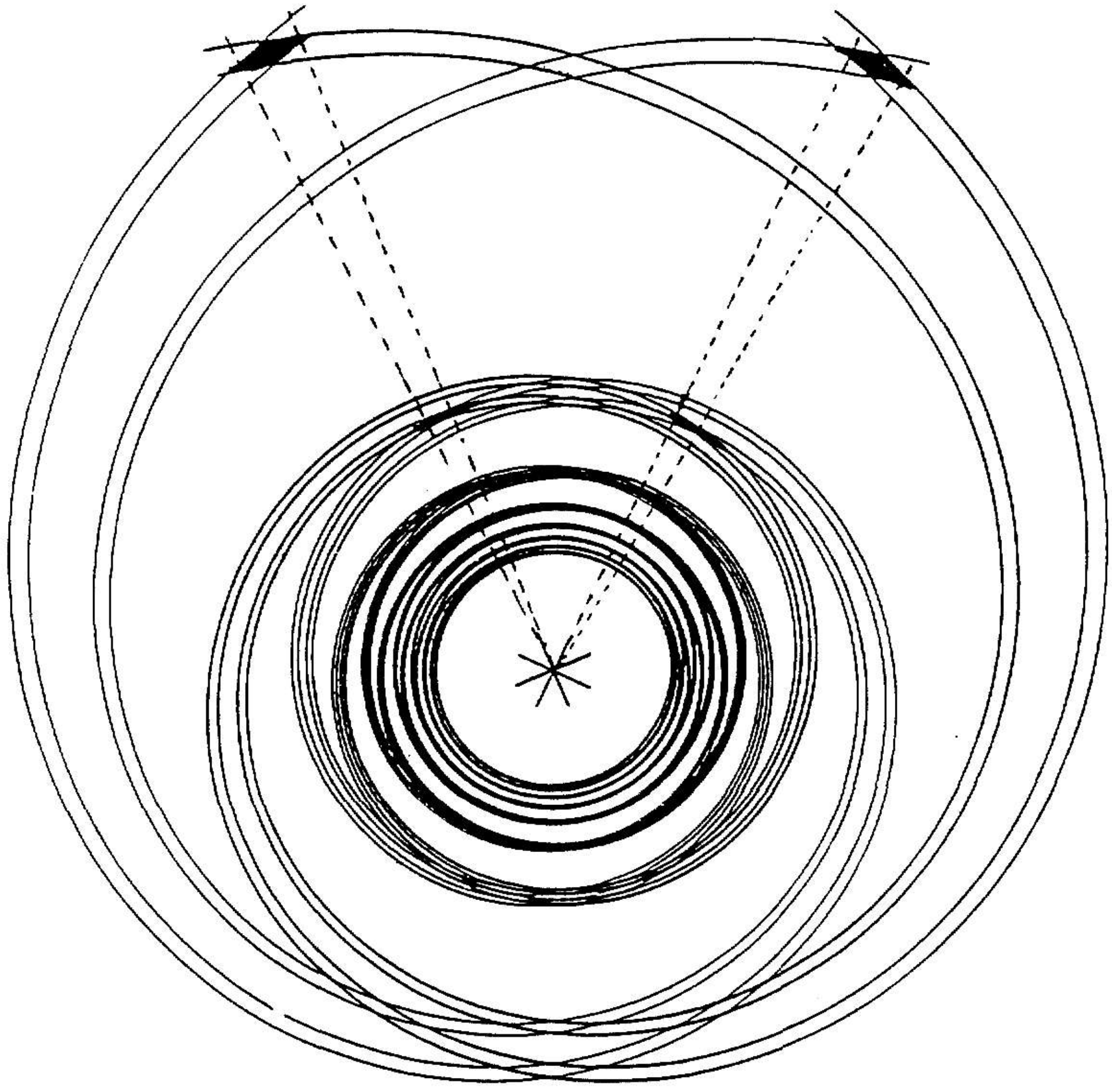


FIGURE 18: INTERSECTING DOUBLE SPIRALS

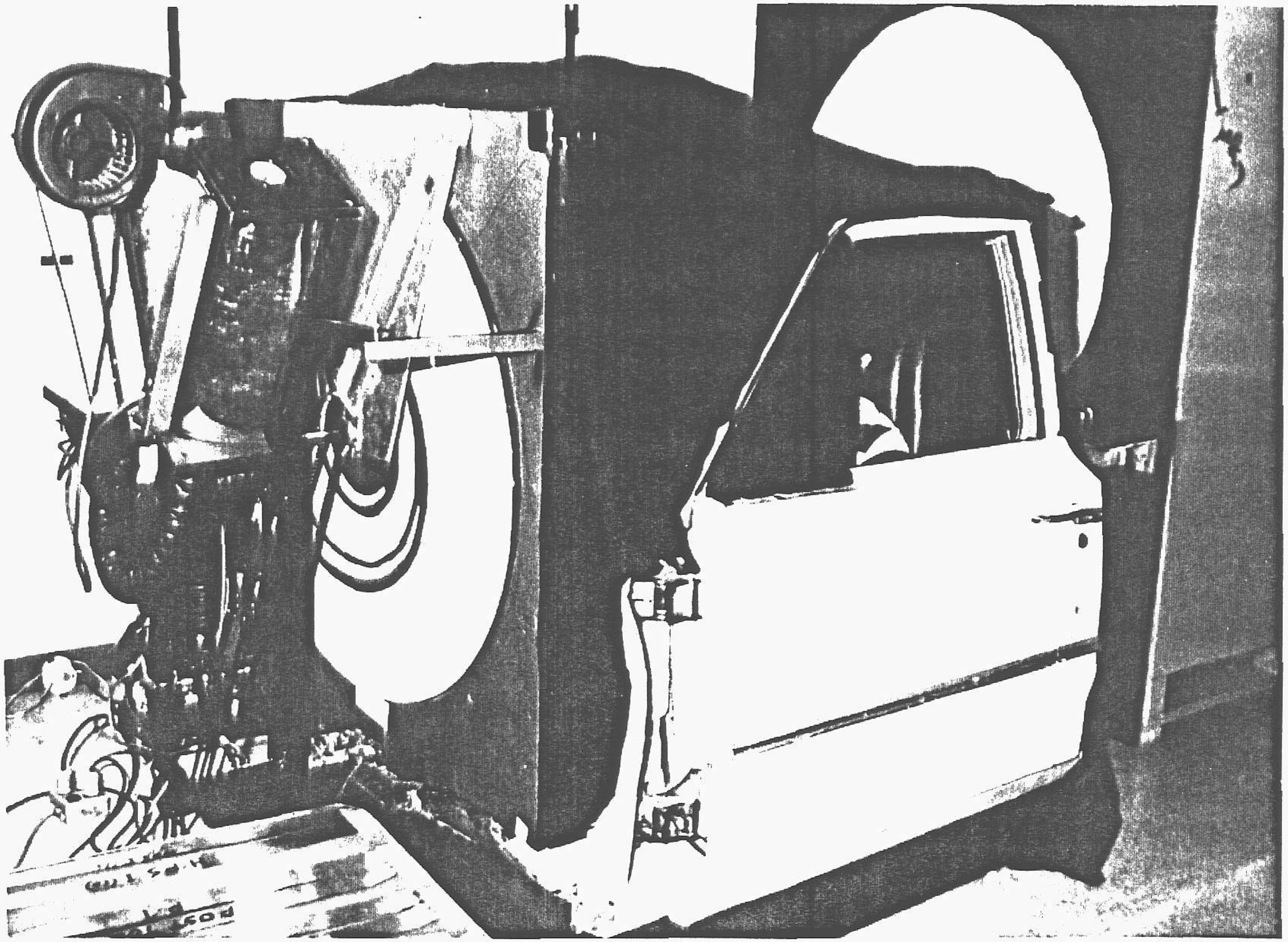


FIGURE 19: SIMULATOR WITH THE DISKS MOUNTED

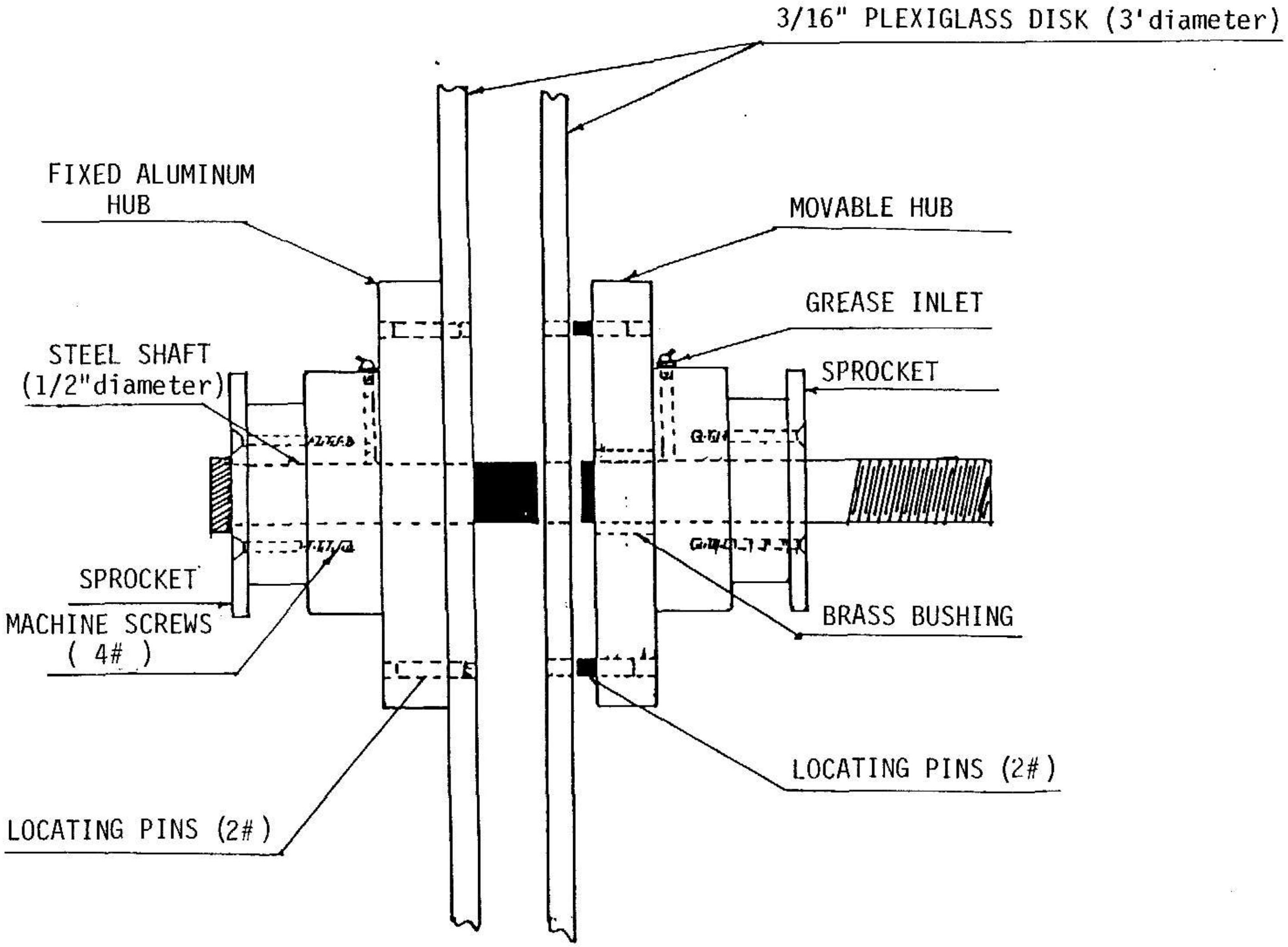


FIGURE 20: MOUNTING SYSTEM

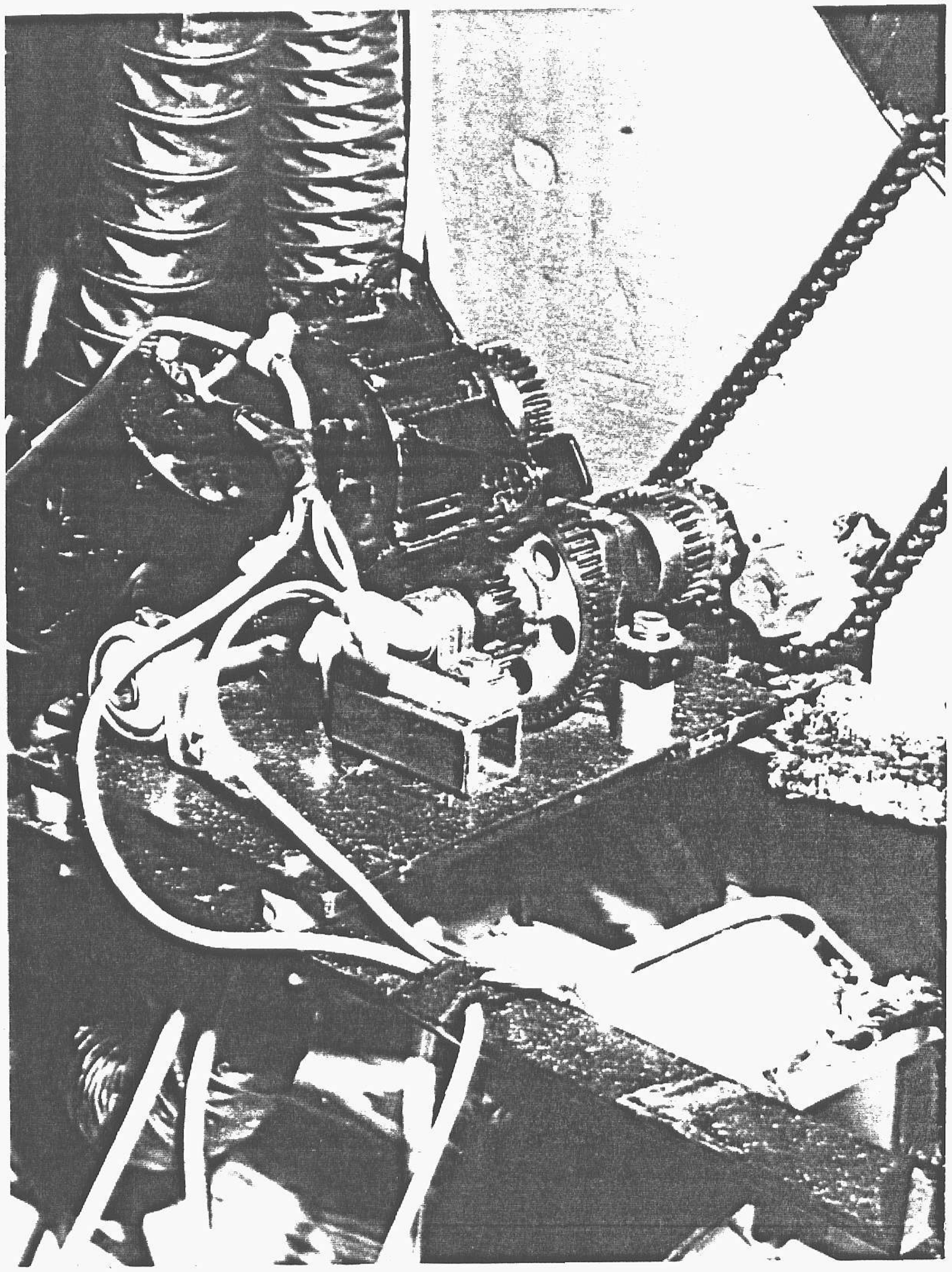


FIGURE 21: DRIVE SYSTEM FOR DISKS

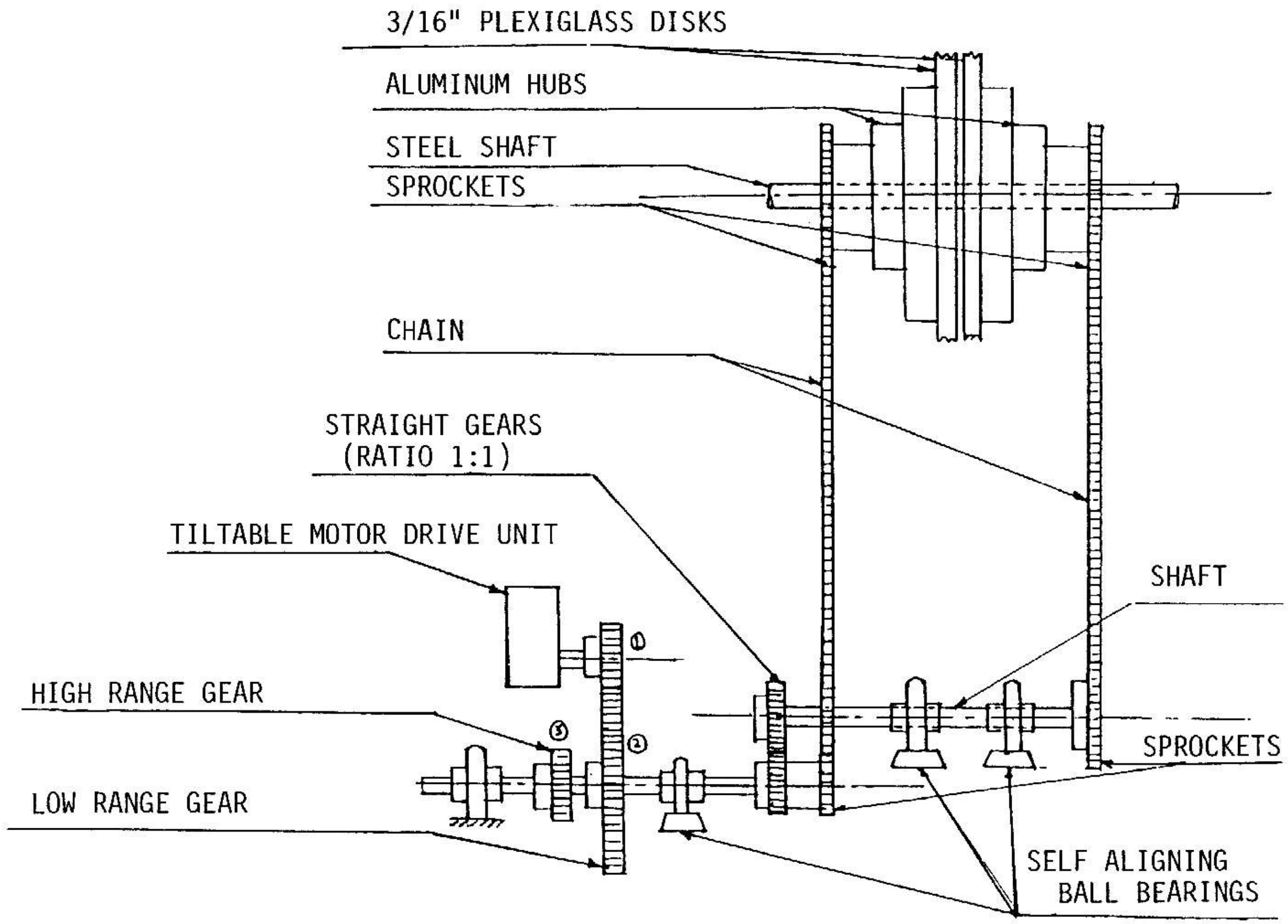


FIGURE 22: DRIVE SYSTEM FOR DISKS

sprockets in such a way that the two chains move in the opposite direction. This in turn rotates the sprockets in the mounting system in the opposite direction which finally rotates the hubs and the disks in the opposite direction.

Luminiare System: Figure 23 gives the details of the luminaire system. Two light fixtures were mounted in line with the open sectors. Each light fixture used five 300 watt quartzline lamps covered with a high heat resistant glass on the front side. All the lamps were arranged in the fixture in a stacked configuration with the flament of each bulb positioned at the focus of the Elliplical Reflector made of tin sheet. The elliplical reflector increased the efficiency of the light source by concentrating the light from the quartzline lamps on a long, narrow piece of diffusing glass (Factorlite). The Factorlite help in diffusing the luminance so that the individual sources are less distinguishable. The net effect is to produce a long narrow bar of intense and well diffused light. Intensities as high as 100,000 cd/m^2 could be obtained by this system.

Cooling System: An effective cooling system was designed as shown in Figure 23 Cool air was circulated in the lighting fixture with the help of flexible rubber hose connected to the lighting fixture from the blower. Another blower was mounted in between the luminaires as shown in Figure 23 which directed cool air on the heat resistant shield and the part of the disk facing the luminaire. A flexible rubber hose from another blower was directed at the center of disk which prevented the center of the disk from getting heated. The heat resistant shield as shown in Figure 24 was made of wood painted with heat resistant aluminum paint which further helped in keeping the disk cool.

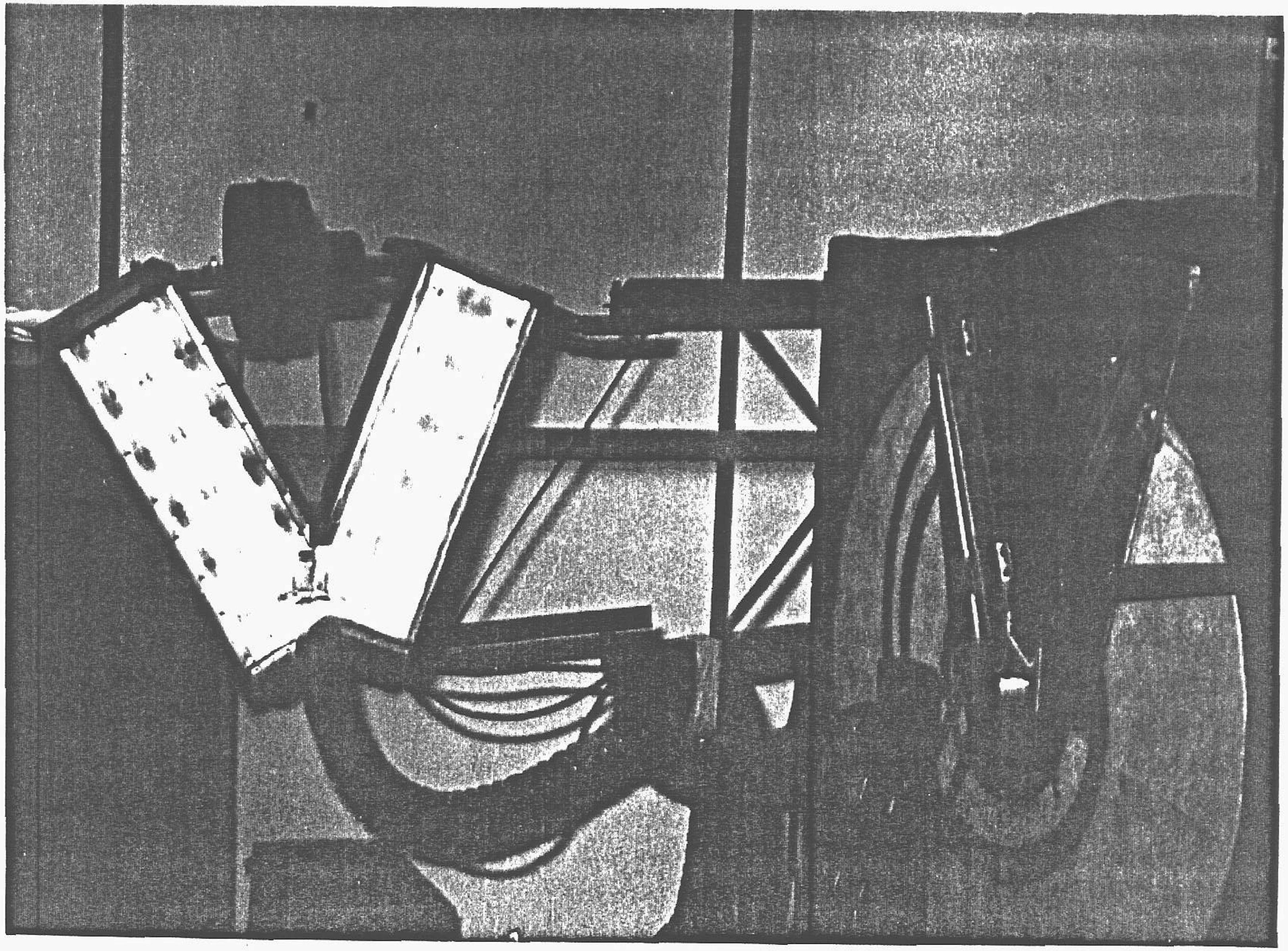


FIGURE 23: LUMINAIRE SYSTEM AND COOLING SYSTEM.

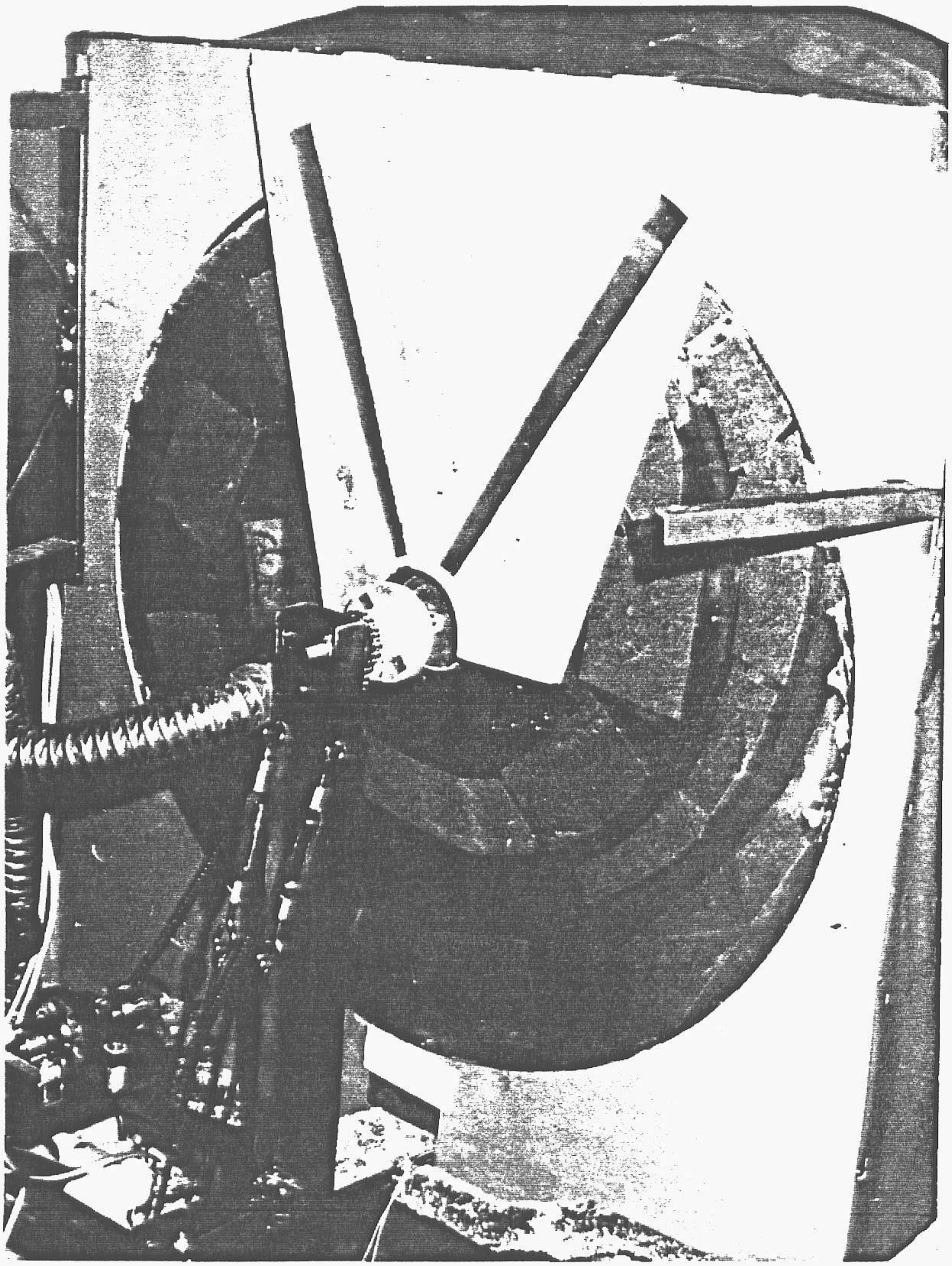


FIGURE 24: HEAT RESISTANT SHIELD IN CLOSED POSITION AFTER MOUNTING DISKS

Opaque mask with the graduated Sectors: The front of the car was covered by a plywood sheet of size 3 1/2' x 3 1/2'. Sectors were cut in this plywood sheet. This acted as the opaque mask with the open sectors. Slots were provided on either side of the sectors. Two graduated sectors for each type of luminaire were made of tin sheet which could be slid along these slots and positioned easily. The graduated sectors were painted black on the side facing the observer.

Control Panel: Figure 25 shows the details of the control panel. Luminance of the light source could be adjusted with an external transformer by the experimenter or by the observer with a transformer inside the car. After adjusting the transformer the corresponding voltage could be read on the voltmeter connected to it. The drive system was controlled by another external transformer. The voltage could be adjusted to increase or decrease the speed of the rotating disks. The background luminance could be adjusted by another external transformer. There was a switch board which connected the transformers, voltmeter and the cooling system to the mains.

FIGURE 25: CONTROL PANEL

Conditions of Study

In the first part of the experiment the task of night driving was performed with the help of the simulator by 12 subjects under four different types of luminaire: Cobrahead, HPS (High Pressure Sodium) Cut-off, HPS long cut-off and Post Top, at two speeds 30 mph and 60 mph. For each combination of luminaire and speed eight levels of luminance 200, 300, 1000, 2000, 5000, 10,000, 20,000 and 50,000 cd/m^2 were set by the experimenter. For each combination of luminaire, speed and luminance level the subject was asked to rate the glare criterion on the New North American Glare Scale shown in Figure 26. The description in enclosed brackets refer to the de Boer Scale where unbearable has a number 1 and unnoticeable has a number 9. In the second part of the experiment for each combination of the luminaire and speed the subject was asked to adjust the luminance to the level called BCD (borderline between comfort and discomfort). Detail written instructions were given to the subjects. These instructions are shown in Figure 27.

Experimental Design

Four types of luminaire and two speeds were the independent variable. The dependent variables were the subjects rating and the adjusted BCD values. As the mounting of the disks took considerable amount of time, instead of a completely randomized design a more practical design called the "Split-Plot" design was used. One luminaire was chosen randomly out of the four types of luminaire. Having fixed the luminaire type the two speeds were selected randomly. For each combination of luminaire and speed the subjects were asked to rate the glare for eight levels of luminance. The same procedure of randomization was repeated for the second part of the experiment. However, now the subject adjusted the luminance level to a criterion called BCD for each combination luminaire type and speed.

NEW NORTH AMERICAN GLARE SCALE

9 INTOLERABLE (UNBEARABLE)

8

7 BORDER LINE BETWEEN UNCOMFORTABLE AND INTOLERABLE (DISTURBING)

6

5 BORDER LINE BETWEEN COMFORT AND DISCOMFORT (BCD) (JUST ADMISSIBLE)

4

3 BORDER LINE BETWEEN COMFORTABLE AND PLEASANT (SATISFACTORY)

2

1 PLEASANT (UNNOTICEABLE)

Figure 26: NEW NORTH AMERICAN GLARE SCALE

INSTRUCTION SHEET *PLEASE READ CAREFULLY*

This simulator is designed to simulate actual dynamic roadway lighting conditions. You, as a subject will be performing an experiment with this simulator.

Take a seat in the car and make yourself comfortable. Locate the string with a metal strip tied to its end in front of you. Grab the metal strip and pull the string over the steering wheel towards you. Now with the other hand adjust your seat so that the end of the metal strip touches your eye lashes. Now you are ready to take-off. Keep your hands on the steering wheel.

You will be driving the car under four different types of luminaire and two different speeds. For each combination of luminaire and speed eight different levels of luminance will be adjusted. In all you will be driving under 16 combinations of luminance and speed for each of the four different types of luminaire.

Under each condition you will be asked to rate the glare criterion for luminance as per the scale in Figure 26. This scale is also posted to your right in the car. You are provided with a flash light to look at this scale. You may go through the same carefully.

After each combination of luminaire and speed you will be asked whether that particular speed was annoying or not.

Also, you will be rating each of the four luminaire systems as per the following scale:

1	2	3	4	5	6	7	8	9	10
↓ BAD ←									→ GOOD ↓

In the second part of the experiment you will be adjusting the luminance level to a criterion called BCD (border line between comfort and discomfort)

FIGURE 27: INSTRUCTION SHEET (cont'd)

as shown on the scale in Figure 26 represented by the number 5. You will follow the procedure described below to adjust for BCD. Locate the transformer to your right beside your seat. Grab the handle of the transformer and rotate in clockwise direction for about 20^o to 25^o. Now press the handle towards you and rotate the handle for about 20^o to 25^o in the anti-clockwise direction to locate a new position on the transformer knob. Now rotate the handle again in the clockwise direction for 20^o to 25^o. Repeat the same procedure. Please note that as you rotate the handle in the clockwise direction the luminance level will increase. To reduce the luminance level repeat the same procedure in the opposite direction. You are now ready to adjust the luminance level to a point called between Comfort and Discomfort ∿ BCD, when I ask you to do so. First take the control and increase the intensity of light to a high level. Look at the light! Most people would say that the light is uncomfortable glaring. Now take the control and turn the light down until it is at a low level. Look at the light! Most people would say that the light is comfortable i.e., not glaring. Now, somewhere between these two extremes should be a point of change, a threshold, where the light is at the borderline between comfort and discomfort. This is what we call BCD. This point should be such that the light is not annoying or uncomfortable to you, BUT, if it were any higher, it would be uncomfortable. Take your time to find the BCD point. DO NOT set the light at the border line between uncomfortable and intolerable —this is a higher level. Similarly do not use the comfortable—pleasantness criterion—this is a lower level. BCD is between these two criteria. You will be repeating the same for each combination of luminaire and speed. After completing the same you will be asked the following questions.

Figure 27: INSTRUCTION SHEET (cont'd)

1) Did the lights in a particular region in the sector trouble you more or constitute to most of the glare?

2) Does the simulation appeal to you giving the same sensation as experienced during night time driving?

The approximate time for you to complete the experiment will be about 1 1/2 hours. I will be glad to answer any questions you might have.

Figure 27: INSTRUCTION SHEET (cont'd)

Twelve subjects — four females and eight males were run for one and half hour each for $6.00 for the pilot study. The age of the subjects varied from 54 years to 23 years with a mean age of 32 years. Their biographical data is listed in Table 3.

TABLE: 3 BIOGRAPHICAL DATA OF SUBJECTS

SUBJECT NUMBER	SEX M/F	AGE YEARS	AREA OF STUDY PROFESSION	COMMENTS
1	M	54	Professor	
2	F	36	Cashier	One side lighting was the worst.
3	M	44	Secretary	Should have music.
4	F	29	Grain Science Grad.	None
5	M	26	Cashier	Comfortable and realistic.
6	M	30	Electrical Engg. Grad.	Projection of road will add to quality of simulators
7	M	26	I.E. Grad.	Good simulation. At higher intensities can get you to sleep. The upper 2-3 spots of light constitute mainly to glare.
8	M	37	I.E. Grad.	Upper half of the lights were more glaring.
9	M	25	Chem. Engg. Grad.	Upper half was more glaring.
10	M	24	I.E. Grad.	Upper half lights have more glare. Appear lights are placed very high on the road.
11	F	26	Cashier	Upper half lights were glaring.
12	F	23	Word Processing	Lights in the upper half were more glaring.

RESULTS

The ratings of the glare criterion by the subjects for each condition is listed in the Appendix. The luminance level for each conditions was transformed into logarithms. For each subject the BCD value was interpolated by computing the luminance value at the level of "5" in the New North American Glare Scale. The mean results are shown in Table 4.

The subject's adjusted values of BCD is listed in Appendix. The mean results are shown in Table 5.

An F-test was performed on the logarithmic values of luminance levels of subject's rating and subject's adjusted value of BCD independently to find the speed and luminaire effect. Table 6 and 7 gives the ANOVA tables. Tables 8 thru 11 gives the LSD means.

The overall subject's rating for each luminaire system is listed in the Appendix. Ratings given by each subject were transformed into ranks and and F-test was performed on the ranks. Table 12 gives the ANOVA table. Table 13 gives the LSD means (rank mean). Table 14 gives the percentage annoyance for each speed and type of luminaire.

The CBE, Glaremark and the mean subject's rating values and their ranks are shown in Table 15 and 16.

TABLE 4: MEAN BCD VALUES FOR SUBJECT'S RATING

VARIABLE	MEAN (Logarithms)	MEAN (cd/m^2)
--- LUM=1	SPEED=30 --	
RAT	3.54166667	3480
--- LUM=1	SPEED=60 --	
RAT	3.35916667	2286
--- LUM=2	SPEED=30 --	
RAT	3.49583333	3132
--- LUM=2	SPEED=60 --	
RAT	3.50666667	3211
--- LUM=3	SPEED=30 --	
RAT	3.75000000	5623
--- LUM=3	SPEED=60 --	
RAT	3.47500000	2985
--- LUM=4	SPEED=30 --	
RAT	3.74166667	5516
--- LUM=4	SPEED=60 --	
RAT	3.53750000	3447

TABLE 5: MEAN BCD VALUES FOR SUBJECT'S ADJUSTED BCD

VARIABLE	MEAN (Logarithms)	MEAN cd/m^2
--- LUM=1	SPEED=30 --	
BCD	3.58066667	3808
--- LUM=1	SPEED=60 --	
BCD	3.49750000	3144
--- LUM=2	SPEED=30 --	
BCD	3.60775000	4053
--- LUM=2	SPEED=60 --	
BCD	3.30941667	2039
--- LUM=3	SPEED=30 --	
BCD	3.56591667	3681
--- LUM=3	SPEED=60 --	
BCD	3.40050000	2515
--- LUM=4	SPEED=30 --	
BCD	3.78466667	6091
--- LUM=4	SPEED=60 --	
BCD	3.67225000	4701

TABLE 6: ANOVA TABLE FOR SUBJECTS RATING

SAS

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: RAT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	51	14.69716146	0.28817964	2.50
ERROR	44	5.07745417	0.11539669	
CORRECTED TOTAL	95	19.77461563		

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LUM	3	0.58131146	1.68	0.1853
SUB	11	9.34112813	7.36	0.0001
LUM*SUB	33	3.87032604	1.02	0.4741
SPEED	1	0.63537604	5.51	0.0235
LUM*SPEED	3	0.26901979	0.78	0.5131

TESTS OF HYPOTHESES USING THE ANOVA MS FOR LUM*SUB AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LUM	3	0.58131146	1.65	0.1963

TABLE 7: ANOVA TABLE FOR SUBJECTS ADJUSTED BCD

SAS

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: BCD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	51	34.70103925	0.68041253	6.84
ERROR	44	4.37595208	0.09945346	
CORRECTED TOTAL	95	39.07699133		

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LUM	3	1.07430975	3.60	0.0207
SUB	11	29.52432183	26.99	0.0001
LUM*SUB	33	3.28683975	1.00	0.4920
SPEED	1	0.65208067	6.56	0.0140
LUM*SPEED	3	0.16343725	0.55	0.6523

TESTS OF HYPOTHESES USING THE ANOVA MS FOR LUM*SUB AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
LUM	3	1.07430975	3.60	0.0237

TABLE 8: LSD MEANS FOR SUBJECTS RATING

T TESTS (LSD) FOR VARIABLE: RAT
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE, NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.05 DF=44 MSE=0.115397
CRITICAL VALUE OF T=2.01537
LEAST SIGNIFICANT DIFFERENCE=0.139748

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

T GROUPING	MEAN (Logarithms)	N	SPEED	MEAN cd/m^2
A	3.6323	48	30	4288
B	3.4696	48	60	2948

TABLE 9: LSD MEANS FOR SUBJECTS ADJUSTED BCD

T TESTS (LSD) FOR VARIABLE: BCD
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.05 DF=44 MSE=.0994535
CRITICAL VALUE OF T=2.01537
LEAST SIGNIFICANT DIFFERENCE=0.129735

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

T GROUPING	MEAN (Logarithms)	N	SPEED	MEAN cd/m^2
A	3.6347	48	30	4607
B	3.4699	48	60	2950

TABLE 10: LSD MEANS FOR SUBJECTS RATING

T TESTS (LSD) FOR VARIABLE: RAT
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE, NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.05 DF=33 MSE=0.117283
CRITICAL VALUE OF T=2.03452
LEAST SIGNIFICANT DIFFERENCE=0.201135

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

T GROUPING	MEAN (Logarithms)	N	LUM	MEAN cd/m^2
A	3.6396	24	4 (POST TOP)	4361
A				
A	3.6125	24	3 (HPS CUT OFF)	4097
A				
A	3.5012	24	2 (HPS LONG CUT OFF)	3171
A				
A	3.4504	24	1 (COBRA HEAD)	2844

TABLE 11: LSD MEANS FOR SUBJECTS ADJUSTED BCD

T TESTS (LSD) FOR VARIABLE: BCD
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE, NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.05 DF=33 MSE=.0996027
CRITICAL VALUE OF T=2.03452
LEAST SIGNIFICANT DIFFERENCE=0.185356

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

T GROUPING	MEAN (Logarithms)	N	LUM	MEAN cd/m^2
A	3.7285	24	4 (POST TOP)	5351
B	3.5391	24	1 (COBRA HEAD)	3460
B				
B	3.4832	24	3 (HPS CUT OFF)	3042
B				
B	3.4586	24	2 (HPS LONG CUT OFF)	2875

TABLE 12: ANOVA TABLE FOR SUBJECTS OVERALL RATING

SAS

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: R_RAT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	14	6.20833333	0.44345238	0.38
ERROR	33	38.29166667	1.16035354	
CORRECTED TOTAL	47	44.50000000		

SOURCE	DF	ANOVA SS	F VALUE	PR > F
SUP	11	0.00000000	0.00	1.0000
LUM	3	6.20833333	1.78	0.1695

TABLE 13: LSD MEANS (RANK MEANS) FOR SUBJECTS OVERALL RATING

```
T TESTS (LSD) FOR VARIABLE: P_RAT
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
      NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.05   DF=33   MSE=1.16035
CRITICAL VALUE OF T=2.03452
LEAST SIGNIFICANT DIFFERENCE=0.894706

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.
```

T GROUPING		MEAN (Rank means)	N	LUM
	A	2.9167	12	4 (POST TOP)
	A			
B	A	2.7083	12	1 (COBRA HEAD)
B	A			
B	A	2.4167	12	3 (HPS CUT OFF)
B				
B		1.9583	12	2 (HPS LONG CUT OFF)

TABLE 14: ANNOYANCE CHART

LUMINAIRE TYPE	COBRA HEAD		POST TOP		HPS (High Pressure Sodium) cut off		HPS long cut off	
SPEED	30 mph	60 mph	30 mph	60 mph	30 mph	60 mph	30 mph	60 mph
Number of subjects Annoyed/Total number of Subjects	3/12	7/12	1/12	9/12	1/12	6/12	1/12	8/12
Percent Annoyed	25	58	8	75	8	50	8	67
Number of Subjects not annoyed/Total number of Subjects	9/12	5/12	11/12	3/12	11/12	6/12	11/12	4/12
Percent not Annoyed	75	42	92	25	92	50	92	33

TABLE 15: CBE, GLAREMARK AND OBSERVERS RATING

LUMINAIRE TYPE	GLAREMARK VALUE	CBE VALUE	SUBJECTS ADJUSTED BCD cd/m^2	SUBJECTS RATING cd/m^2	SUBJECTS OVERALL RATING (RANKS)
POST TOP	6.92	13.37	5351	4361	2.92
HPS CUT-OFF	6.62	3.52	3042	4097	2.42
COBRAHEAD	5.52	22.25	3460	2844	2.70
HPS LONG CUT-OFF	5.26	19.8	2875	3171	1.96

TABLE 16: RANKING OF CBE, GLAREMARK AND SUBJECTS APPRAISALS

	CBE	GLAREMARK	SUBJECTS ADJUSTED BCD	SUBJECTS RATING	SUBJECTS OVERALL RATING
MOST COMFORTABLE	HPSCO	PT	PT	PT	PT
	PT	HPSCO	CH	HPSCO	CH
	HPSLC	CH	HPSCO	HPSLC	HPSCO
LEAST COMFORTABLE	CH	HPSLC	HPSLC	CH	HPSLC

DISCUSSION

The speed effect is found significant in both the F-tests on subjects rating and subjects adjusted values of BCD (Table 6 and 7). The largest mean BCD values 4228 cd/m^2 and 4607 cd/m^2 are for the slower speed of 30 mph (Table 8 and 9) where as the mean BCD values for the higher speed of 60 mph are 2948 and 2950 cd/m^2 (Table 8 and 9). This clearly indicates that higher luminance level is required to produce the same degree of discomfort at a slower speed of 30 mph as compared to 60 mph. These are compatible with the fact that the percentage annoyance for different types of luminaires varied from 50% to 90% with 60 mph condition where as the percentage annoyance for 30 mph condition for different luminaires varied from only 8% to 50% (Table 14). The mean BCD values for each type of luminaire and speed are tested in Table 4.

The luminaire effect is found significant in the F-test on the subjects adjusted value of BCD (Table 7). From the LSD means listed in Table 10 and 11 the largest values of BCD 5351 and 4361 cd/m^2 are for the Post Top luminaire and the smallest BCD values of 2844 cd/m^2 for Cobrahead and 2875 cd/m^2 for HPS long cut off (Table 10 and 11). The result concludes that the Post-Top luminaire is the most comfortable system. This result is contradictory to the expectation. It was expected that the Post-Top luminaire would be the most glaring as the observer sees a bigger area of the source all the time when near and far compared to the other systems which would constitute more brightness and in turn more glare. It was expected that the HPS cut off luminaire would be the most comfortable system as the observer does not see any area of light when he is far away from the light source, but as he approaches closer to the source he sees a small area of source which gets bigger as he gets closer to the source.

However, in case of Post-Top luminaire one side lighting was used. From the overall rating for each luminaire system listed in Appendix, it is seen that most of the subjects rated the Post Top as better than others. They were of the opinion that one side lighting produced less discomfort glare as compared to the two sides lighting used for the other three systems. Results of the Parametric Study in Fall 83 at Kansas State University (Bennett 1983) showed that there is no significant effect between one side lighting and opposite side lighting. However, in the Fry simulator (Bennett 1982) the background lighting was independent of the simulated roadway lights. Therefore the greater background uniformity produced by the two side lighting in the real world could not be achieved in the simulator. This area needs further validation.

Though the F-test on subject's rating and subjects overall rating did not show any significant luminaire effect (Table 6 and 7) in the pilot study there is every possibility that significant luminaire effect may show up when all the 60 subjects are run. Further, the limitation of the present simulator is, the intensity variation of the source as a function of viewing angle is not taken into account. There is a possibility that this could create a major difference between the types of luminaire depending upon whether the closer lights, the farther lights and the lights in between these region cause the discomfort glare. Yet another limitation of the simulator is that the subject did not get the physical feeling of driving at night time. Most of the time in real life the motorist does not look at the closer lights or the far away lights. He concentrates in the region lighted by the head lights of his car. This in effect would cause the motorist to look at the lights which are neither far nor too close. Subject's opinion was that they were many a times forced to look into the larger closer lights which constituted lot of glare which in real life they would not have looked at. Also, in this simulator the effect of head lights is not considered. This calls for the design of a three dimensional model of the simulator to overcome these limitations.

The LSD means for subject's rating, subject's adjusted values of BCD and subject's overall rating as shown in Table 10, 11 and 13. Though the ranking of the means of subject's rating and overall rating match, they do not agree with that of the means of subject's adjusted value of RCD. However, it is too early to compare them as it is only a pilot study.

The CBE and Glaremark values for each of the systems are listed in Table 15. The Glaremark value for each system was computed using equation (18). For each system the value of Luminous Intensity at 80^{o}v and 90^{o}H and 88^{o}v and 90^{o}H is calibrated from the candle power table (Figures 7 thru 16). The flashed area of the luminaire and the other values are computed from the geometry of the road lighting design.

In computing the CBE values it is assumed that the motorist is at the center of the street. Equation (19) is used to compute the CBE value for each system. The distance of the luminaire from the motorist, the lateral angle, the vertical angle and the angle off the line of sight for each luminaire with respect to the motorist is computed from the geometry of the road lighting design. The luminous intensity of each source with respect to the observer is then calibrated from the candle power Tables and knowing the vertical and lateral angle. This value of luminous intensity is then divided by the area of the luminaire as seen by the observer to get the luminance or brightness of the source. The source size in steradians is computed by dividing the area of the luminaire as seen by the observer by the square distance of the source from the observer.

Table 16 gives the comparative ranking for each type of luminaire for CBE, Glaremark, subjects rating, subject adjusted value of BCD and subjects overall rating. The Glaremark and the three subject appraisal systems consider the Post-Top luminaire as the most comfortable. The subjects overall rating, the subject's adjusted value of BCD and the glaremark consider HPS long cut-off as the least comfortable. The subject's rating system considers the cobrahead as the least comfortable. There is no agreement between the glaremark and the three subjects appraisal in the mid range. The CBE system considers the HPS cut-off luminaire as the most comfortable but considers the cobrahead as the least comfortable. Thus, in general we find that the correspondence of rankings is poor between the three observers rating and either CBE and/or Glaremark. The result clearly indicates that the systems do not agree with each other in their appraoch to the effect of discomfort glare produced by the light source in roadway lighting.

In the Glaremark system the luminaire characteristics seen at a long distance is considered to control comfort where as in the CBE system the luminaire closer to the observer controls comfort. From their approach it is clear that the two systems will not agree with each other in their rankings. But, the question arises which is a better predictor of comfort. On comparing CBE and glaremark with subjects rating it is found that none of them agree with subjects appraisal. This leads to the next question whether the closer or the far away lights does constitute to the discomfort glare as the motorist in real life does not look at these lights. Now the question arises as to how the subjects appraisal considers the Post-Top as the most comfortable system. It is too early to come to this conclusion after the pilot study. The results need to be seen after running 60 subjects.

Also, this calls for a detail study of CBE and Glaremark as regards to their validity in application to prediction of discomfort glare in roadway lighting.

CONCLUSIONS

There is a significant luminaire effect. However, the simulated Post-Top luminaire is found to be the most comfortable which is contradictory to the expectation.

The results show a significant speed effect and need for further study of this.

The correspondence of ranking is poor between the observers and either CBE and/or Glaremark. This calls for further detail study of CBE and Glaremark system regarding their validity in application of roadway lighting design to predict discomfort glare.

The subjects answers to the question regarding quality of simulation show that it appealed to the subject as close to the actual night driving condition.

The simulator can be used for further studies of discomfort glare from roadway lighting. Also, a need for three dimensional model is seen to overcome the limitation of the present simulator.

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APPENDIX

DISK RPM CALIBRATION CHART

TYPE OF LUMINAIRE	SPEED MPH	DISK RPM
POST TOP	30	13
	60	27
COBRAHEAD	30	16
	60	32
HPS CUT-OFF	30	13
	60	27
HPS LONG CUT-OFF	30	13
	60	27

LUMINANCE CALIBRATION CHART

cd/m^2	VOLTS
50,000	68.8
20,000	57.0
5,000	42.5
2,000	35.8
1,000	32.0
500	27.5
200	24.5

DOUBLE SPIRAL PROGRAM

```
C--DYNAMIC DISK SPIRIAL PLOT---------BEGIN--------------
C--VARIABLE DECLARATION
      REAL H,V,S,INRAD,CUTANG,LHT,EYELVL,X,Y,RADIUS,ANGLE,
     -    INITAN,HEIGHT,FINANG,SHIFT,SHFT,D,A2,B1,C1
      INTEGER COUNT,INIT,FINAL,REV,I
C--THIS SPACE IS FOR VARIABLE ASSIGNMENT CARDS
      H=32.8          H = mounting height
      V=42.           V = viewing distance in the simulator
      S=164.          S = spacing
      INRAD=2.        INRAD = inneradius
      REV = 8         REV = number of revolutions
      CUTANG=.349     CUTANG = cut off angle
      LHT=6.125       LHT = vertical dimension of the luminaire
      EYELVL = 4.     Eyelvl = eye level of the observer
      D=17.           D = depth of the luminaire
      SHFT = 0.908    SHFT = shift angle between the two double spirals
C--PLOT INNER SPIRAL
      HEIGHT = H-EYELVL
       CALL PLTOPT('PAPERWIDTH =WIDE,PENTYPE=L2#')
      CALL PLOTS
      CALL PLOT(30.0,20.0,23)
      CALL FACTOR(0.95)
      SHIFT=0.
      DO 20 I = 1,2
C--PLOT INITIAL POINT
      RADIUS=V*TAN(CUTANG)
      INITAN   =(2.*3.1416*HEIGHT*V)/(S*RADIUS)  + SHIFT
      X=(RADIUS+INRAD)*COS(INITAN)
      Y=(RADIUS+INRAD)*SIN(INITAN   )
      CALL SMOOTH(X,Y,0)
```

DOUBLE SPIRAL PROGRAM (cont'd)

```
C--FIND LOOP PARAMETERS
      INIT = INT((INITAN - SHIFT)*8. / 3.1416) + 1
      FINAL=16*REV
C--PLOT SPIRAL
      DO 10 COUNT = INIT,FINAL
         ANGLE=COUNT*3.1416/8.  + SHIFT
         RADIUS = ((2.*3.1416*HEIGHT*V)/(S*(ANGLE -SHIFT))) + INRAD
         X=RADIUS*COS(ANGLE)
         Y=RADIUS*SIN(ANGLE)
         CALL SMOOTH(X,Y,2)
10    CONTINUE
C--PLOT FINAL POINT
      FINANG  =(FINAL+1.)*3.1416/8.  + SHIFT
         RADIUS = ((2.*3.1416*HEIGHT*V)/(S*(FINANG-SHIFT))) + INRAD
      X=RADIUS*COS(FINANG)
      Y=RADIUS*SIN(FINANG)
      CALL SMOOTH(X,Y,24)
C--PLOT OUTER SPIRAL
C--PLOT INITIAL POINT
      RADIUS=V*TAN(CUTANG)*(1.+(D/(12.*HEIGHT)))-0.025
      X=(RADIUS+INRAD)*COS(INITAN)
      Y=(RADIUS+INRAD)*SIN(INITAN)
      CALL SMOOTH(X,Y,0)
C--PLOT SPIRAL
      DO 11 COUNT = INIT,FINAL
         ANGLE=COUNT*3.1416/8.  + SHIFT
         LHTV = ((D-LHT)/(INITAN-2*3.1416*REV))*(ANGLE-INITAN)+D
         RADIUS = ((2.*3.1416*HEIGHT*V)/(S*(ANGLE - SHIFT)))*
     -   (1.+(LHTV/(12.*HEIGHT)))+INRAD-0.025
         X=RADIUS*COS(ANGLE)
         Y=RADIUS*SIN(ANGLE)
         CALL SMOOTH(X,Y,2)
11    CONTINUE
```

DOUBLE SPIRAL PROGRAM (cont'd)

```
C--PLOT FINAL POINT
      RADIUS=((2.*3.1416*HEIGHT*V)/(S*(FINANG-SHIFT)))*(1.+
     -  (LHT/(12.*HEIGHT)))-0.025
      X=(RADIUS+INRAD)*COS(FINANG)
      Y=(RADIUS+INRAD)*SIN(FINANG)
      CALL SMOOTH(X,Y,24)
      SHIFT = SHFT
20    CONTINUE
C--PLOT CENTER LINES
      CALL PLOT(0.,1.,3)
      CALL PLOT(0.,-1.,2)
      CALL PLOT(1.,0.,3)
      CALL PLOT(-1.,0.,2)
C--TERMINATE PLOT PROGRAM
      CALL PLOT(0.,0.,999)
      STOP
      END
```

TABLE: SUBJECTS RATING

LUMINAIRE TYPE: HPS CO (High Pressure Sodium) cut off SPEED: 30 mph

SUB	LUMINANCE cd/m²							
NUM.	200	300	1000	2000	5000	10,000	20,000	50,000
1	2	3	3	4	5	6	7	8
2	3	3	5	5	5	7	9	-
3	1	2	3	5	6	7	8	9
4	2	2	3	3	4	4	5	6
5	1	1	2	3	4	4	5	6
6	1	1	2	3	5	7	9	-
7	1	1	2	3	4	5	6	8
8	2	3	3	3	4	5	6	7
9	2	3	3	5	7	8	9	-
10	1	3	4	4	5	6	7	8
11	1	1	2	3	4	5	6	7
12	1	3	5	7	9	-	-	-

TABLE: SUBJECTS RATING

LUMINAIRE TYPE: HPS CO (High Pressure Sodium) cut off SPEED: 60 mph

SUB	LUMINANCE cd/m^2							
NUM.	200	300	1000	2000	5000	10,000	20,000	50,000
1	2	3	3	4	5	6	7	9
2	3	5	5	7	9	-	-	-
3	1	2	3	5	6	7	8	9
4	2	2	3	4	5	5	6	6
5	1	2	3	4	5	6	7	9
6	1	2	3	5	7	9	-	-
7	1	2	3	3	4	5	6	8
8	1	2	3	4	4	5	6	7
9	3	4	5	6	8	9	-	-
10	1	2	3	4	5	6	8	9
11	2	2	3	5	6	7	8	9
12	3	3	5	6	7	9	-	-

TABLE: SUBJECTS RATING

LUMINAIRE TYPE: HPS LC (High Pressure Sodium) long cut off SPEED: 30 mph

SUB	LUMINANCE cd/m^2							
NUM.	200	300	1000	2000	5000	10,000	20,000	50,000
1	3	3	5	5	6	7	8	9
2	1	3	3	5	7	7	9	-
3	1	2	3	4	5	7	8	8
4	2	2	3	3	4	5	5	7
5	1	1	2	3	4	5	6	7
6	2	3	4	5	6	8	9	-
7	1	1	2	2	3	4	5	7
8	2	3	3	4	5	5	6	7
9	1	2	3	4	5	7	8	9
10	2	3	5	6	7	9	-	-
11	3	3	4	5	6	7	7	8
12	5	7	9	-	-	-	-	-

TABLE: SUBJECTS RATING

LUMINAIRE TYPE: HPS LC (High Pressure Sodium) long cut off SPEED: 60 mph

SUB NUM.	LUMINANCE cd/m² 200	300	1000	2000	5000	10,000	20,000	50,000
1	3	4	4	5	6	7	8	9
2	3	3	5	5	7	9	-	-
3	1	2	3	5	6	7	8	9
4	2	3	3	4	4	4	5	6
5	2	3	4	4	5	6	6	7
6	3	4	4	6	7	8	9	-
7	1	2	3	4	5	6	7	7
8	2	2	3	3	4	5	6	7
9	1	2	3	4	5	6	7	9
10	3	3	4	5	7	9	-	-
11	1	1	2	3	4	5	7	8
12	3	5	7	7	9	-	-	-

TABLE: SUBJECTS RATING

LUMINAIRE TYPE: COBRA HEAD SPEED: 30 mph

SUB	LUMINANCE cd/m^2							
NUM.	200	300	1000	2000	5000	10,000	20,000	50,000
1	2	3	4	5	7	7	8	9
2	1	1	3	3	5	7	9	-
3	1	2	3	4	5	7	8	9
4	2	3	3	3	4	4	5	6
5	2	3	4	4	5	6	7	8
6	1	1	3	3	6	8	9	-
7	1	2	3	3	4	5	6	6
8	2	2	3	4	5	6	7	9
9	2	2	3	4	6	8	9	-
10	1	1	2	3	4	5	7	9
11	1	1	3	3	5	6	7	8
12	3	5	7	7	7	9	-	-

TABLE: SUBJECTS RATING

LUMINAIRE TYPE: COBRA HEAD SPEED: 60 mph

SUB NUM.	LUMINANCE cd/m^2							
	200	300	1000	2000	5000	10,000	20,000	50,000
1	3	5	6	7	8	9	-	-
2	1	3	3	5	7	9	-	-
3	2	3	4	5	7	8	9	-
4	4	4	4	5	6	6	6	7
5	2	3	4	4	5	6	7	8
6	2	2	3	6	8	9	-	-
7	1	1	2	3	4	5	6	7
8	3	3	4	4	5	6	7	8
9	3	5	6	7	9	-	-	-
10	1	2	3	3	4	5	6	7
11	3	3	3	4	5	5	6	7
12	1	3	3	5	7	9	-	-

TABLE: SUBJECTS RATING

LUMINAIRE TYPE: POST TOP SPEED: 30 mph

SUB	LUMINANCE cd/m^2							
NUM.	200	300	1000	2000	5000	10,000	20,000	50,000
1	2	2	3	4	5	6	7	8
2	1	1	3	3	5	7	9	-
3	1	1	2	3	4	5	7	9
4	2	2	2	3	4	4	4	5
5	1	2	3	3	4	4	5	6
6	1	1	3	5	7	8	9	-
7	1	1	2	2	3	4	5	6
8	3	3	4	4	6	7	7	8
9	3	3	4	5	6	8	9	-
10	1	1	2	3	4	5	6	7
11	2	2	3	5	5	7	9	-
12	1	1	5	6	7	7	9	-

TABLE: SUBJECTS RATING

LUMINAIRE TYPE: POST TOP SPEED: 60 mph

SUB NUM.	LUMINANCE cd/m^2							
	200	300	1000	2000	5000	10,000	20,000	50,000
1	3	4	5	6	7	8	8	9
2	1	3	3	5	5	7	9	-
3	2	3	3	4	5	5	6	8
4	3	3	3	5	6	6	7	7
5	1	1	3	3	4	5	6	7
6	2	2	4	5	8	9	-	-
7	1	1	2	3	4	5	6	7
8	1	2	3	4	5	7	8	8
9	3	3	4	5	7	8	9	-
10	1	2	3	4	5	6	7	8
11	2	2	3	5	5	7	9	-
12	1	3	4	5	7	9	-	-

TABLE SUBJECTS ADJUSTED LUMINANCE LEVEL FOR BCD

LUMINAIRE TYPE: COBRA HEAD

SUB	SPEED 30 mph				SPEED 60 mph			
NUM	VOLTS r_1	VOLTS r_2	AVG VOLTS $r_1+r_{2/2}$	LUMINANCE cd/m^2	VOLTS r_3	VOLTS r_4	AVG VOLTS $r_3+r_{4/2}$	LUMINANCE cd/m^2
1	27	23	25	250	24	25.5	24.75	225
2	37.5	42.5	40	3880	37	37	37	2360
3	45	48.5	46.75	8540	46	46	46	7920
4	44.5	47.5	46	7920	39.5	39	39.25	3545
5	63	62.5	62.75	21,395	56.5	61.5	59	24,905
6	39	38	38.5	3345	36.5	35.5	36	2090
7	415	40	40.75	4220	41.5	44.5	43	5420
8	43.5	41.5	42.5	5000	44	42.5	43.25	5625
9	32	29.5	30.75	860	24	26.5	25.25	275
10	39	35	37	2540	38	37.5	20.25	2760
11	53.5	56.5	55	17,650	51.5	54.5	53	15.295
12	35.5	39	37.25	2650	39	39	39	3435

TABLE SUBJECTS ADJUSTED LUMINANCE LEVEL FOR BCD

LUMINAIRE TYPE: HPSLC

SUB NUM	SPEED 30 mph				SPEED 60 mph			
	VOLTS r_1	VOLTS r_2	AVG VOLTS $r_1+r_{2}/2$	LUMINANCE cd/m^2	VOLTS r_3	VOLTS r_4	AVG VOLTS $r_3+r_{4}/2$	LUMINANCE ^{2}
1	28	25.5	26.75	425	23.5	25	24.25	200
2	38	33	35.5	1920	28	28	28	555
3	39	41	40	3880	52	46	49	13,825
4	52	52	52	14120	48	50	49	13,825
5	64	62	63	21.060	56	55	55.5	18,240
6	42	46.5	44.25	6460	30.5	28.5	29.5	725
7	45.5	47.5	46.5	8335	46.5	44	24.25	200
8	47	47	47	8750	42	43	42.5	5000
9	26	26	25.5	300	20.5	24	22.25	100
10	47.5	45.5	46.5	8335	40	38.5	39.25	3545
11	47.5	46	46	8540	54.5	52.5	53.5	9170
12	35	37	37	2090	39	41.5	40.25	5710

TABLE SUBJECTS ADJUSTED LUMINANCE LEVEL FOR BCD

LUMINAIRE TYPE: HPS CO

SUB NUM	SPEED 30 mph				SPEED 60 mph			
	VOLTS r_1	VOLTS r_2	AVG VOLTS $r_1+r_{2/2}$	LUMINANCE cd/m^2	VOLTS r_3	VOLTS r_4	AVG VOLTS $r_3+r_{4/2}$	LUMINANCE cd/m^2
1	25.5	27.5	26.5	400	25	255	25.25	275
2	32	31	31.5	944	26	26	26	350
3	53	45.5	50.25	12,050	43	43	43	5415
4	57.5	52	54.75	17,350	45	41	43	5415
5	54.5	49	51.75	13,825	55.5	52.5	54	16470
6	40.5	36	38.25	3095	33	32.5	32.75	1195
7	38	40.5	39.25	3545	37.5	44.5	41	4330
8	53	52	52.5	14,705	47	46	46.5	8330
9	28	28	28	555	24.5	25.5	25.5	250
10	43.5	43.5	43.5	3835	45	43.5	44.25	6460
11	52.5	53	52.75	15,000	53	50	51.5	13530
12	30	29	19.5	725	31.5	36	33.75	1460

TABLE SUBJECTS ADJUSTED LUMINANCE LEVEL FOR BCD

LUMINAIRE TYPE: POST TOP

SUB NUM	SPEED 30 mph				SPEED 60 mph			
	VOLTS r_1	VOLTS r_2	AVG VOLTS $r_1+r_{2/2}$	LUMINANCE cd/m^2	VOLTS r_3	VOLTS r_4	AVG VOLTS $r_3+r_{4/2}$	LUMINANCE cd/m^2
1	32.5	29.5	31	890	26	26	26	350
2	27	29.5	28.25	585	29	30.5	29.75	750
3	51	48.5	49.75	21,470	40.5	50	45.23	7292
4	64	53	58.5	11,765	42	46.5	44.25	6460
5	70	72	71	48.990	67	69	68	46,975
6	50	48	49	13,825	42	50	46	7920
7	51	45.5	27.75	530	42	50	46	7920
8	50.5	50.5	50.5	12,350	47	52.5	49.75	11,470
9	57	47	52	14,120	49	48	48.5	10,000
10	28	29	28.5	6110	26	24	25	250
11	55	53	54	16,470	54	51.5	52.75	15,000
12	38.5	39	38.75	3320	49	42	45.5	7500

TABLE: SUBJECTS OVERALL RATING

SUB NUM	LUMINAIRE TYPE			
	COBRA HEAD	POST TOP	HPS L C	HPS C O
1	8	2	6	4
2	6	8	4	2
3	8	4	2	6
4	6	6	6	6
5	7	7	7	7
6	7	9	6	8
7	8	6	5	4
8	5	7	7	8
9	7	9	7	7
10	5	8	6	8
11	5	6	4	5
12	9	10	10	10

OPERATING PROCEDURE

1. After the observer has seated himself in the car as explained in the instruction sheet (Figure 27) cover the window of the car with the black cloth.
2. Slide the appropriate marked sectors in the two slots with the black painted side facing the observer.
3. Cover the entire simulator. Make sure that the observer does not see any outside light.
4. Turn the dash lights on.
5. Adjust the background luminance depending upon the type of luminaire.
6. Make sure that the drive gear of the motor is disengaged.
7. Keep the heat resistant shield in open position (Figure 28).
8. Keep the luminaire in open position as shown in Figure 23.
9. Now hold the rear disk marked "R" for the particular type of luminaire and locate it on the two pins projecting on the hub (Figure 28). Having located, now rotate the disk so that the yellow mark on the disk is in line with the yellow mark on the top of the plywood.
10. Now take the front disk marked "F" for the particular type of luminaire and mount it on the shaft. Rotate the disk so that the yellow mark on the front disk is in line with the yellow mark of the rear disk and the plywood.
11. Slide the hub and make sure that the two pins on the hub are located in the two holes of the front disk.
12. Make sure that the chain is light.
13. Now engage the motor gear.
14. Make sure that the heat resistant shield is in closed position covering the upper part of the disk facing the luminaire as shown in Figure 24.

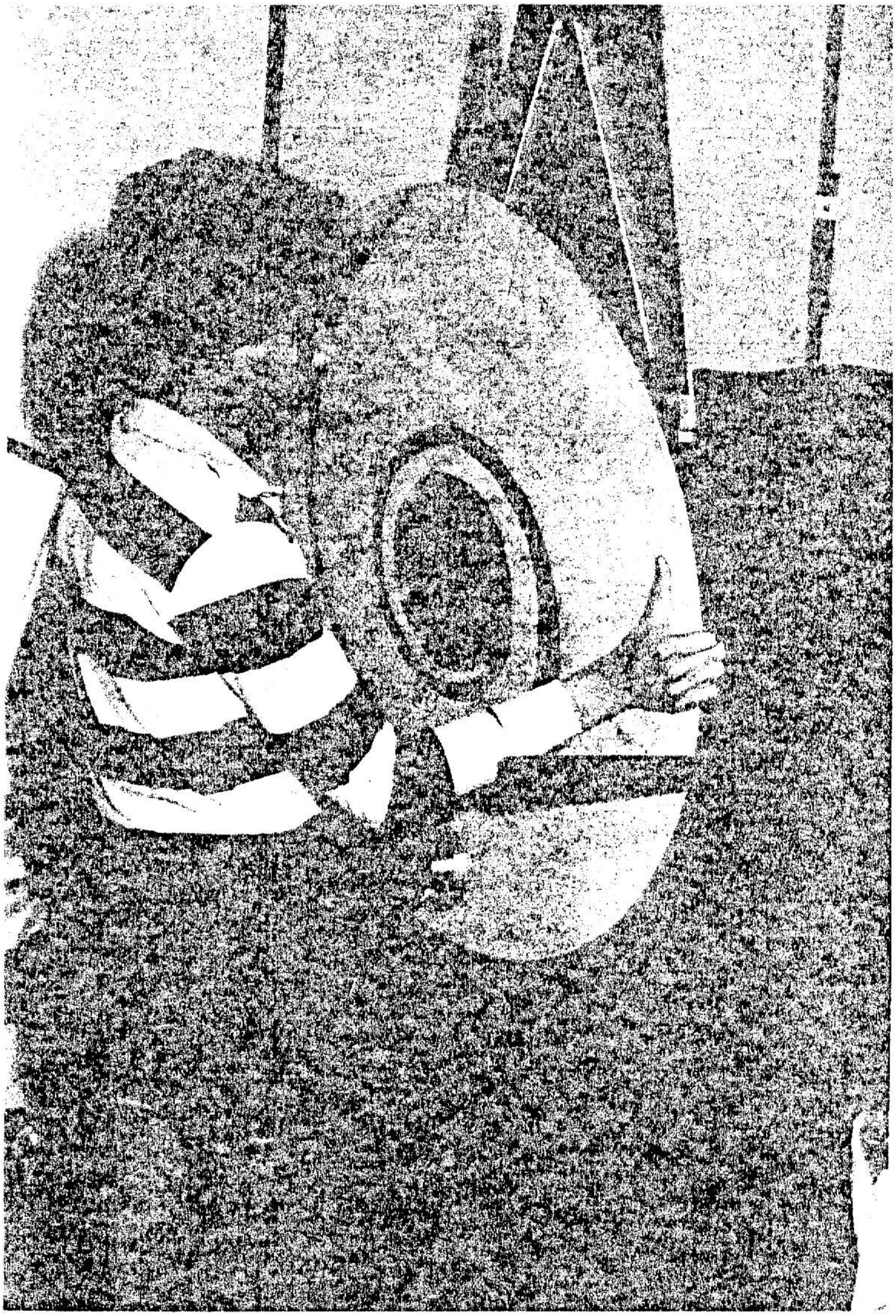

FIGURE 28: DISK MOUNTING PROCEDURE

15. Locate the lighting fixture in position (Figure 19).
16. Make sure that the cooling system is turned on.
17. Adjust the transformer to control the speed of the disk.
18. Luminance adjustment.
    a. External Adjustment: Make sure that the switch for external adjustment is turned on. Turn the transformer and voltmeter switch on. Now you can adjust the luminance levels as per the scale posted on the transformer.
    b. Adjustment by Subjects: Make sure that the switch for adjustment by the subject is turned on. Ask the subject to turn the transformer switch on. Now, with the help of the handle provided on the transformer the subject can adjust the luminance level as explained in the instruction sheet (Figure 27).
19. Once the experiment is completed make sure that all the switches except the one for the cooling system is turned off.
20. Wait for 2 to 3 minutes and turn off the cooling system.
21. Once again check and make sure that all the switches are turned off.
22. Make sure that the disks are placed back in the rack as shown in Figure 29.
23. Repeat the above procedures when you start the experiment.

PRECAUTIONS TO BE TAKEN

1. Make sure that the cooling system is turned on and the disks are rotating before turning the light source on.
2. If by any chance the disks stop rotating or the cooling system fails immediately turn off the light source.
3. Do not turn the transformer knob controlling the speed of the disk above 20 volts.

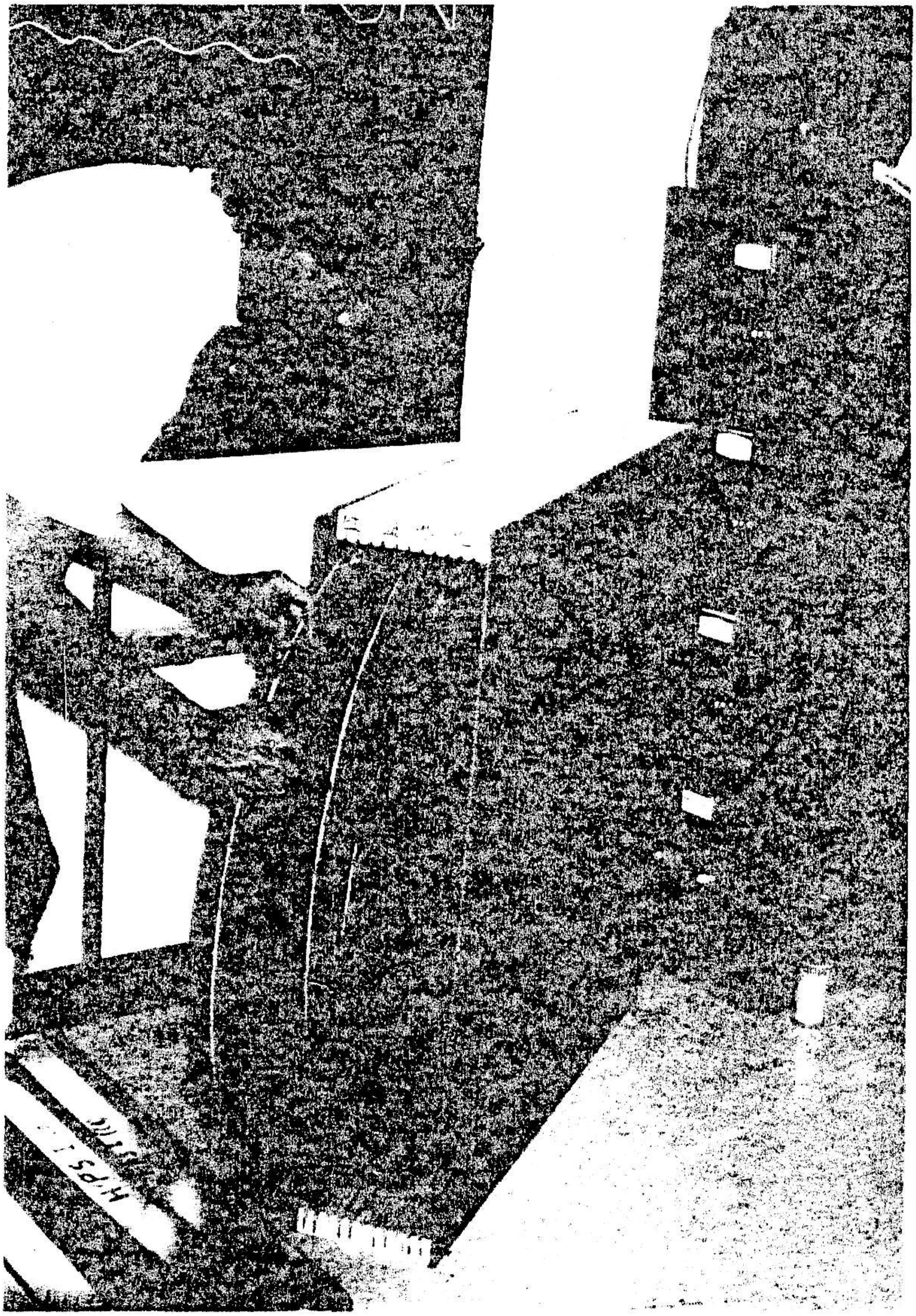

FIGURE 29: PROTECTIVE RACK FOR THE DISKS

MAINTENANCE

1. Grease the hubs with the help of the grease gun once in three weeks if in use.
2. Oil the mounting system and drive system once in three weeks if in use.
3. Make sure that the photonegatives and the felt pieces are firmly glued to the disks. If they loosen use contact cement to glue them to the disk.

DISCOMFORT GLARE: AN IMPROVED DYNAMIC ROADWAY LIGHTING SIMULATION

by

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B.E. (PRODUCTION), V.J.T.I., BOMBAY, INDIA, 1979

AN ABSTRACT OF A MASTER'S REPORT

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ABSTRACT

A simulator was fabricated and it gave the same sensation to the observer as experienced in night time driving. The salient features of the simulator include the observer position, the disk system, the luminaire system, the drive and the mounting system, cooling system and the control panel.

Having fabricated the simulator a pilot study was conducted to find the speed effect, the luminaire effect and to validate the predictive systems namely glaremark and CBE (Cumulative Brightness Evaluation) on comparison to the subjects appraisal. Twelve subjects were employed in the experiment who performed the visual task of night driving. Four types of luminaire Post-Top, HPS (High Pressure Sodium) cut-off, HPS Long cut-off and Cobrahead, two speeds 30 mph and 60 mph and eight luminaire levels, 200, 300, 1000, 2000, 5000, 10,000, 20,000, 50,000 cd/m^2 were used in this experiment. The glaremark and the CBE values were calculated for each luminaire and compared to the subjects rating.

Results showed a significant speed effect. The high BCD (Border line between comfort and discomfort) value for the slower speed of 30 mph showed that a higher luminance level was required for the slower speed to produce the same degree of discomfort as produced at a faster speed of 60 mph. The luminaire effect was found significant. The Post Top luminaire was found to be the most comfortable which was contradictory to the expectations. The poor ranking between the subjects rating and either Glaremark and/or CBE showed that the systems do not agree with each other as regards the prediction of discomfort glare in roadway lighting.