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Further Development of a Computer Simulation to Predict the Visibility Distance Provided by Headlamp Beams

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16. Abstract

This report describes some extensions to a computer simulation program for the evaluation of headlamp beams in terms of visibility and glare of drivers. In particular the effects of glare of headlamps reflected in rearview mirrors, horizontal and vertical road curvature, and a glare discomfort index are incorporated.

Those capabilities are illustrated. A listing of the program and a manual describing its use are included as appendices.

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FOREWORD AND ACKNOWLEDGEMENTS

This report describes some additional work in the modeling of vehicle meetings at night, to assist in the evaluation and to describe the effects of headlamp beams. It is issued under the general contract title: "Passenger Car and Truck Lighting Research: Headlighting Phase III, Evaluation of Candidate Systems."

During the conduct of this work meetings were held with the MVMA Lighting Committee, Headlighting Research Task Force, consisting of Mr. W. Rankin, Chairman; Mr. R.J. Donohue, Mr. P. Lawrenz, Mr. P. Maurer, and Mr. B. Preston. Periodic discussions with the Task Force were helpful and contributed to this study.

INTRODUCTION

The Headlamp Visibility Distance Performance Simulation, incorporating a straight road, two vehicles, a target and an observer, was described earlier by Mortimer and Becker (1973a).* This report will describe some recent additions to the program which make it more versatile and more flexible. Flexibility is needed in dealing with targets that become lost to sight as glare increases. Increased versatility includes a better representation of the shape of the beam patterns near their hot spots, the effects of glare from the headlamps of a following vehicle as reflected in the mirrors of the main vehicle, the effects of horizontal and vertical road curvature, and an estimate of the discomfort glare, as opposed to the disability glare, produced throughout the meeting. Each of these added features will be described in detail and their effects illustrated by sample runs of the program.

A listing of the program in its present state is provided in Appendix 1 and a detailed user's manual in Appendix 2. The program in its present form is operational on the HSRI digital computer which is a DEC 11/45. It is written in Fortran VI. The program is available for use by any interested party on application to HSRI and MVMA.

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*References are listed on page 24.

DESCRIPTION OF ADDITIONS TO PROGRAM

ABILITY TO DEAL WITH TARGETS WHICH BECOME LOST TO SIGHT IN HIGH GLARE

On a few occasions, generally with targets to the left of the driver's lane when the driver is looking toward the oncoming glare car, the situation has arisen in which there are two regions of visibility for the target in the no or low glare case. Here the plot of target visibility versus target distance (normally like that shown in Fig. 8 on p. 22 of Mortimer and Becker, 1973a), has two humps; as in Fig. 1. If the initial estimate of the target distance (as supplied by the program) is larger than that labeled "critical target distance," then the upper region will be the one used by the program. If the initial estimate is smaller, then the program will converge to the lower region. As glare increases, this curve will, in general, move down and to the left. It has happened that the upper visibility region has disappeared as glare increased. Now, if this happens, the program will restart itself and look for the lower visibility region, if any.

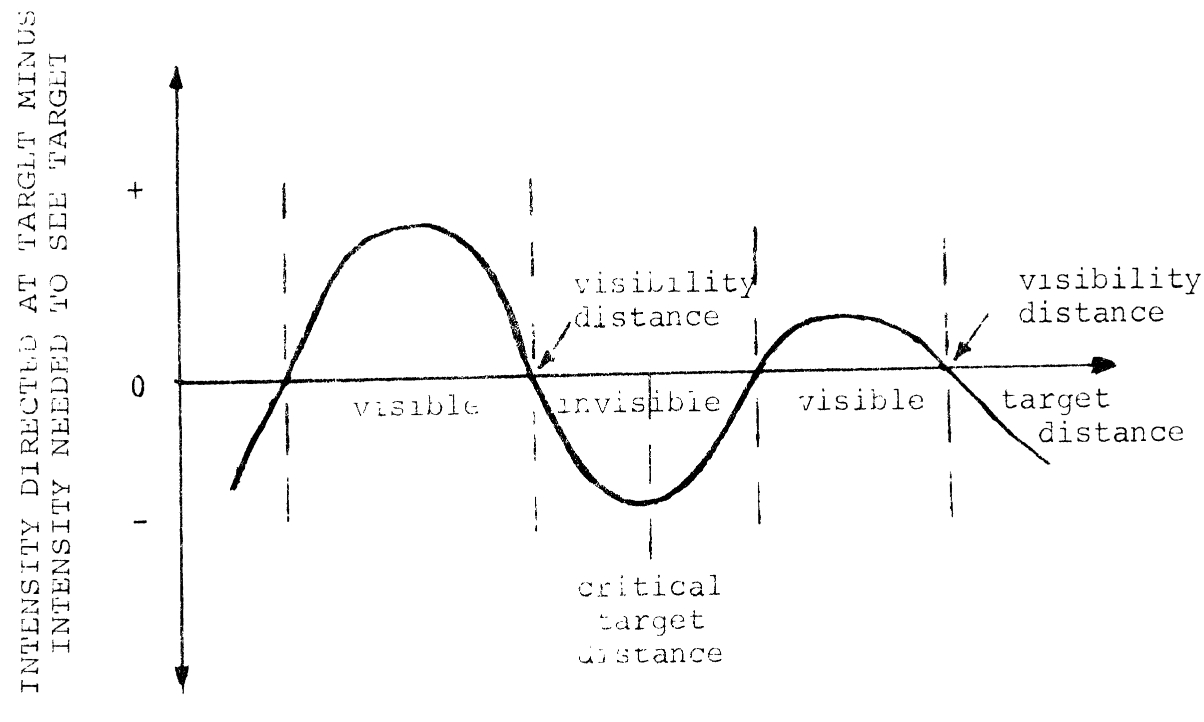

Figure 1. Illustrative plot of target visibility as a function of target distance for the special case of two regions of visibility.

SECOND-ORDER INTERPOLATION IN THE VICINITY OF THE BEAM "HOT-SPOT"

In general a double first order interpolation on the log of the intensity has been used in the beam patterns. The program now has the additional ability to use a second-order interpolation near maxima in the beam pattern; i.e., near the hotspot and the ridges leading away from it. Near the hotspot the second-order interpolation is used in both directions; around the ridges only in the direction that needs it. This produces a flat area near the hotspot/ridges while the linear interpolation in these regions produced a cusp, which was not a good description of the actual behavior there. Near the hotspot the equation is:

$$\begin{aligned}\log I = {} & \tfrac{1}{4}(1-h)(2-h)(1-v)(2-v)AL(I,J) + \tfrac{1}{2}(1-h)(2-h)v(2-v)AL(I,L) \\ & - \tfrac{1}{4}(1-h)(2-h)v(1-v)AL(I,N) + \tfrac{1}{2}h(2-h)(1-v)(2-v)AL(K,J) \\ & + h(2-h)v(2-v)AL(K,L) - \tfrac{1}{2}h(2-h)v(1-v)AL(K,N) \\ & - \tfrac{1}{4}h(1-h)(1-v)(2-v)AL(M,J) - \tfrac{1}{2}h(1-h)v(2-v)AL(M,L) \\ & + \tfrac{1}{4}h(1-h)v(1-v)AL(M,N)\end{aligned}$$

$$\text{where } h = \frac{H-H(I)}{H(K)-H(I)}, \quad v = \frac{V-V(J)}{V(L)-V(J)}$$

and AL(K,J) is the hotspot of the beam pattern.

MIRROR GLARE FROM FOLLOWING TRAFFIC

In addition to glare from the headlamps of opposing traffic and from his own headlamps as reflected back off the pavement ahead, a driver is often exposed to glare from the headlamps of following vehicles via the mirrors in his own car. Figure 2 shows the geometry for this situation. The following car may also have up to five headlamps, misaimed in any direction. The main vehicle may have two mirrors - one interior, one exterior. They may be rectangular or circular. They may be aimed in one of two ways;

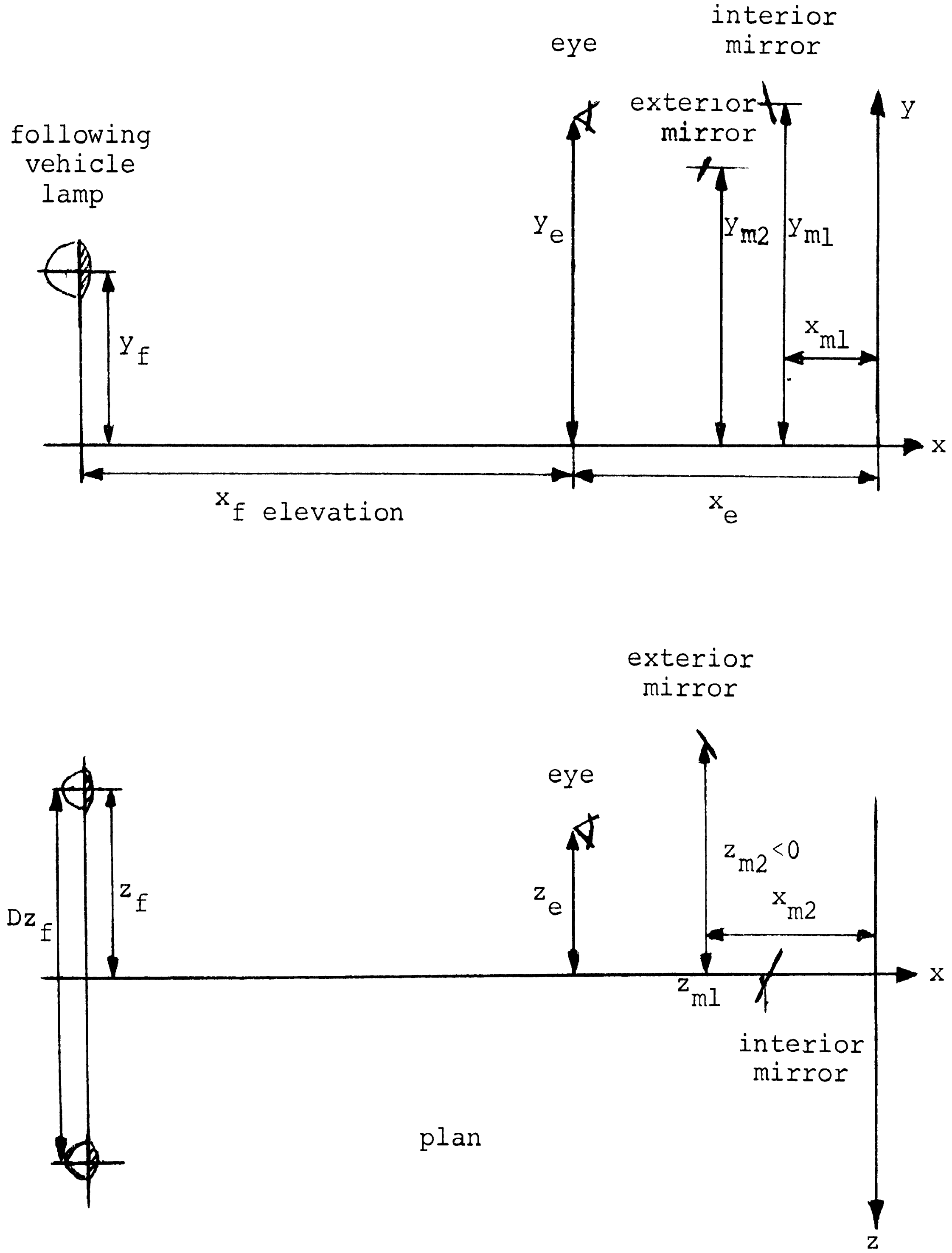

Figure 2. Geometry - mirrors and following vehicle.

either by specifying the point at which the center reference point of the mirror is aimed, in which case the dimensions of the mirror are supplied by the user, or by specifying the desired field-of-view of the mirror at some distance behind the car, in which case the dimensions of the mirror are determined by the program. Figure 3 shows the geometry, where the plane of the paper is the plane containing the eye, the mirror reference point and its aim point.

Mirror aim in yaw (rotation about its own vertical axis) and pitch (rotation about its own horizontal axis) is found from the desired aim point of the mirror center reference point. Mirror roll (rotation about an axis perpendicular to the mirror face) is defined so that a line through the aim point parallel to the z-axis will be imaged as a line through the center reference point parallel to the mirror horizontal axis for rectangular mirrors. For circular mirrors, roll is ignored. Thus:

$$\tan \alpha = \frac{-\left[\frac{r}{f}(z_m - z_q) + z_m\right]}{\left[\frac{r}{f}(x_m - x_q) + x_m\right]}$$

$$\tan \beta = \frac{\left[\frac{r}{f}(y_m - y_q) + y_m\right]}{\sqrt{\left[\frac{r}{f}(x_m - x_q) + x_m\right]^2 + \left[\frac{r}{f}(z_m - z_q) + z_m\right]^2}}$$

where α is yaw, β is pitch, (x_m, y_m, z_m) are the coordinates of the mirror reference point relative to the eye, (x_q, y_q, z_q) are the coordinates of the aim point relative to the eye, and

$$r^2 = x_m^2 + y_m^2 + z_m^2$$

$$f^2 = (x_m - x_q)^2 + (y_m - y_q)^2 + (z_m - z_q)^2$$

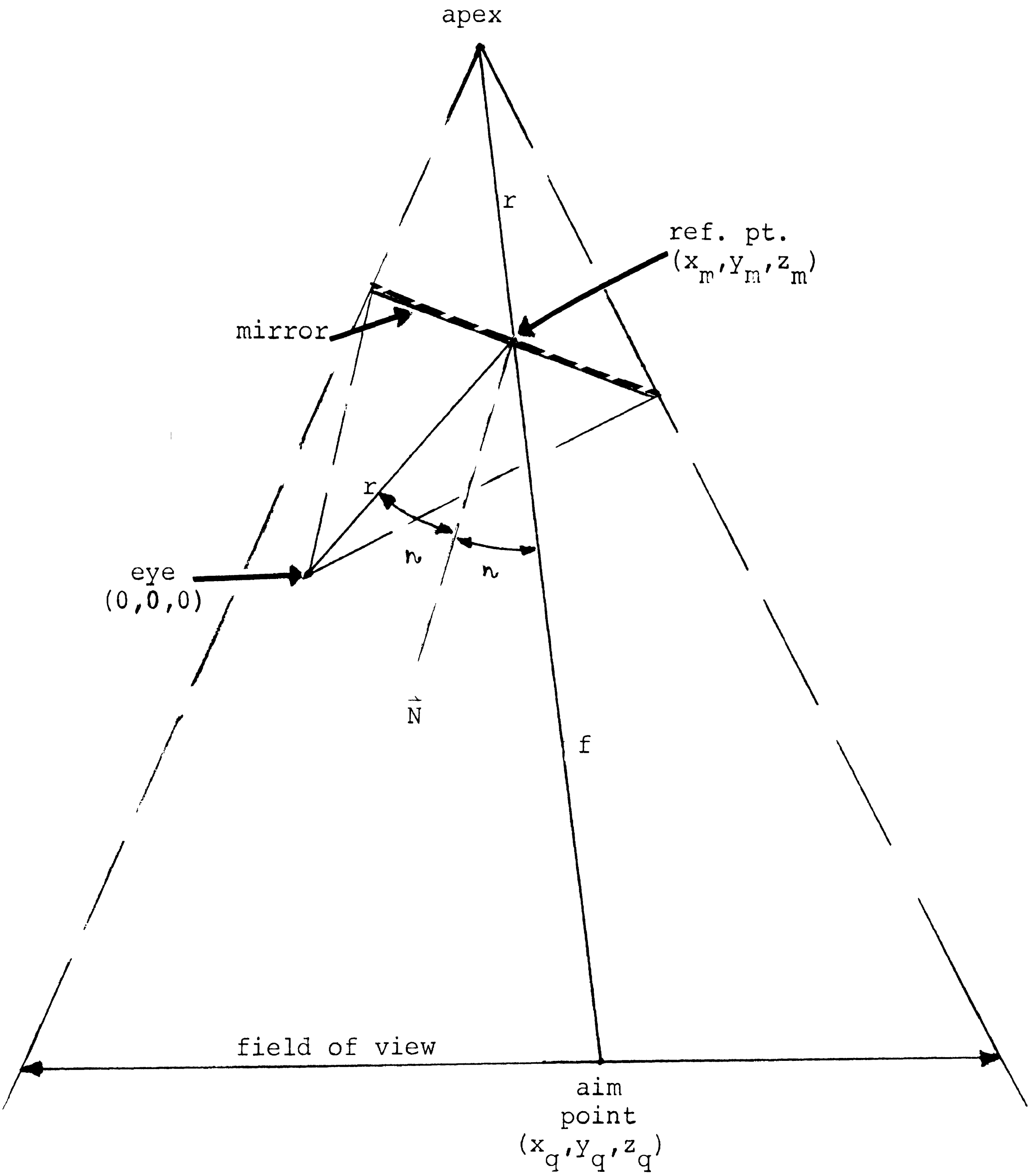

Figure 3. Geometry of mirror aim.

Thus roll (γ) is found from: $\tan\gamma = -\tan\alpha\sin\beta$

If the desired field of view of the mirror has been specified, then the mirror aim is found by an iterative procedure, with the initial guess at the aim point taken as the center of the field of view. For circular mirrors the horizontal field of view will determine the mirror diameter and it will be centered on the vertical field of view. The resulting rotation matrix is:

$$Q = \begin{bmatrix} \cos\alpha\cos\beta & \sin\alpha\sin\gamma-\cos\alpha\sin\beta\cos\gamma & \sin\alpha\cos\gamma+\cos\alpha\sin\beta\sin\gamma \\ \sin\beta & \cos\beta\cos\gamma & -\cos\beta\sin\gamma \\ -\sin\alpha\cos\beta & \cos\alpha\sin\gamma+\sin\alpha\sin\beta\cos\gamma & \cos\alpha\cos\gamma-\sin\alpha\sin\beta\sin\gamma \end{bmatrix}$$

Mirror reflectivity may be specified, as well as the transmissivity of the window associated with each mirror; rear for interior and side for exterior. If polarized beams are to be used on the following vehicle, then these windows could have analyzers associated with them. However, it does not seem likely that rear and side windows would have analyzers, so they have been omitted.

The following car remains at some specified following distance throughout the meeting with an opposing car so that the illumination at the driver's eye from the headlamps of the following car remains constant.

The coordinates of the lamp image point (on the mirror) relative to tne eye are needed for calculating the glare angle. They are:

$$x_i = \left(\frac{e}{d+e}\right)(2Ad + x_\ell)$$

$$y_i = \left(\frac{e}{d+e}\right)(2Bd + y_\ell)$$

$$z_i = \left(\frac{e}{d+e}\right)(2Cd + z_\ell)$$

The coordinates relative to the lamp are needed for the angles in the beam patterns. They are:

$$X_i = \left(\frac{d}{d+e}\right)(2Ae - x_\ell)$$

$$Y_i = \left(\frac{d}{d+e}\right)(2Be - y_\ell)$$

$$Z_i = \left(\frac{d}{d+e}\right)(2Ce - z_\ell)$$

Where $e = Ax_m + By_m + Cz_m$

$d = e - (Ax_\ell + By_\ell + Cz_\ell)$

and A, B, and C are the first column of the mirror aim rotation matrix, Q.

Lamp images may be visible or they may be invisible. The image may fall on the mirror plane outside the given dimensions or the ray from the lamp to the image may be blocked by the structure of the main vehicle. This structure is assumed to be a rectangular plane perpendicular to the longitudinal axis of the vehicle and located in the region of the trunk. Its dimensions and location are specified in the input. In either case the invisible image will not contribute to the illumination at the eye. The value of the illumination at the eye for each visible image and its coordinates relative to the eye are computed for each lamp and each mirror in the input and stored for later use. Then during the meeting the additional veiling glare is calculated by dividing the stored illumination value by the appropriate function of the glare angle (computed from the stored image coordinates and the known eye line-of-sight) and summing over all visible images.

$$\Delta VG = \sum_{\ell=1}^{5} \sum_{m=1}^{2} \frac{I_{\ell m}}{\Theta_{\ell m}(\Theta_{\ell m} + 1.5°)}$$

Since the glare angle between each mirrored image and the eye line-of-sight when tracking the target varies with target distance, the added mirror veiling glare will also. The action of glare from mirrors can be to reduce visibility distance and increase discomfort.

ROAD CURVATURE

It is also of interest to see the effect of road curvature on visibility distance. The program now includes both horizontal and vertical curvature, though only one type can be run at a time.

Each type can be either convex or concave, with a constant radius of curvature. A convex horizontal curve is one on which the glare car moves in a larger circle than the main car; on a concave horizontal curve, therefore, the glare car moves in a smaller circle than the main car (Fig. 4). The convex horizontal curve could also be described as an inside curve, since the main car is thus inside the glare car, or as a right hand curve, since the road curves off ahead to the right. The concave horizontal curve, therefore, is an outside or left hand curve. On a convex vertical curve, the two vehicles move up towards one another and down (relatively speaking) after they pass one another, and vice versa on a concave vertical curve (Fig. 5). The convex vertical curve could be described as the crest of a hill, and the concave vertical curve as a valley.

The radius of a curvature is the distance from the center of curvature to the centerline of the main vehicle, on the road surface. The independent variable, previously the longitudinal separation distance from the driver's eye to the glare vehicle's reference lamp, is now measured along the arc. It could be thought of as that distance measured on the main vehicle's odometer (in the proper units) to bring the glare vehicle reference lamp to the same radial line that the eye is on. The visibility distance to the target is measured in a similar way, as the distance along the arc of the road between the eyes of the driver and the position of the target.

Figure 6 shows an example of the geometry for a convex horizontal curve. The glare angle calculation uses a coordinate system with its origin at the eye. The y-axis is vertical (as before), the z-axis points toward the center of curvature and the x-axis is tangent to the curvature and straight ahead. Then the equations for the coordinates of the glare reference lamp relative to the eye are:

$$x = (\rho+z_{cl}-z_g)\sin\gamma_s$$

$$y = y_g - y_e$$

$$z = z_e + \rho(1-\cos\gamma_s) - (z_{cl}-z_g)\cos\gamma_s$$

where $\gamma_s = \frac{DS}{\rho}$

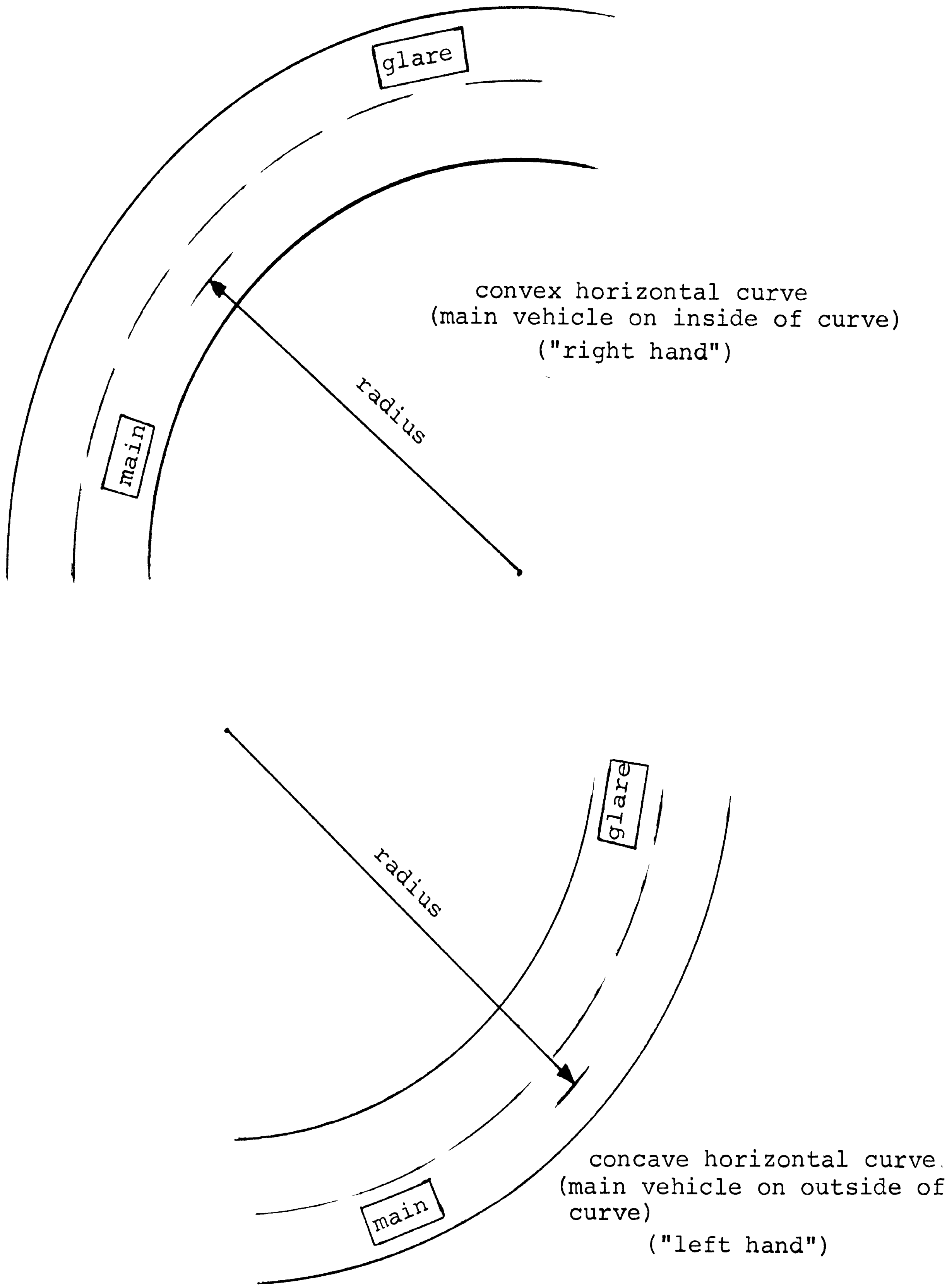

Figure 4. Geometry - horizontal road curvature.

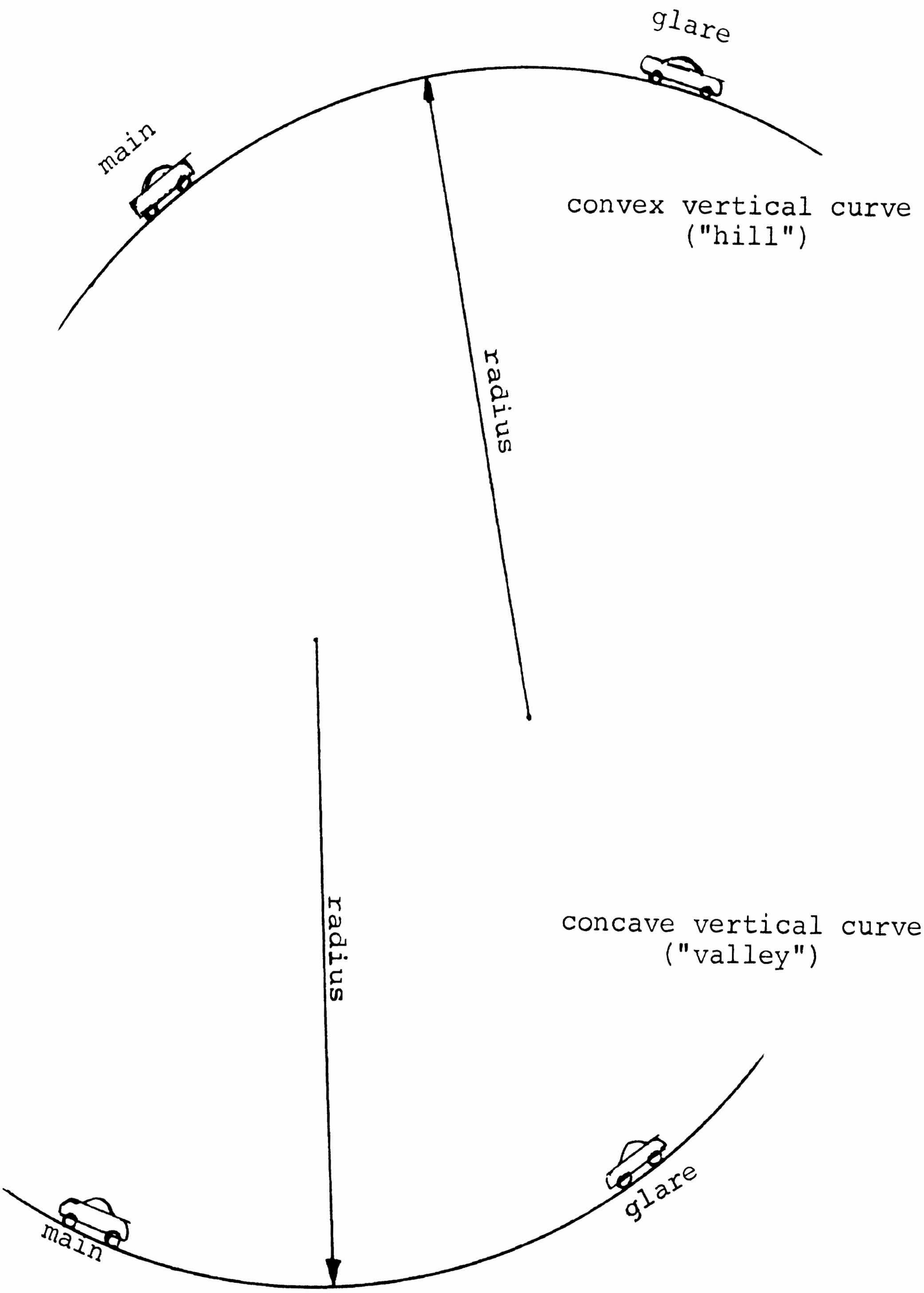

Figure 5. Geometry - vertical road curvature.

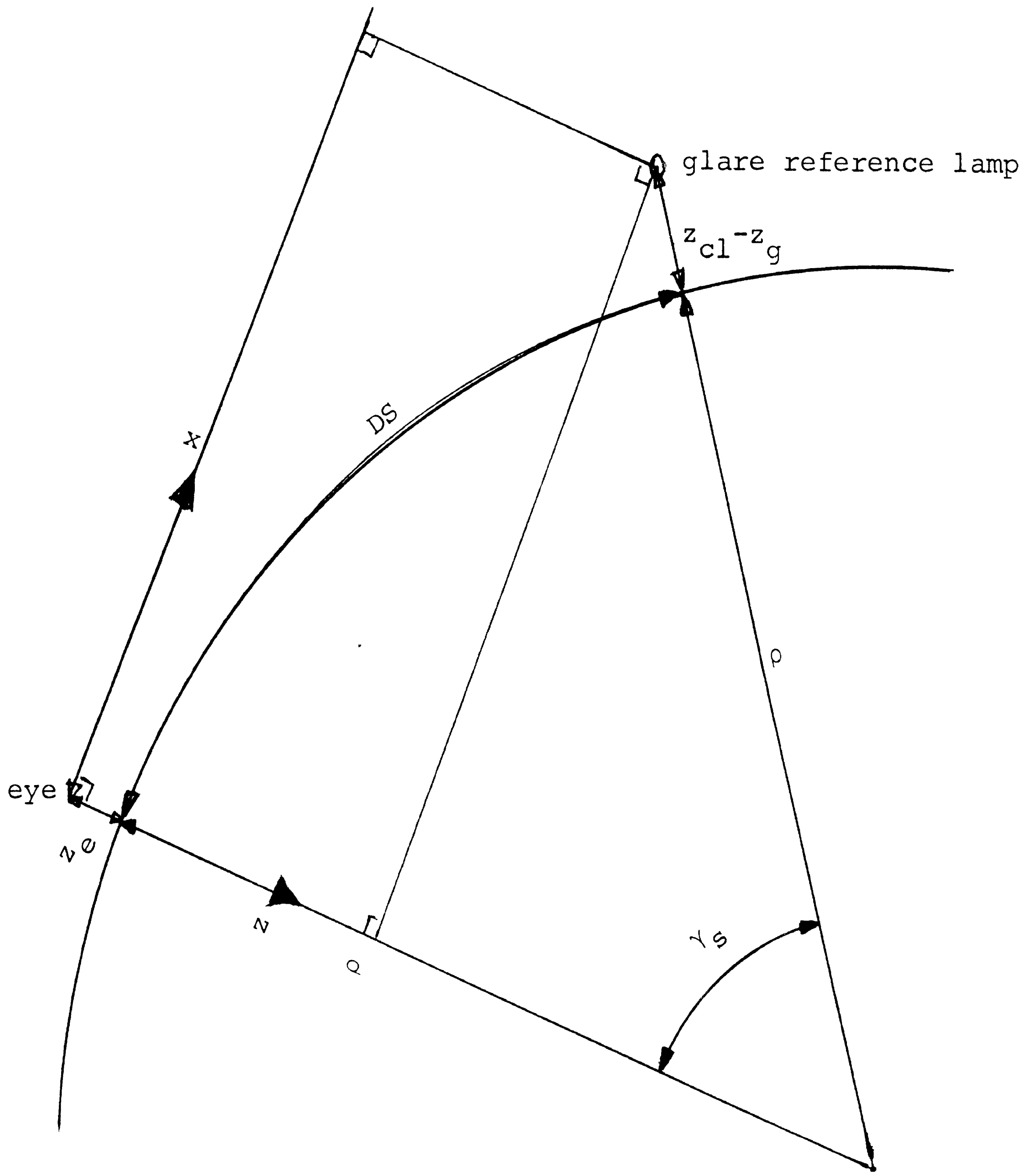

Figure 6. Geometry for calculation of glare lamp coordinates relative to eye.

and z_{cl} is distance between vehicle centerlines, z_g is distance from glare vehicle centerline to reference lamp, z_e is distance from main vehicle centerline to eye, y_g is distance from road to glare reference lamp, and y_e is distance from road to eye.

For a concave horizontal curve, the y-axis is still vertical, the x-axis is still tangent and straight ahead, thus making the z-axis point away from the center of curvature. For the vertical curves, the x-axis remains tangent and straight ahead relative to the vehicle, the z-axis remains horizontal and to the right relative to the vehicle, and the y-axis now points upward toward or away from the center of curvature, depending on whether the curve is concave or convex, respectively.

The coordinates of the eye line-of-sight for target tracking are computed relative to the eye (as above) with the target replacing the glare reference lamp. The beam pattern angles of the target and road are relative to the requisite lamp on the main vehicle; those of the eye are relative to the lamps on the glare vehicle; those of the mirror images are relative to the lamps on the following vehicle.

If the curved road is considered as a complete circle, then the two vehicles may be separated at most by one-half of the circumference (i.e. 180°), while the target may be at most one-quarter of the circumference (i.e. 90°), away from the main vehicle. These limits will be enforced by the program if necessary; e.g., if the initial separation distance is too large, it will be reset to make the angle slightly less than 180°. One-half the circumference is also the maximum separation between the main vehicle and a following vehicle. On curved roads the main vehicle's mirrors are still aimed as though the road were straight and flat.

For the convex vertical curve (which could also be thought of as the crest of a hill), there is a separation distance beyond which the glare vehicle's lamps are invisible; i.e., the light is blocked by the road itself. There will also be a visibility distance beyond which the target is similarly invisible.

Figure 7 shows the geometry for this case for the calculation of these distances.

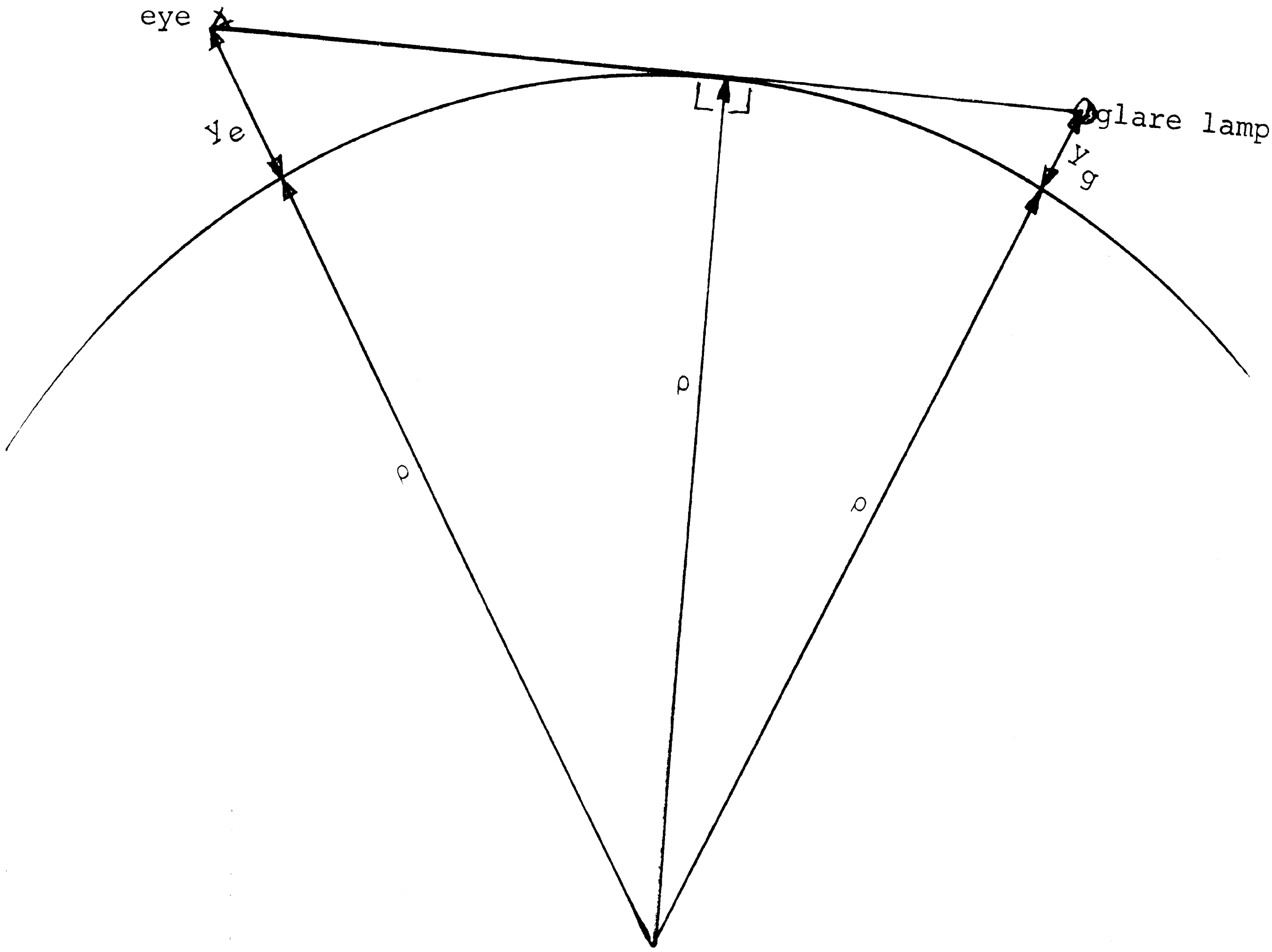

Figure 7. Geometry for grazing distances on convex vertical curve.

$$DSGRZ = \rho\left(\arctan\left[\frac{(2\rho+y_e)y_e}{\rho}\right] + \arctan\left[\frac{(2\rho+y_g)y_g}{\rho}\right]\right)$$

$$XVGRZ = \rho\left(\arctan\left[\frac{(2\rho+y_e)y_e}{\rho}\right] + \arctan\left[\frac{(2\rho+y_t)y_t}{\rho}\right]\right)$$

$$XGRZ = \rho\arctan\left(\frac{(2\rho+y_e)y_e}{\rho}\right)$$

Here DSGRZ is the separation distance beyond which the glare lamps are invisible, XVGRZ is the visibility distance beyond which no light reaches the target, and XGRZ is the distance beyond which no light reaches the road (for foreground glare). The distance from the road surface to the eye is y_e, to the glare lamp is y_g, to the main lamp is y_ℓ, and to the target is y_t.

DISCOMFORT GLARE INDEX

While the visibility distance of a typical target and the associated disability glare are certainly important factors in evaluating a headlamp beam pattern, they are by no means the only criteria to be taken into account. Another important factor is the discomfort glare to which the driver is subjected. J.B. de Boer (1973) has devised a formula for deriving what he calls the Glare Mark (which we will call the discomfort glare index), which is a measure of the discomfort glare produced during a meeting situation. The program now calculates and prints the discomfort glare index according to de Boer's formula, into which we have incorporated the effect of a following vehicle via the main vehicle's mirrors.

Definition of Glare Mark (index) values:

1: Unbearable

3: Disturbing

5: Just Acceptable

7: Satisfactory

9: Unnoticeable

The discomfort glare index as computed by the program may be larger than 9, which merely signifies that the discomfort glare is even less noticeable. After the vehicles pass, the discomfort glare index is not calculated, since there are no glare lamps visible. The negative number printed is merely the additive constant in the formula.

The formula is:

$$DGI = 2 \log(1+C_1 ELU) - 2 \log(DGID+DGIM) - C_2$$

where $$ELU = \frac{R\ TI}{\pi\ D_V^2}$$

$$DGID = \sum_{i=6}^{10} \frac{GL_i}{DL_i^2 (\theta_i)^{.46}}$$

$$DGIM = \sum_{i=11}^{15} \sum_{j=1}^{2} \frac{GM_{ij}}{(\theta_{ij})^{.46}}$$

and R is road reflectivity, C_1 = 269.0966, C_2 = 2.1097, TI is the total intensity directed at the target, D_V is the distance from the eye to the target, GL_i is the intensity directed at the eye of the i-th glare lamp, DL_i is the distance from the eye to the i-th glare lamp, θ_i is the glare angle between the i-th glare lamp and the eye line-of-sight, (measured in minutes of arc), GM_{ij} is the illumination at the eye due to the i-th lamp reflected in the j-th mirror and θ_{ij} is the glare angle between this image and the eye line of sight (measured in minutes of arc). Note that the glare vehicle's lamps are indexed 6-10 and the following vehicle's lamps 11-15.

APPLICATION OF THE PROGRAM

Figure 8 shows a computer printout illustrating the ability of the program to deal with targets which become lost to sight in high glare. On the first page is the printout of the input data, the second page is the output for the upper region of visibility (as far as it exists) and the third page is the output for the lower region of visibility. The various printouts are described in detail in the user's manual. The situation is that of a convex horizontal curve with a radius of 5000 feet. The vehicles are equipped with the European low beam and a type-3 mid beam. They are approaching each other with velocities of 30 mph on a two-lane road. The target is of 12% reflectivity located 6 inches above the left edge of the main vehicle's lane (i.e., midway between the vehicles). Note that the output includes the discomfort glare index. Of all the combinations of data run to date, this is the only one to give these results.

Table 1 shows the effects of glare from a following vehicle as reflected in the main vehicle's mirrors on the maximum visibility distance (i.e., that for no opposing glare vehicle), on the minimum visibility distance (which occurs here at about 150 feet separation distance), on the corresponding maximum veiling glare, and on the discomfort glare index. The situation is a straight, two-lane road with the following vehicle at 100 feet behind the main vehicle and all traveling at 30 mph. The main and glare vehicles are equipped with typical U.S. 4000 low beams, while the following vehicle may have one of five different sets of lamps: U.S. 4000 low, European low, U.S. 4000 low plus a type-3 lamp to form a mid beam (U.S. MID-A), U.S. 4000 low plus a second type-3 (U.S. MID-B), or European low plus the first type-3 (ECE MID-A). There are many possible varieties of type-3 lamps available; these two are the same except for aim. The main vehicle mirrors have reflectivities of 85% for interior and 55% for exterior, and both the associated window transmissivities are 88%. The target is of 12% reflectivity located six inches above the right edge of the lane used by the main vehicle.

```
                              INPUT DATA

          FIELD TEST BEAM EVALUATION  ECE MID   RUN NO. 56

ROAD IS A CONVEX HORIZONTAL CURVE WITH RADIUS OF    5000.0 FEET

CENTERLINE DISTANCE  12.0 FEET, VEHICLE VELOCITIES  MAIN =  30.0 MPH, OPPOSING =  30.0 MPH
EYE IS 106.0 IN. BEHIND LAMPS,  46.0 IN. ABOVE ROAD AND  15.0 IN. LEFT OF CENTERLINE
TARGET IS   6.0 IN. ABOVE ROAD AND -72.0 IN. FROM CENTERLINE

  OBSERVER RELATION FOR TARGET INTENSITY = EXP(A+B*D), WHERE D IS VISIBILITY DISTANCE
COEFFICIENTS FOR  A = C+D(4TH ROOT OF GI),  B = E+F(SQRT OF GI)
      C              D              E              F
  0.3400E 01    0.3600E 00    0.1600E-01    0.8000E-04

TARGET REFLECTIVITY IS       12.0 PER CENT

BASIC TARGET REFLECTIVITY FOR OBSERVER RELATION IS  10.0 PER CENT, NOMINAL EYE RECOVERY RATE PARAMETER IS 0.002858 PER SECOND

ILLUMINATED AREA OF PAVEMENT EXTENDS 200.0 FEET AHEAD OF LAMPS AND  -8.0 AND   8.0 FEET FROM CENTERLINE
ROAD REFLECTIVITY IS  10.0 PER CENT.

SEPARATION DISTANCES   INITIAL   4000.0 FEET, FINAL  -1000.0 FEET

DISTANCE BETWEEN HEADLIGHT NO. 1   MISAIM ANGLES (DEGREES)  BEAM PATTERN
AND    (IN.)  X       Y      Z     INDEX VERT.  HOR.  ROT.  INDEX   NAME
   ORIGIN    0.0    24.0   27.0      1    0.0   0.0   0.0    7    EUROPEAN LOW
   NO. 2     0.0     0.0   54.0      2    0.0   0.0   0.0    7    EUROPEAN LOW
   NO. 3     0.0     0.0    9.0      3    0.0   0.0   0.0    5    TYPE-3 BEAM

DISTANCE BETWEEN HEADLIGHT NO. 6   MISAIM ANGLES (DEGREES)  BEAM PATTERN
AND    (IN.)  X       Y      Z     INDEX VERT.  HOR.  ROT.  INDEX   NAME
   ORIGIN    0.0    24.0   27.0      6    0.0   0.0   0.0    7    EUROPEAN LOW
   NO. 7     0.0     0.0   54.0      7    0.0   0.0   0.0    7    EUROPEAN LOW
   NO. 8     0.0     0.0    9.0      8    0.0   0.0   0.0    5    TYPE-3 BEAM

COEFFICIENTS FOR GOL = GA + (AX-C)*EXP(-X/B)
   0.3237E 01    0.0000E 00   -0.3389E 01    0.1548E 03

 TARGET INVISIBLE AT DS =   450. FEET, CLOSEST TO VISIBILITY AT X =  212.5 FEET
```

Note: DS is the separation distance between vehicles and X is the target distance.

Figure 8. Computer printout illustrating ability of program to deal with targets which become lost to sight in high glare.

OUTPUT DATA

FIELD TEST BEAM EVALUATION ECE MID RUN NO. 56

SEPARATION DISTANCE (FEET)	VISIBILITY DISTANCE (FEET)	VEILING GLARE (FT.CAND.)	GLARE INTENSITY (CANDELAS)	DISCOMFORT GLARE INDEX	SEPARATION DISTANCE (FEET)	VISIBILITY DISTANCE (FEET)	VEILING GLARE (FT.CAND.)	GLARE INTENSITY (CANDELAS)	DISCOMFORT GLARE INDEX
4000.	313.9	0.01122	309.4	11.4	1400.	313.6	0.01128	654.3	8.5
3800.	313.9	0.01122	324.8	11.3	1200.	313.3	0.01135	672.4	8.2
3600.	313.9	0.01122	340.1	11.1	1000.	312.6	0.01152	690.5	7.7
3400.	313.9	0.01122	355.5	11.0	950.	312.2	0.01160	690.4	7.6
3200.	313.9	0.01122	370.9	10.8	900.	311.7	0.01170	690.4	7.5
3000.	313.9	0.01122	386.2	10.6	850.	311.1	0.01185	688.5	7.3
2800.	313.9	0.01122	401.4	10.5	800.	310.2	0.01207	686.6	7.2
2600.	313.9	0.01122	416.5	10.3	750.	308.8	0.01239	686.7	7.0
2400.	313.9	0.01122	434.3	10.1	700.	306.7	0.01289	686.8	6.9
2200.	313.9	0.01122	454.9	9.8	650.	303.6	0.01368	684.4	6.7
2000.	313.9	0.01123	475.4	9.6	600.	298.3	0.01499	682.0	6.5
1800.	313.8	0.01124	543.3	9.2	550.	287.8	0.01714	678.8	6.3
1600.	313.8	0.01125	611.3	8.9	500.	268.5	0.02028	675.5	6.0

MINIMUM VISIBILITY DISTANCE IS 268.5 FEET AT A SEPARATION OF 500. FEET
VISIBILITY DISTANCE FOR NO GLARE CAR IS 313.9 FEET. MAXIMUM VEILING GLARE IS 0.02028 FT.C AT A SEPARATION OF 500. FEET.
COMPONENTS OF MAXIMUM VEILING GLARE ARE 0.00000 FROM OPPOSING CAR AND 0.00000 FROM FOREGROUND
GLARE INTENSITY AND INDEX ARE NOT CALCULATED DURING RECOVERY. VEILING GLARE IS ACTUAL VALUE DIVIDED BY THE FACTOR K.

Figure 8. Computer printout illustrating ability of program to deal with targets which become lost to sight in high glare (Cont.).

OUTPUT DATA

FIELD TEST BEAM EVALUATION ECE MID RUN NO. 56

SEPARATION DISTANCE (FEET)	VISIBILITY DISTANCE (FEET)	VEILING GLARE (FT.CAND.)	GLARE INTENSITY (CANDELAS)	DISCOMFORT GLARE INDEX	SEPARATION DISTANCE (FEET)	VISIBILITY DISTANCE (FEET)	VEILING GLARE (FT.CAND.)	GLARE INTENSITY (CANDELAS)	DISCOMFORT GLARE INDEX
4000.	159.7	0.01354	309.4	10.7	350.	145.7	0.02485	663.6	4.9
3800.	159.7	0.01354	324.8	10.5	300.	138.5	0.03369	656.3	4.6
3600.	159.7	0.01354	340.1	10.4	250.	131.7	0.04759	647.2	4.4
3400.	159.7	0.01354	355.5	10.2	200.	125.5	0.06318	634.1	4.2
3200.	159.7	0.01354	370.9	10.1	150.	124.9	0.06491	597.0	3.9
3000.	159.7	0.01354	386.2	9.9	100.	128.2	0.05616	0.0	3.8
2800.	159.7	0.01354	401.4	9.7	50.	131.2	0.04890	0.0	3.7
2600.	159.7	0.01354	416.5	9.5	0.	133.9	0.04288	0.0	-2.1
2400.	159.7	0.01354	434.3	9.3	-50.	136.3	0.03789	0.0	-2.1
2200.	159.7	0.01354	454.9	9.1	-100.	138.4	0.03376	0.0	-2.1
2000.	159.7	0.01354	475.4	8.9	-150.	140.6	0.03032	0.0	-2.1
1800.	159.7	0.01355	543.3	8.5	-200.	143.1	0.02746	0.0	-2.1
1600.	159.7	0.01356	611.3	8.2	-250.	145.4	0.02508	0.0	-2.1
1400.	159.7	0.01358	654.3	7.8	-300.	147.5	0.02311	0.0	-2.1
1200.	159.6	0.01361	672.4	7.5	-350.	149.3	0.02147	0.0	-2.1
1000.	159.5	0.01370	690.5	7.1	-400.	150.8	0.02011	0.0	-2.1
950.	159.4	0.01373	690.4	7.0	-450.	152.2	0.01899	0.0	-2.1
900.	159.3	0.01378	690.4	6.8	-500.	153.4	0.01805	0.0	-2.1
850.	159.3	0.01383	688.5	6.7	-550.	154.4	0.01728	0.0	-2.1
800.	159.1	0.01391	686.6	6.6	-600.	155.2	0.01664	0.0	-2.1
750.	159.0	0.01402	686.7	6.5	-650.	155.9	0.01611	0.0	-2.1
700.	158.7	0.01418	686.8	6.3	-700.	156.6	0.01567	0.0	-2.1
650.	158.4	0.01440	684.4	6.1	-750.	157.1	0.01530	0.0	-2.1
600.	157.9	0.01473	682.0	6.0	-800.	157.5	0.01500	0.0	-2.1
550.	157.2	0.01524	678.8	5.8	-850.	157.9	0.01475	0.0	-2.1
500.	156.0	0.01606	675.5	5.6	-900.	158.2	0.01454	0.0	-2.1
450.	154.1	0.01748	671.8	5.4	-950.	158.4	0.01437	0.0	-2.1
400.	150.9	0.02004	668.3	5.1	-1000.	158.7	0.01423	0.0	-2.1

MINIMUM VISIBILITY DISTANCE IS 124.9 FEET AT A SEPARATION OF 150. FEET
VISIBILITY DISTANCE FOR NO GLARE CAR IS 159.7 FEET. MAXIMUM VEILING GLARE IS 0.06491 FT.C AT A SEPARATION OF 150. FEET.
COMPONENTS OF MAXIMUM VEILING GLARE ARE 0.04988 FROM OPPOSING CAR AND 0.01446 FROM FOREGROUND
GLARE INTENSITY AND INDEX ARE NOT CALCULATED DURING RECOVERY. VEILING GLARE IS ACTUAL VALUE DIVIDED BY THE FACTOR K.

Figure 8. Computer printout illustrating ability of program to deal with targets which become lost to sight in high glare (Concl.).

TABLE 1. The Effect of Headlamps of a Vehicle Following at 100 Feet on Visibility and Glare During Meetings With an Oncoming Vehicle, When the Main and Opposing Vehicle Both Use U.S. Low Beams.

Target Location	Beams On Following Car	Maximum Visibility Distance	Minimum Visibility Distance	Maximum Veiling Glare	Discomfort Glare Index
Right Edge of Lane	None	269.5	248.0	.01848	5.4
	ECE Low	268.1	247.2	.01891	4.2
	U.S.Low	266.7	246.4	.01936	3.7
	U.S.Mid-B	265.9	245.9	.01962	3.6
	ECE Mid	261.1	243.1	.02127	2.9
	U.S.Mid-A	259.9	242.3	.02172	2.8
Left Edge of Lane (i.e. on center line)	None	183.7	117.9	.06946	4.7
	ECE Low	182.4	117.7	.06989	3.8
	U.S.Low	181.2	117.5	.07033	3.4
	U.S.Mid-B	180.6	117.4	.07057	3.2
	ECE Mid	176.7	116.7	.07205	2.6
	U.S.Mid-A	175.7	116.5	.07248	2.5

It can be seen from the table that mirror glare has a much greater effect on discomfort glare than on visibility distance. In the worst case, for U.S. Mid-A beams on the following vehicle there is only a 10 foot drop in maximum visibility distance, but the discomfort glare index moves from just acceptable to disturbing.

Figure 9 shows the effect of road curvature on visibility distance for a meeting on a two lane road between vehicles equipped with another typical U.S. low beam, traveling at 30 mph. The target is of 10% reflectivity located 6 inches above the right curb line. The radius of curvature in each case is 10,000 feet. Reading downward on the plots the labels should be convex vertical (i.e. hill), convex horizontal (i.e. inside or right hand), none (i.e. straight and flat road), concave horizontal (i.e. outside or left hand), and concave vertical (i.e. valley) curvature.

Further examples of the application of the HSRI Headlamp Visibility Distance Performance Simulation to the evaluation of

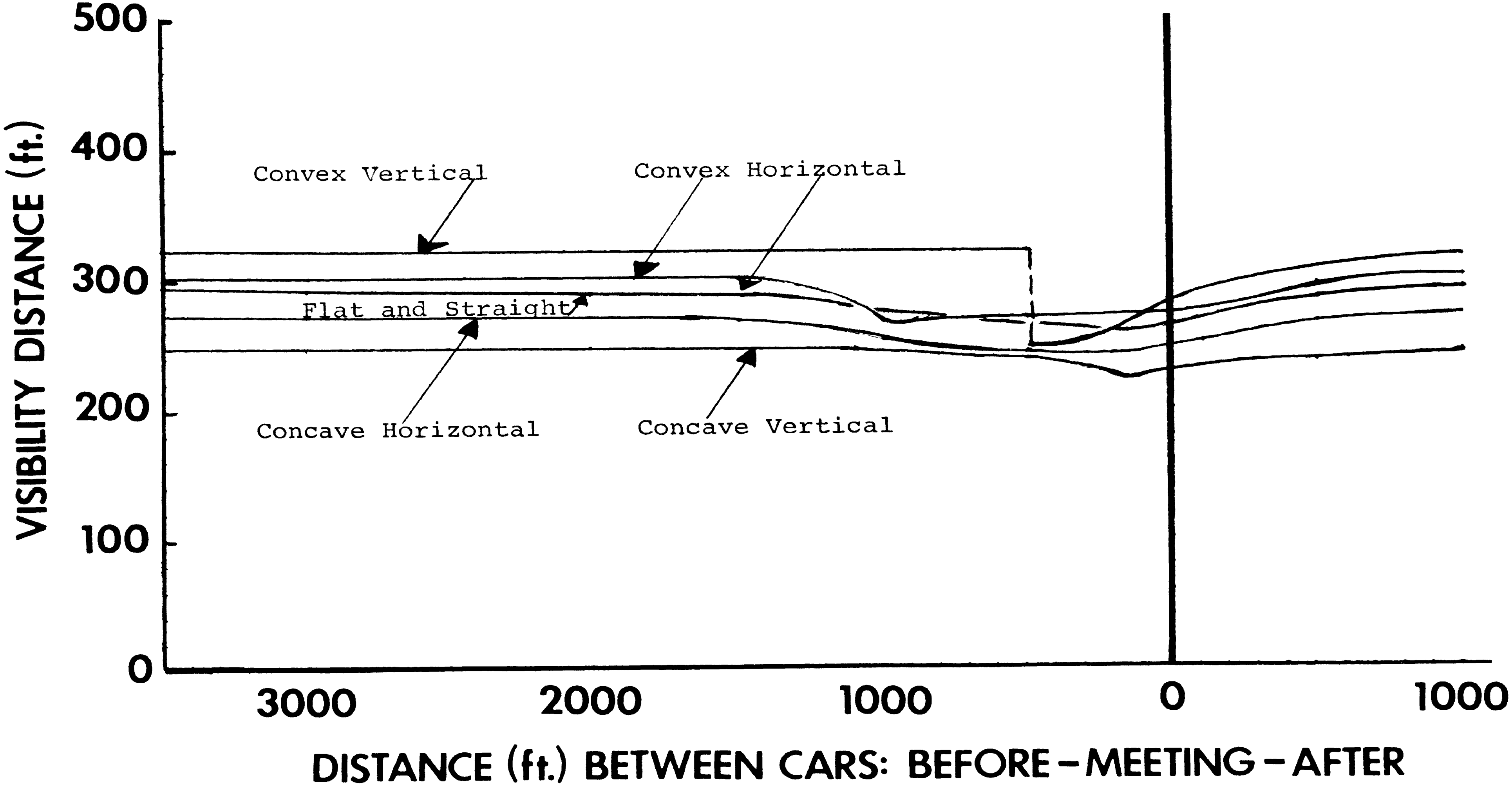

Figure 9. Effects of horizontal and vertical road curvature on visibility distance.

headlamp systems can be found in Mortimer and Becker (1973b), (1973c), (1973d), (1974a) and (1974b) and in Mortimer (1974). Only the last includes the effects of mirrors and road curvature.

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Mortimer, R.G. and Becker, J.M., Computer Simulation Evaluation of Current U.S. and European Headlamp Meeting Beams, and a Proposed Mid Beam. Society of Automotive Engineers, Report No. 740311, 1974b.

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APPENDIX 1

LISTING OF PROGRAM

```
C ----------PROGRAM LAMPER-----------------------------
C               THIS SIMULATION ALLOWS THE RELATIVE EVALUATION OF THE
C               PERFORMANCE OF VARIOUS HEADLAMP BEAM PATTERNS IN TERMS OF THE
C               VISIBILITY DISTANCE PROVIDED AND THE DISABILITY GLARE PRODUCED,
C               AS WELL AS ESTIMATING THE DISCOMFORT GLARE PRODUCED DURING A
C               NIGHT MEETING SITUATION.
C
      DIMENSION IALF(2),DAT(3),VG(3),CARD(8),JTITL(21),ITITL(40)
      COMMON DES(88),DVIS(88),GLR(88),GV(88),DGI(88),DVMIN,DVDS,GVMAX,GV
     1DS,DVAG,GVG,CVF,GMI,GME,IMAX
      COMMON DSTRT,DSTOP,DSD,DST,DSDEL(3),XSTRT,XDEL,EK,FG(4),A(2),B(2),
     1ALX(20,10),XX(20,2),XS,YS,ZS,PO(5),GSP(4),YE,ZE,YT,ZT,GM(5,2),XM(5
     2,2),YM(5,2),ZM(5,2),YGL(5),ZGL(5),RHO,XVMIN,LAMP(15),ILS,IEK,IGM,I
     3HV,ICV,DSGRZ,XVGRZ,RODR
      COMMON DTR,RTD,XSTOP,ZSTRT,ZSTOP,DELX,DELZ,RHOS,RHOT,ZCL,XE,XB,YBT
     1,Z32,Z31,RC,SX(3),SY(3),SZ(3),PS(3),HD(2),VD(2),REFL(2),TRS(2),P(6
     2,2),Q(9,2),AFT(15),IFG
      COMMON HH,VV,IHA,IVA,AL(61,22),DH,DV
      DATA IALF/'D','L'/
      DATA BLANK/' '/
      CALL SETFIL(11,'JBEAM',IERR,'DK',1)
      DEFINE FILE 11(10,2716,U,N1)
C               DEFINE CONSTANTS
      RTD = 57.29578
      DTR = .0174533
      DTRS = .0003046177
      DO 2  I=1,3
    2 DAT(I) = BLANK
C               DETERMINE DATE
      CALL DATE(DAT)
C               DEFINE SEPARATION AND TARGET DISTANCE VECTORS
   95 XX(1,1) = 50.
      XX(1,2) = 50.
      DO 6 I=2,10
    6 XX(I,2) = XX(I-1,2)+50.
      DO 7 I=11,15
    7 XX(I,2) = XX(I-1,2)+100.
      DO 8 I=16,20
    8 XX(I,2) = XX(I-1,2)+500.
      DO 9 I=2,6
    9 XX(I,1) = XX(I-1,1)+10.
      DO 10 I=7,16
   10 XX(I,1) = XX(I-1,1)+20.
      XX(17,1) = 400.
      XX(18,1) = 500.
      XX(19,1) = 800.
      XX(20,1) = 1000.
      IPAGE = 1
      WRITE(5,9994) DAT,IPAGE
 9994 FORMAT (1H1,37X,'HEADLIGHT VISIBILITY PERFORMANCE EVALUATION'5X3A4
     1,5X'PAGE'I3//45X'INPUT DATA')
      IPAGE = IPAGE+1
C               DEFINE DEFAULT VALUES OF PARAMETERS
      BASR = 100.
      RCDR = .1
      [illegible]
```

```
      DSTOP = -1000.
      DST = 100.
      DSDEL(1) = 50.
      DSDEL(2) = 10.
      DSDEL(3) = 1.
      XSTRT = 200.
      XDEL = 8.
      XSTOP = 240.
      ZSTRT = -8.
      ZSTOP = 8.
      DELX = 10.
      DELZ = 2.
      A(1) = 3.4
      A(2) = .36
      B(1) = .016
      B(2) = .0008
      CALL INPUT(BASH,ITITL)
      IF (ILS.LT.0) GO TO 102
      IF (DSTRT.GT.XX(20,2)) XX(20,2)=DSTRT
      WRITE(5,9901)DSTRT,DSTOP
 9901 FORMAT (1H0'SEPARATION DISTANCES   INITIAL ',F8.1,' FEET, FINAL ',
     1F8.1,' FEET')
  100 READ(8,9999)ID,CARD
 9999 FORMAT (A1,F9.0,7E10.0)
      DO 101 I=1,2
      IF (ID-IALF(I)) 101,103,101
  101 CONTINUE
      WRITE(5,9998)ID,CARD
 9998 FORMAT ('0ILLEGAL CARD'/1X,A1,8E13.4)
  102 READ(8,9999)ID,CARD
      IF (ID.EQ.IALF(1)) GO TO 102
      NDS = CARD(1) + .5
      GO TO 710
  103 GO TO (200,600),I
C                CARD D          VEHICLE GEOMETRY AND MISAIM ANGLES
C                READ DISC FILE FOR BEAM PATTERN DATA
  200 N = CARD(8)+.5
      READ(11'N)HH,VV,DD,IHA,IVA,JTITL,((AL(I,J),J=1,IVA),I=1,IHA)
      DV = ABS(DD)
      DH = DD
      IF (DD.LT.0.) DH=2*DV
      CALL BEAMS(VGZ,VG,CARD,JTITL)
      GO TO 100
C                CARD L  PROCESS FOREGROUND GLARE DATA
  600 NDS = CARD(1) + .5
      IF (IFG.NE.0) GO TO 650
      IF (ILS.NE.0) GO TO 605
      FG(1) = VG(1)
      FG(2) = 0.
      FG(3) = 0.
      FG(4) = 1.
      GO TO 630
  605 IF (IHV+ICV.EQ.0) GO TO 606
      TSA = VG(2)-VG(3)
      TSB = VG(1)-VG(2)
      TSC = TSB-TSA
```

```
      FG(2) = 0.
      FG(1) = (VG(1)*VG(3)-VG(2)*VG(2))/TSC
      FG(3) = -TSB/TSA*TSB/TSC*TSB
      FG(4) = XS*ALOG(TSA/TSB)
      GO TO 630
  606 TSA = VG(1)-VGZ
      TSB = VG(2)-VGZ
      TSC = VG(3)-VGZ
      FG(1) = VGZ
      TSE = VG(2)*TSB - VG(3)*TSA + (VG(1)-VG(2))*VGZ
      IF (TSE) 610,610,620
  610 FG(2) = 0.
      TSD = TSA/TSB
      FG(3) = -TSD*TSA
      FG(4) = XS/ALOG(TSD)
      GO TO 630
  620 TSD = SQRT(TSE)
      EBX = (TSB+TSD)/TSC
      IF (EBX.LE.0.) EBX=(TSB-TSD)/TSC
      TSF = (TSB*EBX-TSA)*EBX
      FG(3) = TSE-TSA*EBX
      FG(2) = TSF/XS
      FG(4) = XS/ALOG(EBX)
  630 WRITE(5,9996)FG
 9996 FORMAT (1H0'COEFFICIENTS FOR GOL = GA + (AX-C)*EXP(-X/B)'/4E14.4/)
      FG(4) = -FG(4)
  650 IF (FG(4)) 670,660,660
  660 WRITE(5,9995)
 9995 FORMAT ('0FOREGROUND GLARE DATA BAD')
      GO TO 710
  670 IF (INV.NE.1) GO TO 675
      WRITE(5,9992)XVGHZ
 9992 FORMAT (1H0'TARGET WILL BE BELOW CROWN OF HILL AND INVISIBLE FOR V
     1ISIBILITY DISTANCES GREATER THAN'F7.1' FEET'/' NOTE THAT VISIBILIT
     2Y DISTANCE MAY BE LIMITED TO THIS VALUE')
      WRITE(5,9998)DSGHZ
 9998 FORMAT (' GLARE CAR WILL BE INVISIBLE BELOW CREST OF HILL FOR SEPA
     1RATION DISTANCES GREATER THAN'F8.1' FEET')
  675 IF (IGM.EQ.0) GO TO 690
      DO 680 I=1,5
      K = I+10
      IF (LAMP(K).LE.0) GO TO 680
      WRITE(5,9993)K,(J,GM(I,J),J=1,2)
  680 CONTINUE
 9993 FORMAT (' MIRROR GLARE ILLUMINATION AT EYE FROM LAMP NO.'I3' VIA M
     1IRROR NO.'I2' IS'F10.6' FT-C, AND NO.'I2' IS'F10.6' FT-C.')
  690 INVIS = 0
  695 CALL GLARE(INVIS)
      IF (INVIS.GT.1) GO TO 710
      IF (IMAX.EQ.0) GO TO 700
      WRITE(5,9997) CAT,IPAGE,ITITL
 9997 FORMAT (1H1,30X,'HEADLIGHT VISIBILITY PERFORMANCE EVALUATION'5X3A4
     1,5X'PAGE'I3//55X'OUTPUT DATA'//20X40A2/)
      CALL OUTPUT(DTRS)
  700 IF (INVIS.EQ.0) GO TO 710
      XSTRT = XSTRT/2.

      GO TO 695
  710 IF (NDS.GT.0) GO TO 95
      CALL EXIT
      END
```

```
      SUBROUTINE CURVE(I,J,X,D,E,V,W,R)
C             THIS SUBROUTINE RECOMPUTES THE COORDINATE GIVEN ROAD CURVATURE.
      SMA = .05
      TSA = I*D+R
      IF (J.GT.1) GO TO 105
      A = X/R
      X = TSA*SIN(A)
      GO TO 110
  105 A = ATAN(X/SQRT(TSA*TSA-X*X))
  110 IF (J.EQ.2) GO TO 120
      TSB = COS(A)
      TSC = 1.-TSB
      IF (A.LE.SMA) TSC=A*A*.5
      W = D*TSB-E-I*R*TSC
      IF (J.LT.4) RETURN
  120 V = R*A
      RETURN
      END
```

```
      SUBROUTINE INPUT(BASH,ITITL)
C                THIS SUBROUTINE READS MOST OF THE INPUT CARDS AND PROCESSES THE
C                DATA AS READ.
      DIMENSION IALF(13),ITITL(40),CARD(8),G(8,2),X(2),Y(2),Z(2),NSHP(2)
     1,IT(2),JT(2),KT(2),R(2),C(3),S(3)
      COMMON DS(88),DVIS(88),GLR(88),GV(88),DGI(88),DVMIN,DVDS,GVMAX,GV
     1DS,DVNG,GVG,GVF,GMI,GME,IMAX
      COMMON DSTRT,DSTOP,DSD,DST,DSDEL(3),XSTRT,XDEL,EK,FG(4),A(2),B(2),
     1ALX(20,14),XX(20,2),XS,YS,ZS,PO(5),GSP(4),YE,ZE,YT,ZT,GM(5,2),XM(5
     2,2),YM(5,2),ZM(5,2),YGL(5),ZGL(5),RHO,XVMIN,LAMP(15),ILS,IEK,IGM,I
     3HV,ICV,DSGEZ,XVGEZ,ROUR
      COMMON DTR,RTD,XSTOP,ZSTRT,ZSTOP,DELX,DELZ,RHOS,RHOT,ZCL,XE,XB,YBT
     1,ZBR,ZBL,RC,SX(3),SY(3),SZ(3),RS(3),HD(2),VD(2),REFL(2),TRS(2),P(6
     2,2),Q(9,2),AFT(15),IFG
      DATA IALF/'A','B','S','C','G','M','O','P','T','V','X','Y','Z'/
      DATA IBLNK/' '/
      DATA IT/'IN','EX'/
      DATA JT/'RE','SI'/
      DATA KT/'AR','DE'/
      DO 5 I=1,40
    5 ITITL(I) = IBLNK
      IHV = 0
      ICV = 0
      IGM = 0
      IFG = 0
      ILS = 1
      XS = 100.
      XB = 4.
      YBT = -1.
      ZBR = 4.25
      ZBL = -1.75
      EPS = .01
      DO 10 J=1,2
      HD(J) = 0.
      VD(J) = 0.
      TRS(J) = 1.
   10 REFL(J) = 1.
      DO 30 I=1,15
      AFT(I) = 1.
   30 LAMP(I) = 0
      DSD = 200.
      EK = .251594
  100 READ(8,9999)ID,CARD
 9999 FORMAT (A1,F9.0,7E10.0)
      DO 101 I=1,13
      IF (ID-IALF(I)) 101,103,101
  101 CONTINUE
      WRITE(5,9982)ID,CARD
 9982 FORMAT ('?ILLEGAL CARD'/1X,A1,8E13.4)
  102 READ(8,9999)ID
      IF (ID.NE.IALF(13)) GO TO 102
      ILS = -1
      RETURN
C                A    B    S    C    G    M    O    P    T    V    X    Y    Z
  103 GO TO (200,300,350,400,550,600,610,650,700,750,800,900,1000),I
C                 CARD A     SEPARATION DISTANCE DATA AND ROAD CURVATURE
```

```
  200 IF (CARD(1).GT.0.) DSTRT=CARD(1)
      IF (CARD(2).GE.0.) DSTOP=CARD(2)
      IF (CARD(3).GT.0.) DSD=CARD(3)
      IF (CARD(4).GT.0.) GO TO 201
      IF (DST.GT.DSTRT*.5) DST=DSTRT*.5
      GO TO 202
  201 DST = CARD(4)
  202 IF (CARD(5).GT.0.) DSDEL(1)=CARD(5)
      IF (CARD(6).EQ.0.) GO TO 100
      RHO = CARD(6)
      RHOT = 2.*RHO
      RHOS = RHO*RHO
      DO 203 I=1,20
      IF (XX(I,1).GE.RHO) XX(I,1)=RHO-10.
  203 CONTINUE
      IF (DSTRT.LT.PI*RHO) GO TO 204
      TSA = .01*RHO
      I = TSA
      TSB = I
      DSTRT = 300.*TSB
      WRITE(5,9005)
 9005 FORMAT (1H0'INITIAL SEPARATION DISTANCE TOO LARGE FOR RADIUS OF CU
     1RVATURE')
  204 IF (CARD(7).EQ.0.) GO TO 205
      IHV = CARD(7)
      IF (IHV.GT.0) WRITE(5,9001)RHO
 9001 FORMAT (1H0'ROAD IS A HILL CREST WITH RADIUS OF'F9.1' FEET')
      IF (IHV.LT.0) WRITE(5,9002)RHO
 9002 FORMAT (1H0'ROAD IS A VALLEY WITH RADIUS OF'F9.1' FEET')
      GO TO 100
  205 ICV = CARD(8)
      IF (ICV.GT.0) WRITE(5,9003)RHO
 9003 FORMAT (1H0'ROAD IS A RIGHT HAND CURVE WITH RADIUS OF'F9.1' FEET')
      IF (ICV.LT.0) WRITE(5,9004)RHO
 9004 FORMAT (1H0'ROAD IS A LEFT HAND CURVE WITH RADIUS OF'F9.1' FEET')
      GO TO 100
C                CARD B  ROAD REFLECTIVITY, BASIC TARGET REFLECTIVITY, EYE
C                RECOVERY RATE AND OBSERVER RELATION COEFFICIENTS
  300 IF (CARD(1).GT.0.) RODR=.01*CARD(1)
      IF (CARD(2).GT.0.) BASR=CARD(2)**2
      IF (CARD(3).GT.0.) EK=CARD(3)
      IF (CARD(4).LE.0.) GO TO 100
      A(1) = CARD(4)
      A(2) = CARD(5)
      B(1) = CARD(6)
      B(2) = CARD(7)
      GO TO 100
C                        CARD S     EYE LINE-OF-SIGHT
  350 IF (CARD(1).LE.0.) GO TO 351
      XS = CARD(1)
      ILS = 1
      GO TO 100
  351 XS = CARD(4)
      YS = CARD(5)
      ZS = CARD(6)
      ILS = 0
```

```
      WRITE(5,9994)XS,YS,ZS
 9994 FORMAT (1H0'FIXED EYE LINE-OF-SIGHT COMPONENTS'3E13.4)
      GO TO 100
C                   CARD C           EYE,TARGET,AND VELOCITY DATA
  400 ZCL = CARD(1)
      FK = FK/(CARD(2)+CARD(3))*.6818182
      XI = CARD(4)
      YI = CARD(5)
      ZI = CARD(6)
      XE = XI/12.
      YE = YI/12.
      ZE = ZI/12.
      YT = CARD(7)/12.
      ZT = CARD(8)/12.
      WRITE(5,9904)CARD
 9904 FORMAT (1H0'CENTERLINE DISTANCE'F6.1' FEET, VEHICLE VELOCITIES  MA
     1IN ='F6.1' MPH, OPPOSING ='F6.1' MPH'/' EYE IS'F6.1' IN. BEHIND LA
     2MPS,'F6.1' IN. ABOVE ROAD AND'F6.1' IN. LEFT OF CENTERLINE'/ ' TAR
     3GET IS'F6.1' IN. ABOVE ROAD AND'    F6.1' IN. FROM CENTERLINE')
      IF (ILS.EQ.0) GO TO 401
      YS = YT-YE
      ZS = ZT+ZE
  401 TSA = YS*YS
      TSB = ZS*ZS
      GSP(1) = 9.25*ZS
      GSP(2) = 2.*XS*GSP(1)
      GSP(3) = 85.5625*(TSA+XS**2)
      GSP(4) = TSA+TSB
      ICV = -ICV
      DO 405 I=1,3
      SX(I) = XS*I
      TSA = SX(I)
      TSB = YS
      TSC = ZS
      IF (IHV.NE.0) CALL CURVE(IHV,3,TSA,YT,YE,TSA,TSB,RHO)
      IF (ICV.NE.0) CALL CURVE(ICV,3,TSA,ZT,-ZE,TSA,TSC,RHO)
      SY(I) = TSB
      SZ(I) = TSC
  405 RS(I) = SQRT(TSA*TSA+TSB*TSB+TSC*TSC)
      GO TO 100
C                             CARD G    FOREGROUND GLARE
  550 DO 551 I=1,4
  551 FG(I) = CARD(I)
      WRITE(5,9997)FG
 9997 FORMAT (1H0'FOREGROUND GLARE COEFFICIENTS'/4E12.4)
      FG(4) =-FG(4)
      IFG = 1
      GO TO 100
C                   CARD M      MIRROR DATA
  600 M = CARD(1)+.5
      IGM = 1
      X(M) = XI-CARD(2)
      Y(M) = CARD(3)-YI
      Z(M) = CARD(4)+ZI
      R(M) = SQRT(X(M)*X(M)+Y(M)*Y(M)+Z(M)*Z(M))
      IF (CARD(5).GT.0.) REFL(M)=CARD(5)
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```
      NSHP(M) = CARD(6)+.5
      IF (CARD(7).GT.0.) TRS(M)=CARD(7)
      GO TO 100
C                    CARD O    MIRROR ORIENTATION
  610 M = CARD(1)+.5
      HD(M) = CARD(2)/24.
      VD(M) = CARD(3)/24.
      YQ = CARD(4)-YI
      ZQ = CARD(5)+ZI
      XQ = -360.
      IF (CARD(6).NE.0.) XQ=-12.*CARD(6)
      DX = X(M)-XQ
      DY = Y(M)-YQ
      DZ = Z(M)-ZQ
      F = SQRT(DX*DX+DY*DY+DZ*DZ)
      TSA = R(M)/F
      TSB = TSA*DX+X(M)
      TSC = TSA*DY+Y(M)
      TSD = TSA*DZ+Z(M)
      TSA = SQRT(TSB*TSB+TSD*TSD)
      YAW = RTD*ATAN(-TSD/TSB)
      PTCH = RTD*ATAN(TSC/TSA)
      ROLL = 0.
      IF (NSHP(M).GT.0) ROLL=RTD*ATAN(TSD/TSB*TSC/SQRT(TSA*TSA+TSC*TSC))
      IF (M.EQ.1) WRITE(5,9990)
 9990 FORMAT (1H1'MIRROR  TYPE'6X'LOCATION (INCHES)   SIZE (INCHES)    O
     1RIENTATION (DEGREES)'6X'CENTER POINT AIM'15X'TRANSMISSIVITY'/1H 'N
     2UMBER'13X'X'6X'Y'6X'Z    WIDTH  HEIGHT  YAW'7X'PITCH'5X'ROLL'7X'X'
     36X'Y'6X'Z  REFLECTIVITY    OF WINDOW')
      TSA = X(M)-XI
      TSB = Y(M)+YI
      TSC = Z(M)-ZI
      WRITE(5,9992)M,IT(M),TSA,TSB,TSC,CARD(2),CARD(3),YAW,PTCH,ROLL,XQ,
     1CARD(4),CARD(5),REFL(M),JT(M),KT(M),TRS(M)
 9992 FORMAT (1H I4,3XA2'TERIOR'5F7.1,3F10.5,3F7.1,F9.4,5X2A2,F8.4)
      GO TO 650
C                    CARD P    MIRROR FIELD OF VIEW
  650 M = CARD(1)+.5
      YR = CARD(2)-YI
      YF = CARD(3)-YI
      ZR = CARD(4)+ZI
      ZL = CARD(5)+ZI
      XQ = -360.
      IF (CARD(6).NE.0.) XQ=-12.*CARD(6)
      TSA = -XQ/12.
      WRITE(5,9911)IT(M),TSA,CARD(2),CARD(3),CARD(5),CARD(4)
 9911 FORMAT (1H A2'TERIOR MIRROR FIELD OF VIEW AT'F6.1' FEET BEHIND EYE
     1,'F5.1' TO'F5.1' INCHES ABOVE ROAD,'F7.1' TO'F6.1' INCHES FROM CEN
     2TERLINE')
      IF (CARD(7).NE.0.) EPS=CARD(7)
      YDEL = YF-YR
      ZDEL = ZR-ZL
      YEP = YDEL*EPS
      ZEP = ZDEL*EPS
      DX = X(M)-XQ
      DXS = DX*DX
```

```
      NI = 0
      H = 5.
      V = 1.
      IF (NSHP(M).LE.0) H=2.5
      YQ = .5*(YB+YF)
      ZQ = .5*(ZR+ZL)
651   NI = NI+1
      IF (NI.GT.10) CALL EXIT
      NZ = 0
      DY = Y(M)-YQ
      DZ = Z(M)-ZQ
      F = SQRT(DXS+DY*DY+DZ*DZ)
      TSA = R(M)/F
      XA = DX*TSA
      YA = DY*TSA
      ZA = DZ*TSA
      TSB = X(M)+XA
      TSC = Y(M)+YA
      TSD = Z(M)+ZA
      TSE = SQRT(TSB*TSB+TSC*TSC)
      TSG = SQRT(TSE*TSE+TSD*TSD)
      IF (NSHP(M).LE.0) GO TO 652
      TSA = H/TSG
      TSF = TSB/TSE
      TSG = TSB-XQ
      XP = -TSA*TSF*TSD
      ZP = TSA*TSE
      ZGO = TSD-(ZP+ZA)/(XP+XA)*TSG
      ZGT = TSD-(ZP-ZA)/(XP-XA)*TSG
      XP = -V/TSE*TSC
      YP = V*TSF
      YGO = TSC-(YP+YA)/(XP+XA)*TSG
      YGT = TSC-(YP-YA)/(XP-XA)*TSG
      VV = V/(YGT-YGO)*YDEL
      GO TO 653
652   TSF = SQRT(TSB*TSB+TSD*TSD)
      TSA = H/TSF
      TSE = H/TSG
      TSG = TSB-XQ
      XP = -TSA*TSD
      ZP = TSA*TSB
      ZGO = TSD-(ZP+ZA)/(XP+XA)*TSG
      ZGT = TSD-(ZP-ZA)/(XP-XA)*TSG
      XP = -TSF/TSF*TSB*TSC
      YP = TSE*TSF
      YGO = TSC-(YP+YA)/(XP+XA)*TSG
      YGT = TSC-(YP-YA)/(XP-XA)*TSG
      VV = H
653   ZDO = ZGO-ZL
      ZDT = ZGT-ZR
      YDO = YGO-YB
      YDT = YGT-YF
      IF (ABS(ZDO).GT.ZEP) GO TO 654
      IF (ABS(ZDT).LE.ZEP) GO TO 655
654   ZQ = ZQ-.5*(ZDO+ZDT)
      H = H/(ZGT-ZGO)*ZDEL
```

```
      NZ = 1
  655 IF (ABS(YDD).GT.YEP) GO TO 656
      IF (ABS(YDT).LE.YEP) GO TO 657
  656 YO = YO-.5*(YDD+YDT)
      V = VV
      IF (NSHP(M).GT.0) GO TO 651
      IF (ABS(YDD+YDT).GT.YEP) GO TO 651
  657 IF (NZ.NE.0) GO TO 651
      YAW = RTD*ATAN(-TSD/TSB)
      TSA = SQRT(TSB*TSB+TSD*TSD)
      PTCH = RTD*ATAN(TSC/TSA)
      ROLL = 0.
      IF (NSHP(M).GT.Ø) ROLL=RTD*ATAN(TSD/TSB*TSC/SQRT(TSA*TSA+TSC*TSC))
      IF (NSHP(M).LE.Ø) V=Ø.
      HD(M) = H/12.
      VD(M) = V/12.
      G(1,M) = 2.*H
      G(2,M) = 2.*V
      G(3,M) = YAW
      G(4,M) = PTCH
      G(5,M) = ROLL
      G(6,M) = XO
      G(7,M) = YO+YI
      G(8,M) = ZO-ZI
  658 C(1) = COS(DTR*YAW)
      S(1) = SIN(DTR*YAW)
      C(2) = COS(DTR*PTCH)
      S(2) = SIN(DTR*PTCH)
      C(3) = COS(DTR*ROLL)
      S(3) = SIN(DTR*ROLL)
C           COMPUTE ROTATION MATRIX FOR AIM IN YAW, PITCH AND ROLL
      TSA = C(2)
      Q(1,M) = TSA*C(1)
      Q(8,M) =-TSA*S(3)
      Q(5,M) = TSA*C(3)
      Q(3,M) =-TSA*S(1)
      TSA =-S(2)
      Q(2,M) = -TSA
      TSB = C(1)*C(3)
      TSC = S(1)*S(3)
      Q(4,M) = TSA*TSB+TSC
      Q(9,M) = TSA*TSC+TSB
      TSB = C(1)*S(3)
      TSC = S(1)*C(3)
      Q(6,M) = TSB-TSC*TSA
      Q(7,M) = TSC-TSB*TSA
      DO 659 I=1,3
      J = 3*I-2
      P(I,M) = (X(M)*Q(J,M)+Y(M)*Q(J+1,M)+Z(M)*Q(J+2,M))/12.
  659 P(I+3,M) = 2.*Q(I,M)*P(1,M)
      IF (M.EQ.1) GO TO 1ØØ
      WRITE(5,999Ø)
      DO 66Ø M=1,2
      TSA = X(M)-XI
      TSB = Y(M)+YI
      TSC = Z(M)-ZI
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  660 WRITE(5,9992)M,IT(M),TSA,TSB,TSC,(G(I,M),I=1,8),REFL(M),JT(M),KT(M
     1),TPS(M)
      GO TO 100
C                 CARD T     TITLE
  700 READ(6,9991)ITITL
 9991 FORMAT(40A2)
      WRITE(5,9909)ITITL
 9909 FORMAT (1H0,10X,40A2)
      GO TO 100
C                CARD V    VEHICLE STRUCTURE DATA
  750 XB = CARD(1)/12.-XE
      YBT = CARD(2)/12.-YE
      ZBR = CARD(3)/12.+ZE
      ZBL = CARD(4)/12.+ZE
      GO TO 100
C                 CARD X     ROAD DATA
  800 XSTOP = CARD(2)
      ZSTRT = CARD(3)
      ZSTOP = CARD(4)
      DELX = CARD(5)
      DELZ = CARD(6)
      GO TO 100
C                 CARD Y     POLARIZATION DATA
  900 M = CARD(1)+.5
      IF (M.GT.0) GO TO 902
      TSA = CARD(2)
      TSB = CARD(3)
      YW = TSA+SQRT(TSA*TSA-TSB)
      ZW = TSB/YW
      WRITE(5,9993)TSA,TSB
 9993 FORMAT (1H0,' ANALYZER TRANSMISSIVITY IS'F8.4' AND SELF-EXTINCTION
     1 COEFFICIENT IS'F11.7//4X'BEAM'7X'FILTER'5X'SELF-EXTINCTION ANGLE
     2TO ANALYZER-FILTER'/3X'NUMBER  TRANSMISSIVITY   COEFFICIENT   ANAL
     3YZER  TRANSMISSIVITY')
      GO TO 100
  902 TSA = CARD(2)
      TSB = CARD(3)
      YI = TSA+SQRT(TSA*TSA-TSB)
      ZI = TSB/YI
      TSC = COS(CARD(4)*DTR)
      TSD = .5*(YW*ZI+ZW*YI+(YW-ZW)*(YI-ZI)*TSC*TSC)
      AFT(M) = TSD
      IF (M.GT.11) AFT(M)=TSA
      IF (M.NE.11) GO TO 903
      TSC = 1.
      TSE = 0.
      WRITE(5,9933)TSC,TSE
 9933 FORMAT (1H0'FOR WINDOWS ASSOCIATED WITH MIRRORS, ANALYZER TRANSMIS
     1SIVITY IS'F8.4' AND SELF-EXTINCTION COEFFICIENT IS'F11.7//4X'BEAM'
     27X'FILTER'5X'SELF-EXTINCTION ANGLE TO ANALYZER-FILTER'/3X'NUMBER
     3TRANSMISSIVITY   COEFFICIENT   ANALYZER  TRANSMISSIVITY')
  903 WRITE(5,9996)M,TSA,TSB,CARD(4),TSD
 9996 FORMAT (4XI3,6XF8.4,6XF11.7,5XF5.1,4XF11.7)
      GO TO 100
C                 CARD Z   TARGET REFLECTIVITY
 1000 IF (CARD(2).GT.0.) XSTRT=CARD(2)
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      IF (CARD(3).GT.Ø.) XDEL=CARD(3)
      IF (IS[illegible].EQ.Ø) GO TO 999
      TSA = (XB+XF)*12.
      TSB = (YE+YRT)*12.
      TSC = (ZBR-ZE)*12.
      TSD = (ZBL-ZE)*12.
      WRITE(5,99Ø1)TSA,TSB,TSC,TSD
 99Ø1 FORMAT (1H0'OBSTRUCTING PLANE IS'F6.1' INCHES BEHIND LAMPS, TOP IS
     1'F5.1' INCHES ABOVE ROAD, EDGES ARE'F5.1' AND'F6.1' INCHES FROM CE
     2NTERLINE')
  999 WRITE(5,99Ø6)
 99Ø6 FORMAT (1H0,'  OBSERVER RELATION FOR TARGET INTENSITY = EXP(A+B*D)
     1, WHERE D IS VISIBILITY DISTANCE')
      WRITE(5,9995)A,B
 9995 FORMAT (1H 'COEFFICIENTS FOR  A = C+D(4TH ROOT OF GI),  B = E+F(SQ
     1RT OF GI)'/7X'C'12X'D'12X'E'12X'F'/4E13.4)
      IF (CARD(4).LE.Ø.) GO TO 1ØØ1
      REFT = CARD(4)/BASR*CARD(4)
      WRITE(5,9988)CARD(4)
 9988 FORMAT (1H0'TARGET REFLECTIVITY IS'F1Ø.1' PER CENT')
      A(1) = A(1)-ALOG(REFT)
 1ØØ1 TSA = 1ØØ.*RODR
      WRITE(5,9989)TSA,EK
 9989 FORMAT (1H0'BASIC TARGET REFLECTIVITY FOR OBSERVER RELATION IS'F6.
     11' PER CENT, NOMINAL EYE RECOVERY RATE PARAMETER IS'F9.6' PER SECO
     2ND')
      TSA = 1ØØ.*RODR
      WRITE(5,9987)XSTOP,ZSTRT,ZSTOP,TSA
 9987 FORMAT (1H0'ILLUMINATED AREA OF PAVEMENT EXTENDS'F6.1' FEET AHEAD
     1OF LAMPS AND'F6.1' AND'F6.1' FEET FROM CENTERLINE'/1X'ROAD REFLECT
     2IVITY IS'F6.1' PER CENT.')
      RC = YE*DFLX*DELZ*RODR
      IEK = CARD(7)
      RETURN
      END
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      SUBROUTINE BEAMS(VGZ,VG,CARD,JTITL)
C             THIS SUBROUTINE TAKES THE LAMP GEOMETRY AND MISAIM AND CALCULATES
C             THE ANGLES OF THE ROAD AND TARGET, EYE OR MIRRORS IN EACH MAIN,
C             GLARE OR FOLLOWING VEHICLE LAMP BEAM PATTERN, RESPECTIVELY.
      DIMENSION AC(9),C(3),D(3),E(3),S(3),VG(3),JTITL(21),CARD(8),W(9)
      COMMON DDS(88),DVIS(88),GLR(88),GV(88),DGI(88),DVMIN,DVDS,GVMAX,GV
     1DS,DVNG,GVG,GVF,GMI,GME,IMAX
      COMMON DSTRT,DSTOP,DSD,DST,DSDEL(3),XSTRT,XDEL,EK,FG(4),A(2),B(2),
     1ALX(20,10),XX(20,2),XS,YS,ZS,PD(5),GSP(4),YE,ZE,YT,ZT,GM(5,2),XM(5
     2,2),YM(5,2),ZM(5,2),YGL(5),ZGL(5),RHO,XVMIN,LAMP(15),ILS,IEK,IGM,I
     3HV,ICV,DSGPZ,XVGRZ,RODR
      COMMON DTR,RTD,XSTOP,ZSTRT,ZSTOP,DELX,DELZ,RHOS,RHOT,ZCL,XE,XB,YBT
     1,ZBR,ZBL,RC,SX(3),SY(3),SZ(3),RS(3),HD(2),VD(2),REFL(2),TRS(2),P(6
     2,2),Q(9,2),AFT(15),IFG
      M = CARD(1)+.5
      MM = CARD(8) + .5
C             COMPUTE THE ROTATION MATRIX FOR MISAIM IN PITCH, YAW AND ROLL.
      DO  10 I=1,3
      TSA = CARD(I+4)*DTR
      S(I) = SIN(TSA)
   10 C(I) = COS(TSA)
      TSA = S(2)*S(3)
      TSB = C(2)*C(3)
      TSC = S(1)
      W(6) = TSB+TSA*TSC
      W(7) = -TSA-TSB*TSC
      TSA = S(2)*C(3)
      TSB = C(2)*S(3)
      W(4) = TSC*TSB-TSA
      W(9) = TSB-TSA*TSC
      W(2) = TSC
      TSA = C(1)
      W(1) = TSA*C(2)
      W(8) = TSA*C(3)
      W(3) = TSA*S(2)
      W(5) = -TSA*S(3)
      IF (LAMP(M).EQ.0) LAMP(M)=1
      LAMP(M) = M*LAMP(M)
      IF (M.GT.10) GO TO 230
      IF (M-6)  20,160,170
C             PROCESS MAIN VEHICLE LAMP GEOMETRY
   20 IF (M.NE.1) GO TO 40
      D(1) = -XE
      D(2) = CARD(3)/12.
      D(3) = -CARD(4)/12.
      VGZ = 0.
      DO  30 I=1,3
      VG(I) = 0.
   30 E(I) = D(I)
      TSA = D(2)+.5
      XC = XE/(YE-TSA)*TSA
      XVMIN = XE
      WRITE(5,9905)M,(CARD(I),I=2,4),M,(CARD(I),I=5,7),MM,JTITL
 9905 FORMAT (1H0,'DISTANCE BETWEEN HEADLIGHT NO.'I2'   MISAIM ANGLES (D
     1EGREES)  BEAM PATTERN'/' AND    (IN.)  X'6X'Y'6X'Z'7X'INDEX VERT.
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     2HOR,  ROT.,  INDEX    NAME'/4X'ORIGIN'3F7.1,I8,1X3F6.1,I6,3X21A2)
      IF (IHV.NE.1) GO TO 60
      XGRZ = RHO*ATAN((SQRT((RHOT+D(2))*D(2)))/RHO)
      XVGRZ = XGRZ+RHO*ATAN((SQRT((RHOT+YT)*YT))/RHO)
      IF (XSTOP.GT.XGRZ) XSTOP=XGRZ
      GO TO 60
   40 DO  50 I=1,3
   50 D(I) = E(I)+CARD(I+1)/12.
      WRITE(5,9906)M,(CARD(I),I=2,4),M,(CARD(I),I=5,7),MM,JTITL
 9906 FORMAT (4X'NO.'I2,1X3F7.1,6XI2,1X3F6.1,4XI2,3X21A2)
      TSB = D(2)+.5
      TSA = (YE*CARD(2)/12.+D(1)*TSB)/(TSB-YE)
      IF (TSA.GT.XC) XC=TSA
      TSA = -D(1)
      IF (TSA.GT.XVMIN) XVMIN=TSA
   60 IF (IFG.NE.0) GO TO 120
C              CALCULATE FOREGROUND GLARE  FOR THREE POINTS AND STRAIGHT AHEAD
      RM = RC*AFT(M)
      X = XC+.5*DELX
      YLP = -D(2)
      YEP = -YE
   70 XLP = X
      XEP = X-CARD(2)+XE
      XLPS = XLP*XLP
      XEPS = XEP*XEP
      IF (IHV.NE.0) CALL CURVE(IHV,3,XLP,0.,D(2),TSA,YLP,RHO)
      IF (IHV.NE.0) CALL CURVE(IHV,3,XEP,0.,YE,TSA,YEP,RHO)
      YLPS = YLP*YLP
      YEPS = YEP*YEP
      Z = ZSTRT
   90 ZLP = Z-D(3)
      ZEP = Z+ZE
      TSA = XLP*W(1)+YLP*W(2)+ZLP*W(3)
      H = RTD*ATAN((XLP*W(4)+YLP*W(5)+ZLP*W(6))/TSA)
      V = RTD*ATAN((XLP*W(7)+YLP*W(8)+ZLP*W(9))/TSA)
      CALL INTAB(H,V,T)
      TSA = YEPS+ZEP*ZEP
      TSB = XLPS+YLPS+ZLP*ZLP
      TSC = XEPS+TSA
      TSE = T/TSC*RM/TSC/TSB
      TSB = ATAN((SQRT(TSA))/XEP)
      VGZ = VGZ+TSE/TSB*XEP/(TSB+.02618)
      DO 100 I=1,3
      TSD = XEP*SX(I)+YEP*SY(I)+ZEP*SZ(I)
      TSA = YEP*SX(I)-XEP*SY(I)
      TSB = ZEP*SX(I)-XEP*SZ(I)
      TSC = ZEP*SY(I)-YEP*SZ(I)
      TSF = ATAN((SQRT(TSA*TSA+TSB*TSB+TSC*TSC))/TSD)
  100 VG(I) = VG(I)+TSE/TSF*TSD/RS(I)/(TSF+.02618)
      IF (Z.GE.ZSTOP) GO TO 110
      Z = Z+DELZ
      GO TO 90
  110 IF (X.GE.XSTOP) GO TO 120
      X = X+DELX
      GO TO 70
C              CALCULATE INTENSITIES DIRECTED AT TARGET
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120 Y = YT-D(2)
    Z = ZT-D(3)
    DO 150 I=1,20
    X = XX(I,1)-XE
    IF (IHV.NE.0) CALL CURVE(IHV,3,X,YT,D(2),TSA,Y,RHO)
    IF (ICV.NE.0) CALL CURVE(ICV,3,X,ZT,D(3),TSA,Z,RHO)
    TSA = X*W(1)+Y*W(2)+Z*W(3)
    H = RTD*ATAN((X*W(4)+Y*W(5)+Z*W(6))/TSA)
    V = RTD*ATAN((X*W(7)+Y*W(8)+Z*W(9))/TSA)
    CALL INTAB(H,V,T)
150 ALX(I,M) = T*AFT(M)
    RETURN
C             PROCESS GLARE VEHICLE LAMP GEOMETRY
160 D(1) = 0.
    D(2) = CARD(3)/12.
    D(3) = CARD(4)/12.-ZCL
    E(2) = D(2)
    E(3) = D(3)
    IF (IHV.NE.1) GO TO 165
    DSGRZ = RHO*(ATAN((SQRT(D(2)*(D(2)+RHOT)))/RHO)+ATAN((SQRT(YE*(YE+
   1RHOT)))/RHO))
165 WRITE(5,9905)M,D(1), (CARD(I),I=3,4),M,(CARD(I),I=5,7),MM,JTITL
    GO TO 180
170 D(1) = CARD(2)/12.
    D(2) = E(2)+CARD(3)/12.
    D(3) = E(3)-CARD(4)/12.
    WRITE(5,9906)M,(CARD(I),I=2,4),M,(CARD(I),I=5,7),MM,JTITL
C             CALCULATE INTENSITIES DIRECTED AT EYE
180 N = M-5
    PO(N) = D(1)
    YGL(N) = D(2)
    ZGL(N) = D(3)
    Y = YE-D(2)
    Z = ZE+D(3)
    DO 220 I=1,20
    X = XX(I,2)
    IF (IHV.NE.0) CALL CURVE(IHV,1,X,YE,D(2),TSA,Y,RHO)
    IF (ICV.NE.0) CALL CURVE(-ICV,1,X,ZE,-D(3),TSA,Z,RHO)
    TSA = X*W(1)+Y*W(2)+Z*W(3)
    H = RTD*ATAN((X*W(4)+Y*W(5)+Z*W(6))/TSA)
    V = RTD*ATAN((X*W(7)+Y*W(8)+Z*W(9))/TSA)
    CALL INTAB(H,V,T)
    ALX(I,M) = T*AFT(M)
220 CONTINUE
    RETURN
C             PROCESS FOLLOWING VEHICLE LAMP GEOMETRY
230 IF (M.NE.11) GO TO 240
    XFA = CARD(2)
    YLA =  CARD(3)/12.
    ZLA = -CARD(4)/12.
    XFS = XFA
    YL = YLA
    ZL = ZLA
    WRITE(5,9904)XFS
9904 FORMAT (1H0'DISTANCE FROM EYE TO HEADLAMP NO. 11 IS'F7.1' FEET')
    TSA = 0.
```

```
      WRITE(5,9905)M,TSA,(CARD(I),I=3,4),M,(CARD(I),I=5,7),MM,JTITL
      GO TO 250
  240 XFS = XFA-CARD(2)/12.
      YL = YLA+CARD(3)/12.
      ZL = ZLA+CARD(4)/12.
      WRITE(5,9906)M,(CARD(I),I=2,4),M,(CARD(I),I=5,7),MM,JTITL
C                CALCULATE INTENSITIES DIRECTED AT MIRRORS
  250 X = XFS
      Y = YL-YE
      Z = ZL+ZF
      M = M-10
      IF (IHV.NE.0) CALL CURVE(IHV,1,X,YL,YE,TSA,Y,RHO)
      IF (ICV.NE.0) CALL CURVE(ICV,1,X,ZL,-ZE,TSA,Z,RHO)
      DO 310 N=1,2
      GM(M,N) = 0.
      IF (HD(N).EQ.0.) GO TO 310
      TSA = Q(2,N)*Y + Q(3,N)*Z
      TSD = P(1,N)/(2.*P(1,N)+Q(1,N)*X-TSA)
      DEL = (Q(9,N)*Z + Q(8,N)*Y - Q(7,N)*X)*TSD-P(3,N)
      EPS = (Q(6,N)*Z + Q(5,N)*Y - Q(4,N)*X)*TSD-P(2,N)
      TSB = (Q(2,N)*Q(2,N)+Q(3,N)*Q(3,N))*X
      TSE = P(1,N)*TSA+TSB
      IF (VD(N).GT.0.) GO TO 280
      IF (SQRT(EPS*EPS+DEL*DEL).GT.HD(N)) GO TO 310
      GO TO 290
  280 IF (ABS(EPS).GT.VD(N)) GO TO 310
      IF (ABS(DEL).GT.HD(N)) GO TO 310
  290 TSC = P(1,N)+Q(1,N)*X - TSA
      XM(M,N) = TSD*(2.*TSC*Q(1,N)-X)
      YM(M,N) = TSD*(2.*TSC*Q(2,N)+Y)
      ZM(M,N) = TSD*(2.*TSC*Q(3,N)+Z)
      TSD = TSC/(TSC+P(1,N))
      TSA = P(5,N)-Y
      TSB = P(6,N)-Z
      YB = TSD*(XB*TSA+Y*P(4,N)+X*P(5,N))
      ZB = TSD*(XB*TSB+Z*P(4,N)+X*P(6,N))
      IF (YB.GT.YBT) GO TO 300
      IF (ZB.GT.ZBR) GO TO 300
      IF (ZB.GT.ZBL) GO TO 310
  300 TSC = P(4,N)+X
      TSD = TSC*W(1)+TSA*W(2)+TSB*W(3)
      H = RTD*ATAN((TSC*W(4)+TSA*W(5)+TSB*W(6))/TSD)
      V = RTD*ATAN((TSC*W(7)+TSA*W(8)+TSB*W(9))/TSD)
      TSD = TSA*TSA+TSB*TSB
      CALL INTAB(H,V,T)
      TSA = TSC*TSC+TSD
      GM(M,N) = T/TSA*AFT(M+10)*TRS(N)*REFL(N)
  310 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE INTAR(H,V,T)
C              THIS SUBROUTINE INTERPOLATES TO FIND THE INTENSITY FOR A PAIR OF
C              HORIZONTAL AND VERTICAL ANGLES IN THE BEAM PATTERN. IT USES A
C              DOUBLE SECOND ORDER SCHEME NEAR THE HOTSPOT, SECOND ORDER IN ONE
C              DIRECTION AND FIRST ORDER IN THE OTHER NEAR RIDGES, AND DOUBLE
C              FIRST ORDER ELSEWHERE.
      COMMON DOS(88),DVIS(88),GLR(88),GV(88),DGI(88),DVMIN,DVDS,GVMAX,GV
     1DS,DVNG,GVG,GVF,GMI,GME,IMAX
      COMMON DSTRT,DSTOP,DSD,DST,DSDEL(3),XSTRT,XDEL,EK,FG(4),A(2),B(2),
     1ALX(2Ø,1Ø),XX(2Ø,2),XS,YS,ZS,PO(5),GSP(4),YE,ZE,YT,ZT,GM(5,2),XM(5
     2,2),YM(5,2),ZM(5,2),YGL(5),ZGL(5),RHO,XVMIN,LAMP(15),ILS,IEK,IGM,I
     3HV,ICV,DSGRZ,XVGRZ,ROOR
      COMMON DTR,RTD,XSTOP,ZSTRT,ZSTOP,DELX,DELZ,RHOS,RHOT,ZCL,XE,XB,YBT
     1,ZBR,ZBL,RC,SX(3),SY(3),SZ(3),RS(3),HD(2),VD(2),REFL(2),TRS(2),P(6
     2,2),Q(9,2),AFT(15),IFG
      COMMON HH,VV,IHA,IVA,AL(61,22),DH,DV
      DATA EPS/.ØØ1/
      JH = 1
      JV = 1
      KH = 1
      LV = 1
      M = Ø
      N = Ø
      TSE = 1.
      TSF = 1.
      IF (H.GE.HH) GO TO 1Ø
      K = 2
      I = 1
      JH = -1
      GO TO 3Ø
   1Ø I = 1 + (H-HH)/DH
      IF (I.GE.IHA) GO TO 2Ø
      K = I+1
      GO TO 3Ø
   2Ø I = IHA
      K = I-1
      JH = -1
      KH = -1
      TSE = -1.
   3Ø TSD = HH-DH+DH*I
      TSA = (H-TSD)/DH*TSE
      IF (V.GE.VV) GO TO 4Ø
      L = 2
      J = 1
      JV = -1
      LV = -1
      GO TO 6Ø
   4Ø J = 1 + (V-VV)/DV
      IF (J.GE.IVA) GO TO 5Ø
      L = J+1
      GO TO 6Ø
   5Ø J = IVA
      L = J-1
      JV = -1
      TSF = -1.
   6Ø TSD = VV-DV+DV*J
```

```
      TSB = (V-TSD)/DV
C               CHECK FOR EXTRAPOLATION
      IF (LV.LT.JH) GO TO 160
   64 IF (JH+JV) 65,120,80
C               DOUBLE EXTRAPOLATION
   65 TSC = AL(K,J)
      TSD = AL(I,J)
      TSG = AL(K,L)
      TSH = AL(I,L)
      TSE = TSC-TSD
      IF (ABS(TSG-TSE-TSH).LT.EPS) GO TO 75
      DAL = ((TSG-TSE-TSH)*TSA+TSH-TSD)*TSB+TSE*TSA
      IF (DAL.LE.0.) GO TO 70
      N = 1 + (VV-V)/DV
      M = 1 + (HH-H)/DH*KH + (KH-1)/2*(IHA-1)
      EN = N
      EM = M
      EL = (EM+EN)/2./EM/EN
      DAL = ((TSE+TSH-TSG)*EL*TSA+TSH-TSD)*TSB+TSE*TSA
      IF (DAL.LE.0.) GO TO 70
      T = 0.
      RETURN
   70 T = EXP(TSD+DAL)
      RETURN
   75 T = EXP(TSD)
      RETURN
C               CHECK FOR SECOND ORDER USE
   80 II = I
      IF (AL(I,J).LT.AL(K,J)) GO TO 90
      IF (I.EQ.1) GO TO 100
      IF (AL(I-1,J).GT.AL(I,J)) GO TO 100
      M = K
      K = I
      I = I-1
      TSA = TSA+1.
      GO TO 100
   90 IF (K.EQ.IHA) GO TO 120
      IF (AL(K+1,J).LT.AL(K,J)) M=K+1
  100 IF (AL(II,J).LT.AL(II,L)) GO TO 110
      IF (J.EQ.1) GO TO 120
      IF (AL(II,J-1).GT.AL(II,J)) GO TO 120
      N = L
      L = J
      J = J-1
      TSB = TSB+1.
      GO TO 120
  110 IF (L.EQ.IVA) GO TO 120
      IF (AL(II,L+1).LT.AL(II,L)) N=L+1
  120 TSC = 1.-TSA
      TSD = 1.-TSB
      IF (M+N.GT.4) GO TO 130
C               DOUBLE FIRST ORDER
      T = EXP(TSC*(TSD*AL(I,J)+TSB*AL(I,L))+TSA*(TSD*AL(K,J)+TSB*AL(K,L)
     1))
      RETURN
  130 TSE = 2.-TSA
```

```
      TSF = 2.-TSB
      IF (N.NE.2) GO TO 140
C                FIRST ORDER VERTICALLY, SECOND ORDER HORIZONTALLY
      TSC = TSC/2.
      T = EXP(TSE*TSC*(TSB*AL(I,L)+TSD*AL(I,J))+TSE*TSA*(TSB*AL(K,L)+TSD
     1*AL(K,J))-TSC*TSA*(TSB*AL(M,L)+TSD*AL(M,J)))
      RETURN
  140 IF (M.NE.2) GO TO 150
C                FIRST ORDER HORIZONTALLY, SECOND ORDER VERTICALLY
      TSD = TSD/2.
      T = EXP(TSF*TSD*(TSA*AL(K,J)+TSC*AL(I,J))+TSF*TSB*(TSA*AL(K,L)+TSC
     1*AL(I,L))-TSD*TSB*(TSA*AL(K,N)+TSC*AL(I,N)))
      RETURN
C                DOUBLE SECOND ORDER
  150 TSC = TSC/2.
      TSG = TSF*TSB
      TSF = TSF/2.*TSD
      TSD = -TSD/2.*TSB
      T = EXP(TSE*(TSA*(TSG*AL(K,L)+TSF*AL(K,J)+TSD*AL(K,N))+TSC*(TSG*AL
     1(I,L)+TSF*AL(I,J)+TSD*AL(I,N)))-TSC*TSA*(TSG*AL(M,L)+TSF*AL(M,J)+T
     2SD*AL(M,N)))
      RETURN
  160 IF (AL(I,J).LT.AL(I,L)) GO TO 64
      N = 3
      TSC = 1.-TSA
      TSD = (1.-TSB)/2.
      TSF = 2.-TSD
      T = EXP(TSF*TSD*(TSA*AL(K,J)+TSC*AL(I,J))+TSF*TSB*(TSA*AL(K,L)+TSC
     1*AL(I,L))-TSD*TSB*(TSA*AL(K,N)+TSC*AL(I,N)))
      IF (ALOG(T).GT..3+AL(I,J)) T=EXP(VV/V*AL(I,J))
      RETURN
      END
```

```
      SUBROUTINE GLARE(IDVIS)
C                THIS SUBROUTINE COMPUTES THE VISIBILITY DISTANCE, DISABILITY
C                GLARE AND DISCOMFORT GLARE INDEX DURING THE NIGHT MEETING.
      DIMENSION XG(5),YG(5),ZG(5),THM(5,2)
      DIMENSION GL(5),DLR(5)
      COMMON DDS(88),DVIS(88),GLR(88),GV(88),DGI(88),DVMIN,DVDS,GVMAX,GV
     1DS,DVNG,GVG,GVF,GMI,GME,IMAX
      COMMON DSTRT,DSTOP,DSD,DST,DSDFL(3),XSTRT,XDEL,EK,FG(4),A(2),B(2),
     1ALX(22,10),XX(22,2),XS,YS,ZS,PO(5),GSP(4),YE,ZE,YT,ZT,GM(5,2),XM(5
     2,2),YM(5,2),ZM(5,2),YGL(5),ZGL(5),RHO,XVMIN,LAMP(15),ILS,IEK,IGM,I
     3HV,ICV,DSGRZ,XVGRZ,RGDR
      IMAX = 0
      IANG = 0
      ISTOR = 0
      JSTOR = 0
      IDS = 1
      JDS = 0
      NGL = 0
      IDIS = 1
      GDM = 0.
      GMI = 0.
      GME = 0.
      EGIM = 0.
      EGDS = 0.
      PGOL = 0.
      PGVL = 0.
      GVMAX = 0.
      PX  = .1E10
      DVMIN = PX
      XVMIN = XVMIN+2.
      EPS = 1.0001
      DO 10 I=1,88
      DGI(I) = -2.109695
   10 GLR(I) = 0.
      X = XSTRT
      DS = DSTRT
      DELDS = DSD
      IGRZ = 0
      PI = 3.141593
  100 EO = EK
      XD = XDEL
      IGDS = 0
      DGID = 1.
C                CHECK EYE STATUS - READAPTATION, ADAPTATION, RECOVERY
      IF (IANG) 230,200,220
  200 IF (DS.GT.0.) GO TO 231
      GO TO 590
C                COMPUTE RECOVERY VEILING GLARE
  220 GDS = GDSA*EXP(EK*(DS-DSA))
      IGDS = 1
      GO TO 270
  230 IF (IEK.EQ.2) EO=EK*(1.+.4342945*ALOG((PGDS+PGOL)/(5.52+PGOL)))
      GDSR = PGDS*EXP(EO*(DS-PDS))
  231 IF (IHV.NE.1) GO TO 240
C                CHECK FOR GLARE VEHICLE BELOW CREST OF HILL
      IF (IGRZ.GT.0) GO TO 243
```

```
      PDS = DS
      IF (DS.GT.DSGRZ) GO TO 232
      IGRZ = IDIS
      DDS(IDIS) = DSGRZ
      PDS = DDS(IDIS-1)
      GO TO 233
  232 DDS(IDIS) = DS
  233 IF (JDS.EQ.1) GO TO 805
      IF (DS.GT.DST) GO TO 805
      JDS = 1
      DSD = DSDEL(1)
      GO TO 805
C               COMPUTE GLARE INTENSITIES DIRECTED AT EYE
  240 DO 241 I=1,20
      IF (DS-XX(I,2)) 242,245,241
  241 CONTINUE
      J = 19
      GO TO 244
  242 J = 1
      IF (I.GT.1) J=I-1
  244 K = J+1
      TSB = XX(J,2)
      TSD = (DS-TSB)/(XX(K,2)-TSB)
      GO TO 247
  245 J = I
      K = J
      TSD = 0.
  247 DO 260 I=6,10
      IF (LAMP(I).LE.0) GO TO 260
      L = I-5
      TSA = ALX(J,I)
      GL(L) = TSA+(ALX(K,I)-TSA)*TSD
      TSF = YGL(L)
      TSE = ZGL(L)
      TSA = PO(L)+DS
      TSB = TSF-YE
      TSC = TSE+ZE
      IF (IHV.NE.0) CALL CURVE(IHV,1,TSA,TSF,YE,XV,TSB,RHO)
      IF (ICV.NE.0) CALL CURVE(ICV,1,TSA,TSE,-ZE,XV,TSC,RHO)
      XG(L) = TSA
      YG(L) = TSB
      ZG(L) = TSC
      IF (IHV.NE.1) GO TO 255
      IF (DS.GT.DSGRZ) GL(L)=0.
  255 DLR(L) = XG(L)*XG(L)+YG(L)*YG(L)+ZG(L)*ZG(L)
  260 CONTINUE
  270 IXC = 0
  275 IX = 0
C               COMPUTE TOTAL INTENSITY DIRECTED AT TARGET FOR THIS TARGET DIST.
  280 TII = 0.
      DO 281 I=1,20
      IF (X-XX(I,1)) 282,282,281
  281 CONTINUE
      J = 20
      K = J-1
      GO TO 284
```

```
  282 J = 1
      IF (I-1) 284,284,283
  283 J = I-1
  284 K = J+1
      TSB = XX(J,1)
      TSC = (X-TSB)/(XX(K,1)-TSB)
      DO 300 I=1,5
      IF (LAMP(I).LE.0) GO TO 300
      TSA = ALX(J,I)
      TII = TII+TSA+(ALX(K,I)-TSA)*TSC
  300 CONTINUE
      Y = YT-YE
      Z = ZT+ZE
      XV = X
      IF (IHV.NE.0) CALL CURVE(IHV,4,X,YT,YE,XV,Y,RHO)
      IF (ICV.NE.0) CALL CURVE(ICV,4,X,ZT,-ZE,XV,Z,RHO)
      DV = SQRT(X*X+Y*Y+Z*Z)
      TSB = X-10.
C             COMPUTE FOREGROUND VEILING GLARE
      GOL = FG(1)
      IF (ILS.EQ.0) GO TO 320
      TSA = ATAN((SQRT((107.1111*X-292.2222)*X+1375.806))/(X*TSB-6.9375)
     1)
      TSA = ABS(TSA)
      GOL = FG(1)+(FG(2)*X-FG(3))*EXP(X/FG(4))
      XS = X
      YS = Y
      ZS = Z
      GO TO 325
  320 TSA = ATAN((SQRT((GSP(4)*TSB+GSP(2))*TSB+GSP(3)))/(TSB*XS-GSP(1)))
      TSA = ABS(TSA)
  325 GSI = (TSB*TSB+85.5625)*TSA*(TSA+.02618)
      IF (GS.LE.0.) GO TO 355
      IF (IGDS.LE.0) GDS=0.
      DGID = 0.
C             COMPUTE GLARE VEHICLE VEILING GLARE
      DO 350 I=1,5
      J = I+5
      IF (LAMP(J).LE.0) GO TO 350
      TSA = XS*YG(I)-YS*XG(I)
      TSB = XS*ZG(I)-ZS*XG(I)
      TSC = YS*ZG(I)-ZS*YG(I)
      TSD = ATAN((SQRT(TSA*TSA+TSB*TSB+TSC*TSC))/(XS*XG(I)+YS*YG(I)+ZS*Z
     1G(I)))
      TSD = ABS(TSD)
      TSB = 3437.747*TSD
      TSA = GL(I)/DLF(I)
      DGID = DGID + TSA/TSB**.46
      IF (IGDS.GT.0) GO TO 350
      GDS = GDS + TSA/TSD/(TSD+.02618)
  350 CONTINUE
  355 IF (IGM.EQ.0) GO TO 370
      GDM = 0.
      DGIM = 0.
C             COMPUTE FOLLOWING VEHICLE VEILING GLARE
      DO 360 I=1,5
```

```
      IF (LAMP(I+10).LE.0) GO TO 360
      DO 360 J=1,2
      IF (GM(I,J).EQ.0) GO TO 360
      TSA = XS*YM(I,J)-YS*XM(I,J)
      TSB = XS*ZM(I,J)-ZS*XM(I,J)
      TSC = YS*ZM(I,J)-ZS*YM(I,J)
      TSD = ATAN((SQRT(TSA*TSA+TSB*TSB+TSC*TSC))/(XS*XM(I,J)+YS*YM(I,J)+
     1ZS*ZM(I,J)))
      TSD = ABS(TSD)
      TSB = 3437.747*TSD
      TSA = TSD*(TSD+.02618)
      THM(I,J) = TSA
      GDM = GDM+GM(I,J)/TSA
      DGIM = DGIM + GM(I,J)/TSB**.46
  360 CONTINUE
C               COMPUTE TOTAL ACTUAL VEILING GLARE AND ADJUSTED GLARE INTENSITY
C               FOR OBSERVER RELATION
  370 GVL = GDS+GDL+GDM
      GI = GSI*GVL
      TSC = SQRT(GI)
      TSA = A(1)+A(2)*SQRT(TSC)
      TSB = B(1)+B(2)*TSC
C               COMPUTE INTENSITY NEEDED TO SEE TARGET
      TJ = EXP(TSA+TSB*DV)
      R = TII-TJ
      CALL CONVF(IX,J,X,R,GVL,XD)
C               CHECK WHETHER TARGET IS JUST VISIBLE AND INCREMENT TARGET DISTANCE
C               IF NECESSARY
      IF (J-2) 410,440,380
  380 GO TO (400,590,590,400),IDS
  400 IF (IDIS.GT.1) GO TO 405
      X = X/2.
      GO TO 270
  405 INVIS = INVIS + 1
      IF (INVIS.GT.1) RETURN
      WRITE(5,9994)DS,XV
 9994 FORMAT (1H0,' TARGET INVISIBLE AT DS = 'F6.0' FEET, CLOSEST TO VISI
     1BILITY AT X = 'F6.1' FEET')
      IF (DSL.NE.0) RETURN
      DSD = DFLDS
      GO TO 815
  410 IF (X-XVMIN) 420,420,280
  420 X = XVMIN
      IF (IXC) 815,430,815
  430 IXC = 1
      IF (INVIS.NE.0) RETURN
      WRITE(5,9997)IDIS
 9997 FORMAT (1H0,' TRIAL TARGET POSITION BEHIND HEADLIGHT AT IDIS ='I4)
      GO TO 280
  440 GDL = FG(1)+(FG(2)*X-FG(3))*EXP(X/FG(4))
      GDS = GVL-GDL-GDM
      XV = X
C               COMPUTE BACKGROUND LUMINANCE FOR DISCOMFORT GLARE INDEX
      ELU = RHOR/PI*TII/DV/DV
      IF (IHV.NE.0) CALL CURVE(IHV,2,X,YT,0.,XV,TSA,RHO)
      IF (ICV.NE.0) CALL CURVE(ICV,2,X,ZT,0.,XV,TSA,RHO)
```

```
      IF (NGL) 45Ø,45Ø,85Ø
  45Ø IF (JDS) 48Ø,48Ø,5ØØ
C                 CHECK TO CHANGE SEPARATION DISTANCE INCREMENT
  48Ø IF (DS-DST) 49Ø,49Ø,5ØØ
  49Ø JDS = 1
      DSD = DSDEL(1)
C                 CHECK EYE STATUS
  5ØØ IF (IANG) 51Ø,55Ø,7ØØ
  51Ø IF (DS) 82Ø,82Ø,52Ø
C                 CHECK FOR TRANSITION TO RECOVERY
  52Ø IF (GDS-GDSR) 53Ø,67Ø,67Ø
  53Ø J = IDIS-1
      IANG = J
      DSA = PDS
      GDSA = PGDS
      TSA = EK
      IF (IEK.EQ.Ø) EK = TSA*(1.+.4342945*ALOG((GDSA+GOL)/(5.52+GOL)))
      XD = XDEL
      X = PX
      DSD = DSDEL(1)
      ISTOR = Ø
      DS = DDS(J)-DSD
      GO TO 22Ø
C                 CHECK FOR TRANSITION TO READAPTATION
  55Ø IF (PGVL/GVL.LE.EPS) GO TO 68Ø
  59Ø IDS = IDS+1
      K = IDS-1
      GO TO (6ØØ,63Ø,65Ø),K
  6ØØ IF (JDS) 61Ø,61Ø,62Ø
  61Ø JDS = 1
      JSTOR = DSD/DSDEL(1)-.5
      KST = 5
      KSTOR = KST
  62Ø GLR(IDIS) = Ø.
  63Ø ISTOR = 1
      DSD = DSDEL(IDS)
      GO TO 81Ø
  65Ø IF (DS-DSDEL(2)) 651,651,652
  651 DSD = DSDEL(3)
      KSTOR=DSDEL(2)/DSDEL(3)+.1
      GO TO 653
  652 DSD = DSDEL(2)
      KSTOR=DSDEL(1)/DSDEL(2)+.1
  653 JSTOR = -1
      IANG = -1
      KST = KSTOR
      J = DS/DSD
      DS = J*DSD
      ISTOR = DDS(IDIS-1)/DSD-J+.5
      IF (KSTOR.GT.5) ISTOR=KSTOR-J
      GVG = GDS
      GVF = GOL
      IF (IGM.EQ.Ø) GO TO 1ØØ
      DO 665 I=1,5
      IF (LAMP(I+1Ø).LE.Ø) GO TO 665
      IF (GM(I,1).EQ.Ø.) GO TO 664
```

```
      GMI = GMI+GM(I,1)/THM(I,1)
  664 IF (GM(I,2).EQ.0.) GO TO 665
      GME = GME+GM(I,2)/THM(I,2)
  665 CONTINUE
      GO TO 100
  670 IF (GVMAX-GVL) 680,685,685
  680 GVMAX = GVL
      GVDS = DS
  685 IF (XV.GT.DVMIN) GO TO 700
      DVMIN = XV
      DVDS = DS
  700 PGDS = GDS
      PGDL = GDL
      PGVL = GVL
      PDS = DS
      PX = X
C               STORE DATA FOR OUTPUT
      IF (ISTOR) 760,760,720
  720 IF (IDS-4) 810,730,810
  730 IF (JSTOR) 740,810,740
  740 ISTOR = ISTOR+1
      IF (ISTOR-KSTOR) 810,810,750
  750 JSTOR = JSTOR-1
      KSTOR = KSTOR+KST
  760 DVIS(IDIS) = XV
      IF (IHV.NE.1) GO TO 765
      IF (XV.GT.XVGRZ) DVIS(IDIS)=XVGRZ
  765 DDS(IDIS) = DS
      GV(IDIS) = GVL
      IF (IGDS.GT.0) GO TO 795
      DO 790 I=1,5
      IF (LAMP(I+5)) 790,790,780
  780 GLR(IDIS) = GLR(IDIS)+GL(I)
  790 CONTINUE
  795 IF (DS.LE.0.) GO TO 800
      IF (DGID+DGIM.LE.0.) GO TO 800
      DGI(IDIS) = 2.*ALOG10(1.+269.0966*ELU)-2.*ALOG10(DGID+DGIM)-2.1097
  800 IF (DS-DSTOP) 830,840,805
  805 IDIS = IDIS+1
      IF (IDIS.GT.88)  GO TO 830
C               DECREASE SEPARATION DISTANCE
  810 DS = PDS-DSD
      GO TO 100
  815 IGDS = 1
      X = XSTRT
      XD = XDEL
  820 IMAX = IDIS-1
      IANG = IMAX
      GO TO 840
  830 IMAX = IDIS-1
C               SET UP CONDITIONS FOR NO GLARE VISIBILITY DISTANCE
  840 GDS = 0.
      NGL = 1
      GO TO 275
  850 DVNG = XV
      IF (IMAX.EQ.0) IMAX=IDIS

      IF (IHV.NE.1) RETURN
      DO 860 I=1,IGRZ
      DVIS(I) = DVNG
      IF (DVNG.GT.XVGRZ) DVIS(I)=XVGRZ
  860 GV(I) = GVL
      RETURN
      END
```

```
      SUBROUTINE CONVR(I,J,X,R,G,XD)
C              THIS SUBROUTINE CHECKS WHETHER THE TARGET IS JUST VISIBLE AND
C              DETERMINES WHETHER THE TARGET SHOULD BE MOVED CLOSER OR FARTHER.
      DATA XMIN/1./
      T = R
      IF (R) 120,290,130
  120 RTOP = R
      XTOP = X
      GTOP = G
      IF (I.LE.0) GO TO 135
      ITOP = ITOP+1
      IF (IBOT.EQ.ITOP) K=0
      GO TO 135
  130 RBOT = R
      XBOT = X
      GBOT = G
      IF (I.LE.0) GO TO 135
      IBOT = IBOT+1
      IF (IBOT.EQ.ITOP) K=0
  135 IF (I) 180,140,150
  140 K = 0
      ITOP = 0
      IBOT = 0
      GO TO 270
  150 IF (R*PR) 160,290,190
  160 IF (K) 190,170,170
  170 I = -1
  180 XD = XD*.5
      IF (XD-XMIN) 280,275,275
  190 IF (R) 200,290,260
  200 S = (R-PR)/(X-PX)
      IF (S) 210,300,220
  210 K = 1
      GO TO 230
  220 K = -1
      T = S
  230 IF (I-1) 140,250,240
  240 IF (S*PS) 300,300,250
  250 PS = S
  260 PPR = PR
  270 I = I+1
  275 PR = R
      PX = X
      X = PX+SIGN(XD,T)
      J = 1
      RETURN
  280 TSA = RBOT/(RBOT-RTOP)
      X = XBOT+(XTOP-XBOT)*TSA
      G = GBOT+(GTOP-GBOT)*TSA
  290 J = 2
      RETURN
  300 TSA = XD/2.*(3.*R-4.*PR+PPR)/(R-2.*PR+PPR)
      X = X+SIGN(TSA,S)
      J = 3
      RETURN
      END
```

```
      SUBROUTINE OUTPUT(DTRS)
C                THIS SUBROUTINE PRINTS THE RESULTS.
      COMMON DDS(88),DVIS(88),GLR(88),GV(88),DGI(88),DVMIN,DVDS,GVMAX,GV
     1DS,DVNG,GVG,GVF,GMI,GME,IMAX
      DO 490 I=1,IMAX
  490 GV(I) = DTRS*GV(I)
      GVMAX = GVMAX*DTRS
      GVG = GVG*DTRS
      GVF = GVF*DTRS
      GMI = GMI*DTRS
      GME = GME*DTRS
      IHLF = (IMAX+1)/2
      IDEL = IHLF - IMAX/2
      WRITE(5,9996)
 9996 FORMAT (1H ,2('SEPARATION VISIBILITY  VEILING'5X'GLARE   DISCOMFOR
     1T  ')/1H ,2(' DISTANCE   DISTANCE    GLARE'4X'INTENSITY   GLARE'5X
     2)/1H ,2('  (FEET)'5X'(FEET)  (FT.LAMB.) (CANDELAS)   INDEX'5X)/)
      DO 500 I=1,IHLF
      J = I+IHLF-IDEL
  500 WRITE(5,9995)DDS(I),DVIS(I),GV(I),GLR(I),DGI(I),DDS(J),DVIS(J),GV(
     1J),GLR(J),DGI(J)
 9995 FORMAT (1H ,2(F7.0,F11.1,F12.5,F10.1,F9.1,6X))
      WRITE(5,9807)DVMIN,DVDS
 9807 FORMAT ('0MINIMUM VISIBILITY DISTANCE IS ',F6.1,' FEET AT A SEPARA
     1TION OF ',F5.0,' FEET')
      WRITE(5,9808)DVNG,GVMAX,GVDS
 9808 FORMAT (1H 'VISIBILITY DISTANCE FOR NO GLARE CAR IS'F7.1' FEET. MA
     1XIMUM VEILING GLARE IS'F8.5' FT.C AT A SEPARATION OF'F6.0' FEET.')
      WRITE(5,9809)GVG,GVF
 9809 FORMAT (' COMPONENTS OF MAXIMUM VEILING GLARE ARE'F8.5' FROM OPPOS
     1ING CAR AND'F8.5' FROM FOREGROUND')
      IF (GMI+GME.GT.0.)WRITE(5,9806)GMI,GME
 9806 FORMAT (36X' AND'F8.5' FROM INTERIOR'5X    'AND'F8.5' FROM EXTERIO
     1R MIRROR')
      WRITE(5,9992)
 9992 FORMAT (' GLARE INTENSITY AND INDEX ARE NOT CALCULATED DURING RECO
     1VERY. VEILING GLARE IS ACTUAL VALUE DIVIDED BY THE FACTOR K.')
      RETURN
      END
```

```
C     --------------------------- PROGRAM BEMPAT ----------------------
C              THIS PROGRAM READS THE BEAM PATTERNS OFF CARDS AND WRITES THEM
C              INTO A DISC FILE. THERE MAY BE A TOTAL OF TEN DIFFERENT BEAM
C              PATTERNS STORED IN THE DISC FILE AT ONE TIME.
      DIMENSION AL(61,22),ITITL(21),DUM(22),DAT(3)
      COMMON IFPR
      DATA BLANK/' '/
      CALL SETFIL(11,'JBEAM',IERR,'DK',1)
      DEFINE FILE 11(10,2716,U,N1)
      KFILE=11
      IPR=5
      IRD=8
      DO 2  I=1,3
    2 DAT(I)=BLANK
      CALL DATE(DAT)
      READ(IRD,9999)MN,IPT
 9999 FORMAT (3I5,3E5.0,21A2,E8.0)
      N = 0
  120 READ(IRD,9999)M,K,L,H,V,D,ITITL,FILT
      N = N+1
      DV = D
      DH = D
      IF (D) 122,122,123
  122 DV = -D
      DH = 2.*DV
  123 DUM(1) = V
      DO 130 J=2,L
  130 DUM(J) = DUM(J-1)+DV
      MH = K
      MV = L
      IF (L-14) 132,132,131
  131 MV =1.1-V/DV
      IF (MV.GT.14) MV=14
  132 IF (K-51) 134,134,133
  133 MH =1.1-H/DH
  134 DO 140 I=1,K
  140 READ(IRD,9998)(AL(I,J),J=1,L)
      IF (FILT) 250,143,141
  141 DO 142 I=1,K
      DO 142 J=1,L
  142 AL(I,J) = FILT*AL(I,J)
  143 WRITE(IPR,9997)M,ITITL,DAT
 9997 FORMAT (1H1,3X'BEAM PATTERN NO.'I3' FOR '21A2,2X,3A4        //1H '
     1HORIZONTAL      VERTICAL ANGLES')
      WRITE(IPR,9992)(DUM(J),J=1,MV)
 9992 FORMAT (1H 'ANGLE'14F9.1)
      TSA = H
      DO 150 I=1,MH
      WRITE(IPR,9995)TSA,(AL(I,J),J=1,MV)
  150 TSA = TSA+DH
      IF (MH-K) 151,160,160
  151 WRITE(IPR,9997)M,ITITL,DAT
      WRITE(IPR,9992)(DUM(J),J=1,MV)
      TSA = TSA-DH
      DO 152 I= MH,K
      WRITE(IPR,9995)TSA,(AL(I,J),J=1,MV)
```

```
  152 TSA = TSA+DH
  16Ø IF (MV-L) 161,17Ø,17Ø
  161 WRITE(IPR,9997)M,ITITL,DAT
      WRITE(IPR,9992)(DUM(J),J=MV,L)
      TSA = H
      DO 162 I=1,MH
      WRITE(IPR,9995)TSA,(AL(I,J),J=MV,L)
  162 TSA = TSA+DH
      IF (MH-K) 163,17Ø,17Ø
  163 WRITE(IPR,9997)M,ITITL,DAT
      WRITE(IPR,9992)(DUM(J),J=MV,L)
      TSA = TSA-DH
      DO 164 I=MH,K
      WRITE(IPR,9995)TSA,(AL(I,J),J=MV,L)
  164 TSA = TSA+DH
 9998 FORMAT (11E7.Ø,3X)
 9995 FORMAT (1H ,F5.1,2X,14F9.1)
  17Ø IF (IPT) 19Ø,18Ø,19Ø
  18Ø DO 185 I=1,K
      DO 185 J=1,L
  185 AL(I,J) = ALOG(AL(I,J)+.Ø1)
      WRITE(KFILE'M )H,V,D,K,L,ITITL,((AL(I,J),J=1,L),I=1,K)
  19Ø IF (M-MK) 12Ø,25Ø,25Ø
  25Ø CALL FXIT
      END
```

APPENDIX 2

USER'S MANUAL FOR THE COMPUTER SIMULATION TO PREDICT THE VISIBILITY DISTANCE PROVIDED BY HEADLAMP BEAMS

It is well known that visibility is much reduced in night driving due to glare from oncoming vehicles and other sources. Field test studies have been done but have the disadvantages of being time-consuming, expensive and highly non-repeatable. It was therefore desirable to develop a computer program which would incorporate as many of the variables which affect night visibility as possible. This program was developed at the Highway Safety Research Institute under contract number UM7204-C128 from the Motor Vehicle Manufacturers Association and is fully described in Report No: UM-HSRI-HF-73-15; "Development of a Computer Simulation to Predict the Visibility Distance Provided by Headlamp Beams" by Rudolf G. Mortimer and Judith M. Becker. The program has been subsequently revised and enlarged to include glare from a following vehicle's headlamps as reflected in interior and exterior mirrors and to allow curved road geometry in one direction; i.e., a hill, a valley, an inside or an outside curve, as described in the body of this report. This preliminary version of the user's manual consists of a detailed description of the input cards, an explanation of the diagnostic statements produced by the program, a description of the output, and a very short description of the program itself. It is intended that, with its help, the user will be able to make up his own input data cards and run the program.

The input cards all have the same layout or format, except for the card which immediately follows the T card. This format consists of a letter for identification in column one, a real number in columns two through ten, and seven more real numbers in the next seven groups of ten columns each. In programming terms, this format is described as: A1, E9.0, 7E10.0. It does not matter where in the group of nine or ten columns the decimal point appears, but it must be present. A group of columns is called a field, and they are numbered for each reference consecutively from one to eight across the card. Thus, field one has nine columns, while fields two through eight each have ten columns. Each input card can thus contain up to eight pieces of input data, the nature of which is determined by the identification letter, referred to as ID. For each field of each card there is given in

Table 1 the definition of the piece of input data, its default value (if any) and its units (if pertinent). The default value is the value the datum will have if the user does not specify a value.

The diagnostic statements will be produced by the program as needed. The first can be prevented by care in making up the input cards. The others generally are the result of the approximate nature of the foreground glare calculation. Sometimes use of card S to make the first eye line-of-sight closer to the eye (say 50 ft instead of the default value of 100 ft) will improve things enough to allow the program to run.

ILLEGAL CARD SKIPPED. This comment indicates the presence of an input card with some sort of error in the data.

TRIAL TARGET POSITION BEHIND HEADLIGHT AT IDIS = ______

This comment indicates that the target is not visible at all. It is printed the first time the situation occurs, then the trial target position is reset to be in front of the headlight and a switch is set. If the situation occurs a second time during the calculations for the same separation distance, the program will be terminated and the results up to and including the preceeding separation distance will be printed and plotted.

TARGET INVISIBLE AT DS = _____ FEET, CLOSEST TO VISIBILITY AT X = _____ FEET

This comment means that there is no region of visibility for the target at this separation distance. When it occurs, the program will be terminated and the results printed and plotted.

Note that the last two comments indicate essentially the same condition. They are often the results of excessive foreground glare for targets close to the vehicle.

FOREGROUND GLARE DATA BAD

This comment means that the foreground glare increases exponentially with target distance instead of approaching some value asymptotically. It sometimes indicates an error in the beam pattern intensity values.

TABLE 1.

ID	Field	Definition	Default Value	Units
T	-	Trigger for title card reading	-	-
		(title may be 80 characters long, including spaces, and should be centered on the card)		
A	1	Initial separation distance	4000	feet
	2	Final separation distance	-1000	feet
	3	First separation distance interval	200	feet
	4	Last separation distance at which first interval will be used	1500*	feet
	5	Second separation distance interval	50	feet
	6	Radius of curvature	-	feet
	7	Hill/valley indicator; +1=hill, -1=valley	0	-
	8	Curve indicator; +1=inside, -1=outside	0	-
B	1	Road reflectivity	10	%
	2	Basic target reflectivity	10	%
	3	Nominal eye threshold recovery rate	.251504	sec^{-1}
	4	Observer relation coefficient parameters	3.4	-
	5		.36	-
	6		.016	-
	7		.00008	-
S	1	X-component of first eye line-of-sight for foreground glare calculation with target tracking	100	feet
	2	X-component of fixed eye line-of-sight	--	feet
	3	Y-component of fixed eye line-of-sight	--	feet
	4	Z-component of fixed eye line-of-sight	--	feet

*If input is zero, this will be set to smaller of half of initial distance and 1500

TABLE 1 (Cont.)

ID	Field	Definition	Default Value	Units
C	1	Lateral distance between vehicle centerlines	-	feet
	2	Main vehicle speed	-	mph
	3	Glare vehicle speed	-	mph
	4	Forward distance from eye to lamp #1, positive for eye behind lamp	-	inches
	5	Vertical distance from eye to road, positive for eye above road	-	inches
	6	Lateral distance from eye to vehicle centerline, positive for eye to left	-	inches
	7	Vertical distance from target to road, positive for target above road	-	inches
	8	Lateral distance from target to vehicle centerline, positive for target to right	-	inches
G	1-4	Foreground glare coefficients; default values will be calculated by program		
M	1	Mirror index: 1=interior, 2=exterior	-	-
	2	Distance from lamp plane to mirror, positive for mirror behind lamps	-	inches
	3	Distance from road to mirror, positive for mirror above road	-	inches
	4	Distance from vehicle centerline to mirror, positive for mirror to right	-	inches
	5	Mirror reflectivity	1	-
	6	Shape indicator: 0=circular, 1=rectangular	-	-
	7	Transmissivity of associated window	1	-
O	1	Mirror index: 1=interior, 2=exterior	-	-
	2	Lateral dimension of mirror	0	inches
	3	Vertical dimension of mirror	0	inches
	4	Distance from road to mirror center aim point, positive for point above road	-	inches
	5	Distance from vehicle centerline to mirror center aim point, positive for point to right	-	inches
	6	Distance from eye to mirror center aim point, positive for point behind eye	30	feet

TABLE 1 (Cont.)

ID	Field	Definition	Default Value	Units
P	1	Mirror index: 1=interior, 2=exterior	-	-
	2	Distance from road to lower edge of field of view, positive for edge above road	-	inches
	3	Distance from road to upper edge of field of view, positive for edge above road	-	inches
	4	Distance from vehicle centerline to right side of field of view, positive for side to right	-	inches
	5	Distance from vehicle centerline to left side of field of view, positive for side to right	-	inches
	6	Distance from eye to field of view, positive for field behind eye	30	feet
	7	Fractional error allowed in aim	.01	-
V	1	Distance from lamp plane to vehicle obstructing plane, positive for plane behind lamps	154	inches
	2	Distance from road to top of obstructing plane, positive up	37	inches
	3	Distance from vehicle centerline to right side of obstructing plane, positive to right	32	inches
	4	Distance from vehicle centerline to left side of obstructing plane, positive to right	-32	inches
X	1	Not used		
	2	Longitudinal distance from eye to farthest edge of pavement area for foreground glare calculation, positive down the road	200	feet
	3	Lateral distance from eye to leftmost edge of pavement area, positive to right	-8	feet
	4	Lateral distance from eye to rightmost edge of pavement area, positive to right	8	feet
	5	Longitudinal increment	10	feet
	6	Lateral increment	2	feet

TABLE 1 (Cont.)

ID	Field	Definition	Default Value	Units
Y	1	Lamp index if 1-10; 0 means windshield analyzer	-	-
	2	Transmissivity parallel to filter axis	-	-
	3	Transmissivity perpendicular to filter axis	-	-
	4	If 1-10, angle of polarization axis relative to analyzer axis; otherwise not used	-	degrees
Z	1	Not used	-	-
	2	Initial estimate of visibility distance	200	feet
	3	Initial visibility distance interval	8	feet
	4	Target reflectivity	10	%
	5	Not used	-	-
	6	Not used	-	-
	7	EK reset switch; 0 means yes, otherwise no	0	-
D	1	Lamp index: 1-6 main, 7-10 glare, 11-15 following vehicles	-	-
	2	M=1, 6; not used M=11; distance from eye to lamp, positive for lamp following eye	-	feet
		M=2-5,7-10, 12-15; forward distance from reference lamp (#1,6,11) to lamp #M, positive if lamp in front of local reference lamp	-	inches
	3	M=1,6,11; distance from road to lamp	-	inches
		M=2-5, 7-10, 12-15; vertical distance from reference lamp to lamp #M, positive for lamp above reference	-	inches
	4	M=1, 6, 11; distance from vehicle centerline to lamp	-	inches
		M=2-5, 7-10, 12-15; lateral distance from reference lamp to lamp #M, positive for lamp to own right of reference	-	inches
	5	Vertical misaim angle, positive up	-	degrees
	6	Horizontal misaim angle, positive to right	-	degrees
	7	Rotational misaim angle, positive counter-clockwise	-	degrees
	8	Beam pattern index in disk file	-	-
L	1	Multiple data set indicator; 0 or blank means no, otherwise yes		

TABLE 1 (Concl.)

Notes:

1) For best results, cards should be ordered as follows:

T A B S C G M O P V X Y Z D L

2) Cards A, B and X may be omitted if the default values are satisfactory

3) For any lamp not in use, omit its D and Y cards

4) Cards O and P should not be used in the same data set as they are alternate methods of computing the same data

5) For non-polarized beams without an analyzer, omit all Y cards

6) If analyzer is used, then Y cards for all lamps in use must be included. If any lamp in use does not have a filter, inputs of 1., 1., 0. in fields 2-4 of its Y card are required.

7) If analyzer is not used, but some lamps do have filters, then inputs of 1., 1. in fields 2 and 3 of the Y card for M=0 are required

8) Non-polarized filters can be simulated by putting the transmissivity in field 2, zero in field 3, and 90. in field 4.

   (Even fictitious filters with transmissivities greater than one can be simulated.)

9) Card S is omitted if target tracking is desired.

10) For multiple data set runs, any card that duplicates a card in the previous data set may be omitted.

11) Card G is normally omitted

12) For any mirror not used, omit its M and O or P cards.

13) For straight road, omit fields 6, 7 and 8 on card A

14) If the hill/valley indicator input is nonzero, then the curve indicator will not be read and will default to zero; i.e., curves can only be done in one direction at a time.

The output for a run with one data set consists of two or more pages of printing. Page one contains a printout of the important pieces of input data, including those which are using their default values. The first line contains a general title, the date and the page number. The second line of printing just says "INPUT DATA." The third line is the title as supplied by the user. (If no title is supplied, a blank line will be printed.) Cards S, V, G and Y (if used) will be printed when read. If mirror orientation is specified by the user, it will be printed next, along with mirror location, reflectivity and the transmissivity of the appropriate window (rear for interior, side for exterior). If mirror orientation is specified by the desired field of view, the dimensions of each field of view will be printed next, followed by mirror location, orientation, reflectivity and window transmissivity. If the target reflectivity is to be other than the basic value, it will be printed. Then comes the printout of the observer relation coefficient parameters, the basic target reflectivity and the nominal eye recovery rate parameter. Then comes the distance between the vehicle centerlines, the vehicle velocities, the eye position relative to the origin, and the location of the target. Next is printed a description of the pavement area to be used in the foreground glare calculation and its reflectivity.

Then comes the printout of the initial and final separation distance values. There may be a maximum of 88 of these points processed per run. Then the data for the various lamps in use will be printed: location, misaim, and the name of beam used. For each lamp associated with the following vehicle for mirror glare, the image intensity and location relative to the eye are printed. Then finally, the values of the foreground glare coefficients as calculated by the program will be printed out.

Page two has the same general title, date and its own page number, then the words "OUTPUT DATA," then the user's title.

Then it prints headings for separation distance, visibility distance, veiling glare (disability), and the glare intensity directed at the eye from the opposing vehicle's lamps, summed over all the lamps in use. Then the data as calculated by the program is printed out in the proper places. Next comes some special data, which may or may not appear in the tabulated data, and several comments.

These two pages will be produced for each data set included in the run.

If curved roads are being simulated, then the separation distance and the visibility distance become arc lengths rather than straight line distances. In any case, one could think of both these distances as the distance measured on the main vehicle's odometer (in the proper units) needed to bring the glare vehicle reference lamp or the target, respectively, into line with the driver's eye.

The program was originally derived for an IBM-1800 computer. Due to the small core size of this computer, the program was divided into five links. The first three processed the input, the fourth did the calculations, and the fifth printed and plotted the output. The two plots were produced by a Calcomp plotter. At the bottom was the user's title, page 3, and the date. The first plot had the glare intensity and the veiling glare plotted against separation distance. The second had visibility distance versus separation distance. This program is now operational on a DEC PDP 11-45 computer equipped with Fortran 6 as a main program with four major subroutines, but without the plotting facility. Card decks for the Fortran source programs for both computers can be available. The IBM-1800 version does not have the mirror glare option or the curved road geometry option.

Before the Headlight Visibility Performance Evaluation Simulation program can be run, the beam patterns to be used must be written into a disk file by a separate program, which is also available.

The first input data card specifies the number of beam patterns to be written into the disk file. A maximum of ten may be done at one time; i.e., the disk file is large enough to hold ten different beam patterns. Five columns are allowed for this number, which is an integer. Thus, for one through nine different beam patterns, the appropriate integer appears in column five. For ten, put a "1" in column four and a "0" in column five. Then comes a card describing the beam pattern, as follows: first, the index of the beam (1 through 10) in the first five columns (integer, as above); second, the number of horizontal angle points in the beam pattern, with a maximum value of 61 in columns 6-10 (integer); third, the number of vertical angle points, with a maximum value of 22 in columns 11-15 (integer); fourth, the value of the leftmost (most negative) horizontal angle in degrees (real) in columns 16-20; fifth, the value of the lowest (most negative) vertical angle in degrees (real) in columns 21-25; sixth, the value of the angle increment (degrees real) in columns 26-30; seventh, a description in words of the beam pattern in columns 31-72; eighth, the value of any constant filter factor to be applied across the beam as a decimal fraction (real) in columns 73-80. Then come the cards bearing the values of the beam pattern headlight intensity for the various angle pairs. Starting with the leftmost horizontal angle, there will be one or two cards giving the intensity values in candelas for each vertical angle, starting with the lowest. The intensity values are real numbers with decimal points occupying seven columns each across the card. Thus, there will be eleven values on the first card, with three columns unused at the end, and the same on the second. Each horizontal angle has its own pair of cards.

APPENDIX 3

ERRATA FOR REPORT NO. UM-HSRI-HF-73-15

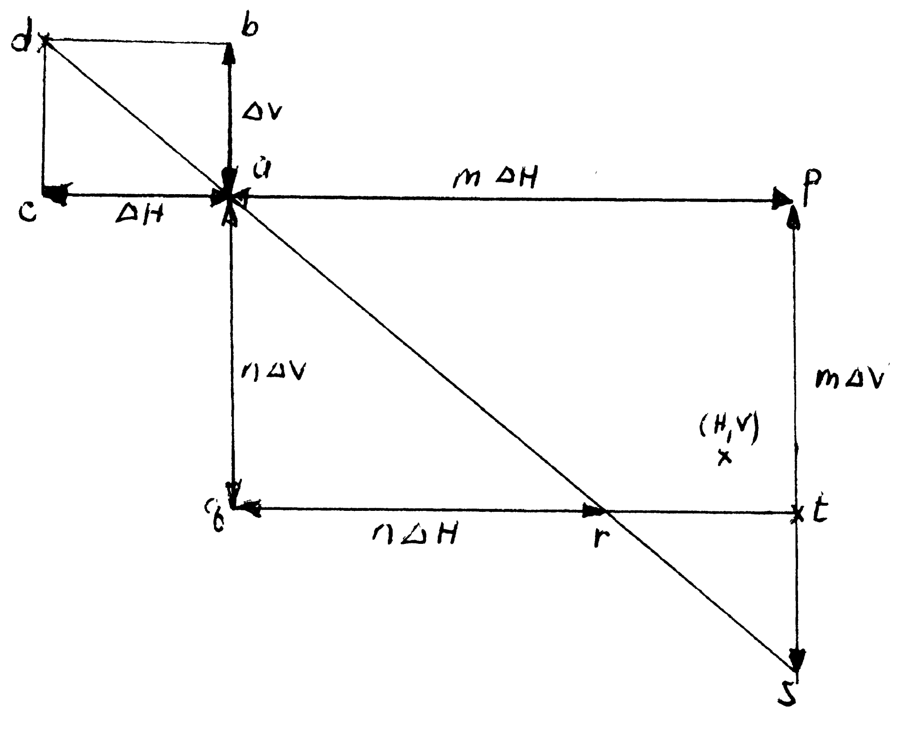
Appendix 3:

Errata for Report No.: UM-HSRI-HF-73-15

On page 4, it is stated that each lamp may be switched off or on twice at specified distances. This ability has been deleted from the program due to the fact that, whenever a lamp on the main vehicle is switched the foreground glare should be completely recalculated. This was deemed not feasible at the present. If interest is expressed in this feature, it could be worked out and added.

There is a misprint on p. 10 in the last equation. The last argument (subscript) should be a 1 not a 2.

On page 11, the calculation of the fourth point is now different. The following sketch depicts the conditions. Log inten-



sity values p and q have been calculated from values a and c and a and b, respectively, as before. Now values r and s are calculated from a and d, and used to predict two values for t. (One value uses r and q; the other uses s and p.) Then the average of these two values is used along with p, q and a as corner points to find the needed value using the regular interpolation scheme.

On p. 12 in Fig. 4 there is a label missing. An "α" belongs above the arc in the elevation section.

On p. 13 the word "edge" in the second clause of the first paragraph should be "eye."