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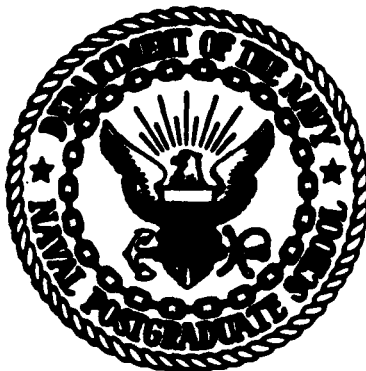
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THESIS

CONICAL LENS FOR 5"/54
GUN LAUNCHED MISSILE

by

James M. Terrell

June 1981

Thesis Advisor:

Allen E. Fuhs

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Conical Lens for 5"/54
Gun Launched Missile

by

James M. Terrell
Lieutenant, United States Navy
B.S., University of Oklahoma, 1975

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN PHYSICS

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ABSTRACT

Under the sponsorship of the Defense Advanced Research Projects Agency (DARPA), a conical lens for a 5"/54 ramjet propelled, optically guided projectile was investigated.

The resulting conical lens for the gun-launched missile (GLM) will focus parallel incident light through the lens to a design focal point. A conical lens was designed using an algorithm written for the HP-9845T desktop minicomputer. The examples illustrate the automated design procedure, selection of possible lenses and final lens design. Recommendations for further research are discussed.

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LIST OF SYMBOLS

Symbol	Explanation	Units
A	GLM (x-axis) intercept	Inches
F	Focal point on the GLM axis	Inches
NORM	Acute angle of the normal to the surface measured with respect to the GLM axis	Degrees, radians
O	Origin; located at the vertex of the GLM conical lens	Inches
OP	Length of the line segment connecting point O and point P	Inches
P	Focal point on the GLM axis intersection of the light ray and the radius vector in the GRIN lens	Inches
Q	Point of intersection of the light ray and the first surface	
QA	Length of the line segment connecting point Q and point A	Inches
QP	Length of the line segment connecting point Q and point P	Inches
r	Radial distance from the origin	Inches
Rho-initial	Angle the incident ray in medium 1 makes with the GLM axis	Degrees, radians
(REF)	Reference direction defined as the GLM axis	
RT	Length of the line segment connecting point R and point T	Inches

Symbol	Explanation	Units
RO-max	Radius from the origin at which the index of refraction is maximum	Inches
T	Point of refraction of the ray in the lens	
Theta (critical)	Angle of incidence θ_I at which $\sin(\theta_R)=1$	Degrees, radians
Z1	Point at which the lens intercepts the GLM axis	Inches
Z3	Intercept of the first, movable, image plane and the GLM axis	Inches
Z4	Intercept of the second, fixed, image plane and the GLM axis	Inches
n_1	Index of refraction of medium 1	
n_2	Index of refraction of medium 2	
n_3	Index of refraction of medium 3	
$n=f(r)$	Index of refraction is a function of the radius from the origin	
\hat{n}_1	Normal direction to a surface	
n_{23}	Ratio of n_2/n_3	
s	Distance along the ray in the lens	Inches
x	Distance along the GLM axis	Inches

Symbol	Explanation	Units
y	Radial distance from the GLM axis	Inches
y_b	Upper bound of the aperture	Inches
y_a	Lower bound of the aperture	Inches
(x_i, y_i)	Coordinate values of the intercept of the ray and a refracting surface or an image plane	Inches
(x_c, y_c)	Coordinate values of the intercept of the ray and the GLM axis	Inches
$x=f(y)$	Distance along the GLM axis is a function of the radial distance from the GLM axis	
$y=f(x)$	Radial distance from the GLM axis is a function of the distance along the GLM axis	
$ x $	Absolute value of x	Units of x
f	Focal length	Inches
l	Length of line segment QP	Inches
α	Cone half-angle	Degrees, radians
α_2	$\tan(\alpha_2)$ = slope of the second surface	Degrees, radians
β	Angle formed by QP with respect to the GLM axis	Degrees, radians
γ	Complementary angle of θ_{R_4}	Degrees, radians
δ	Angular difference between two surface normals	Degrees, radians

Symbol	Explanation	Units
θ^*	Angle between two successive rays in GRIN	Degrees, radians
θ^*	General angle	Degrees, radians
θ_I^*	Angle of incidence with respect to the local normal	Degrees, radians
θ_R^*	Angle of refraction with respect to the local normal	Degrees, radians
π	Number of radians in semi-circle	Radians
ρ_I, ρ_0	Angle of incident rays in medium 1 with respect to the GLM axis	Degrees, radians
ρ_1^*	Angle of the ray in the lens with respect to the GLM axis	Degrees, radians
ρ_2	Angle of the ray in medium 3 with respect to the GLM axis	Degrees, radians
ϕ	Angle between the radius vector and the refracted ray in the GRIN lens	Degrees, radians
l	Surface number Step of a sequence	
(32.5,45.6)	(x,y) coordinate position	Inches
Subscripts not already shown:		
1,2,3,...	Point number	
	Iteration number	
i	Iteration number	
	Surface number	

Symbol	Explanation	Units
n	Iteration number	
max	Maximum value of the symbol	
next	Next quantity in the sequence	

*: Indicates the symbol can be used with additional subscripts.

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I. INTRODUCTION

A. THE PROBLEM

Since World War II the presence of two conflicting requirements in missile sensor design has forced unsatisfactory compromises to be made in either the optical system, airframe or both. Examples of this are the Sidewinder air to air (AAM) and Chapparral surface to air (SAM) missile. The operational requirements are simple: from a "long" range, fly fast enough to pursue and overtake an adversary, destroy or disable the adversary and perform all of the guidance and tracking functions without assistance from the firing platform. The guidance decisions in the Sidewinder AAM are made by tracking the thermal radiation emitted from enemy aircraft. The radiation enters the missile optical system via a hemispherical dome on the nose of the missile.

Long range and high speed require sleek, low-drag airframes and efficient, high power engines. In the visible or infrared, accurate measurement of the line of sight (LOS) from the missile to the target requires optical lenses which routinely come in the shape of spheres. Spheres and similar blunt shapes have very high drag coefficients compared to conical or ogive nose shapes. Thus the Sidewinder and Chapparral missiles contain excellent optics, yet suffer in range and operational capability.

The targets expected to be encountered in surface AAW are the Soviet anti-ship missiles (ASM). These weapons have evolved from simple straight line weapons to those with large warheads, multiple seekers and flight profiles which sometimes require operational tracking systems to perform beyond their design limits.

The fleet AAW battle doctrine of today is based on a "defense in depth" concept. According to this concept the E-2C/F-14/Phoenix combat system will be the first unit to engage enemy ASM, hopefully at maximum range. The next units able to engage the ASM at extended range, assuming the target is above the radar horizon, are the units employing the SM-2 (ER) and SM-1 (ER) missiles. While within the SM-2/1 (ER) engagement envelope, the SM-1 (MR) missile enters the engagement at medium range. Finally, once the ASM has penetrated this missile cover, the defense in depth concept reduces to a "defend each unit, especially the carrier" concept. In this region the 5"/54 gun system, Basic Point Defense System, NATO Sea Sparrow and Phalanx system are brought to bear.

The battle group could conceivably consist of an aircraft carrier, three Aegis cruisers, two SM-1 (ER) cruisers, two guided missile destroyers, two guided missile frigates, two fast frigates and three destroyers; or a total of fifteen units not including logistics ships. The capital assets for the ships, aircraft and equipment are in the tens of billions of dollars and perhaps 10,000 men. These assets demand

protection. However, with three exceptions the AAW combat systems presently in the fleet, or near operational status are not designed to engage a low-flying ASM in a timely manner. The exceptions are the Aegis cruiser, NATO Sea Sparrow system and Phalanx system; even with these three systems, there exists a gap in the 1-10 nautical mile range in the defense in depth concept.

A possible attack scenario is with the battle group steaming in an AAW formation when the Soviet commander launches a series of three saturation raids of ASM's against the battle group. The second and third raid are launched to arrive at the moment when the U.S. forces are totally engaged with the previous raid. Hence, the second and third raid will substantially penetrate the battle group, with perhaps the carrier and several of the major escorts at least mission disabled. The Soviet commander can now operate at will.

Two factors are critical to the battle group commander: munition assets and engagement time. Compared to the number of threats in a saturation attack, the battle group's missile assets are limited in number with limited reload capability. The battle group commander's gun ammunition assets are large, compared to the available missiles. However, with the current gun systems the engagement time per round is extremely long, on the order of 60 seconds. If the gun engagement time could be reduced by a factor of 2, then each gun barrel could be twice as effective.

Unguided, ballastic projectiles can be replaced by gun launched missiles (GLM). The GLM flying at Mach 3.0 can intercept in 15 seconds an inbound ASM flying at Mach 1.0 at a range of 20,000 yards. This engagement time and range are superior to any close-in system presently in the fleet. Therefore the GLM enhances the battle group's capability to survive a raid which saturates the group's long range combat systems. The GLM is not designed to replace any existing systems but complement them by providing the ability to strike out and defeat the enemy in the region from 1 to 10 nautical miles. In this range interval, defense capability presently exists; however, the magazine capacity is limited. The GLM will accomplish the ASMD task by marrying existing ramjet technology and a new generation of missile optics to provide a missile which is able to defeat the Soviet ASM at a range far greater than is realizable with today's gun systems.

This thesis involved the writing of and the application of computer algorithms to accomplish the following:

- 1) Compute and trace monochromatic light rays through a conical lens.
- 2) Compute a refracting surface to focus monochromatic light rays to a point on the GLM axis.
- 3) Apply an optimization computer algorithm to the lens design problem.
- 4) Apply gradient index optics (GRIN) to the lens design.

B. ASSUMPTIONS AND SIGN CONVENTION

The computer algorithms are written based on Snell's law without approximations. All rays are assumed to be transmitted without loss of energy in the medium. When total internal reflection occurs, the ray is assumed to stop at the point of reflection. The algorithms are written to provide a basic understanding of the optics involved. Flexible computer programs have been written with the capability of adding ray tracing ability by adding subroutines.

The medium ahead of the GLM is assumed to be air. Flying at Mach 3.0 the GLM will produce shock waves which will act like a refracting surface [1]. This thesis assumes the air to be homogenous, isotropic, linear, time independent (HILT) and free of shock waves in order to investigate the fundamental problem of designing a conical lens. The lens medium and the medium after the lens are assumed to be composed of an HILT material unless otherwise noted.

The sign convention used is a right-handed system with distances positive to the right and up as seen by the reader. All angles are positive for a counterclockwise rotation from the horizontal axis to the point in question. When used in derivation of geometrical relationships, the absolute values of angles are used in all trigonometric expressions.

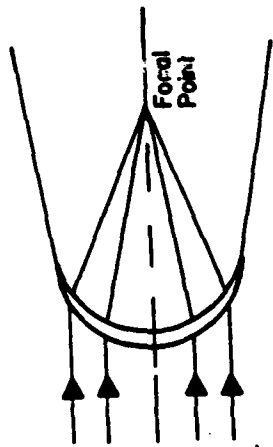
All linear dimensions are inches unless otherwise noted.

II. FIRST SURFACE

A spiked nose used as a ramjet inlet optimizes the aerodynamic qualities yet degrades the optical qualities. Figure 1 [2] illustrates the inability in the past of a spiked nose to focus light rays while a spherical lens accomplishes an excellent focus. Thus, optimizing the aerodynamic qualities degrades the optical qualities and vice versa.

Replacing the solid propellant rocket motor now used on most missiles with a ramjet engine further complicates the compromise between optical quality and aerodynamic efficiency. Replacing the rocket with an air-breathing ramjet is motivated by fuel economy and the ability to throttle the ramjet. The ability to throttle allows the missile to fly a thrust equal drag trajectory. This type of trajectory results in a vacuum-like trajectory with less sensitivity to wind and a marked increase in maximum range [3].

Ramjets operate with inlets configured for cruise performance at the design Mach number. The configuration of the inlet shown in figure 2 is based on a design Mach number of 3.0 [3]. The spike of the inlet is a combination of a cone and curved geometry to provide high pressure recovery during supersonic operation [3].



Blunt nose having poor aerodynamic qualities and good optical qualities.



Conical spike nose having good aerodynamic qualities and poor optical qualities.

Figure 1. Spiked vs. Blunt Ramjet Inlets.
(Reproduced from Ref. 2, p 19)

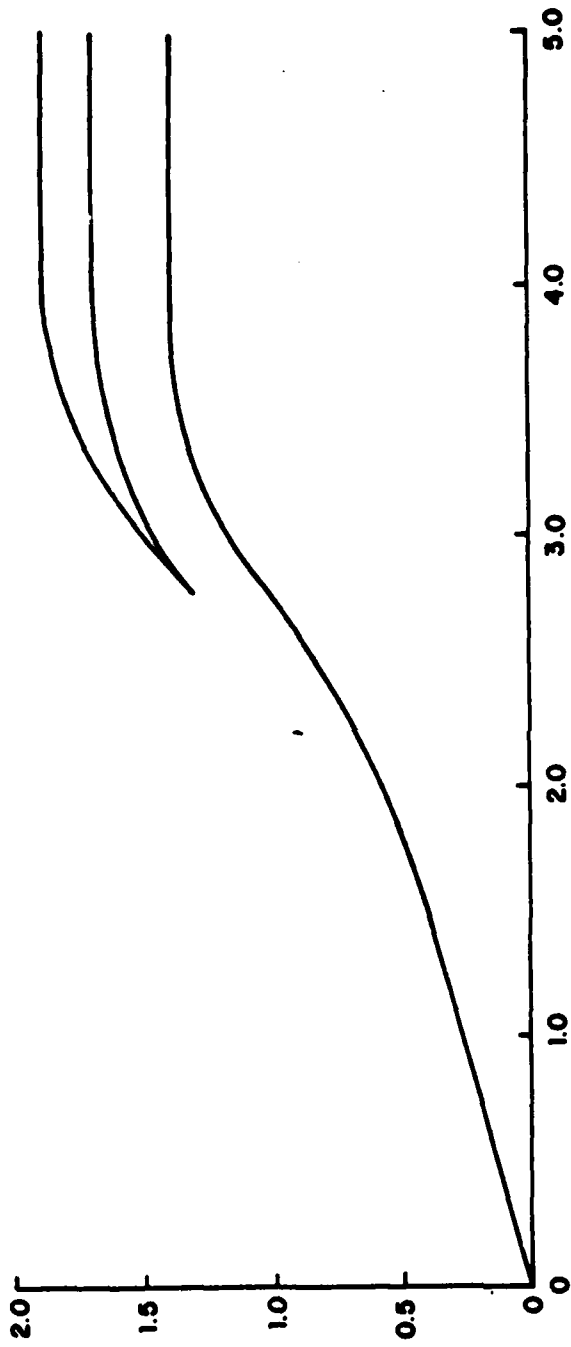


Figure 2. Dimensions of 15° Tip Axisymmetric Isentropic Inlet Designed for Mach 3. (Reproduced from Ref. 3, p 37).

The inlet spike geometry is a complex surface which further complicates the task of the lens system which is to form an image of the target on the GLM axis. The inlet is a fluid mechanical device, called a diffuser, used to decelerate the air flow to a subsonic Mach number. The diffuser converts the kinetic energy of the flow into an increase in pressure of the air, known as pressure recovery, and decelerates the flow to a subsonic Mach number. Diffusers are required because the combustion of fuel is more efficient at high pressure and low velocity.

A desirable inlet is one which decelerates the flow at constant entropy, produces no shocks, creates zero drag exclusive of ram drag, and is insensitive to angle of attack. Inlets which operate off the design Mach number may have additive drag. Additive drag is the sum of the forces acting along the streamline A-B shown in figure 3 [4]. The pressure multiplied by the area of the streamtube A-B is a force which is in a direction opposite to that of flight and therefore is drag. Examples of other types of supersonic diffusers are shown in figures 4 and 5 [4].

The marriage of missile optics and a controllable engine promises a potent weapon. Preliminary feasibility studies have shown that ramjet engines, control systems, guidance laws and warhead designs can be integrated into a 5"/54 projectile [2,3,5,6]. The optical system has been identified as a major subsystem which requires additional investigation.

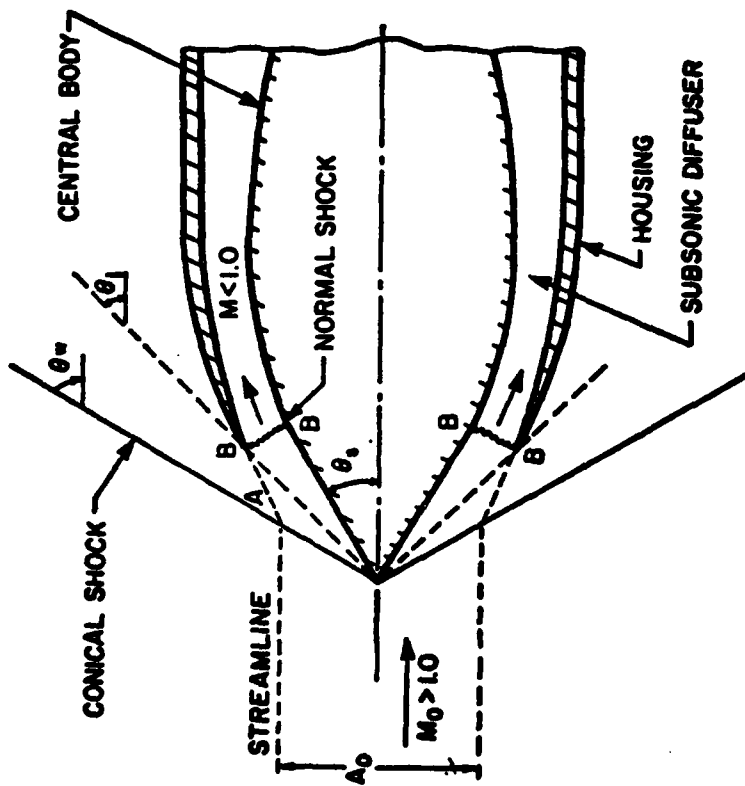


Figure 3. Schematic Diagram of a Conical Shock
(Oswatitsch Type) Supersonic Diffuser.
(Reproduced from Ref. 4, p. 245)

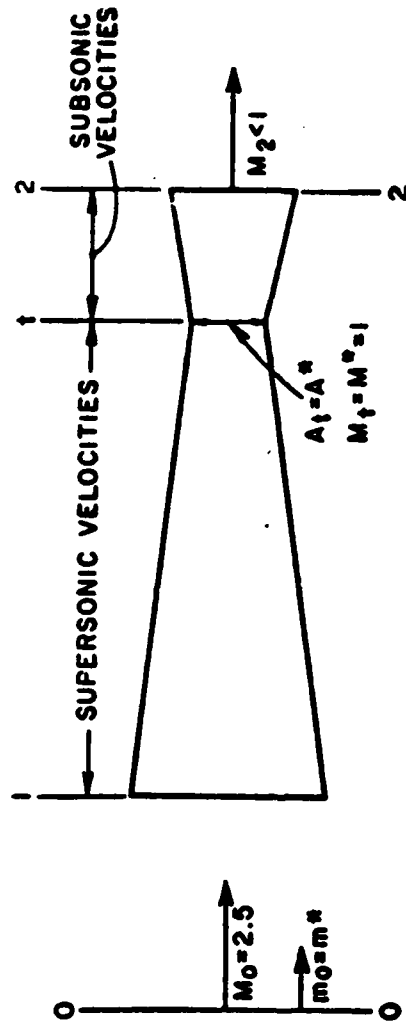


Figure 4. Scheme of Using a REVERSED Converging-Diverging Isentropic Nozzle as a Supersonic Diffuser. (Reproduced from Ref. 4, p. 239)

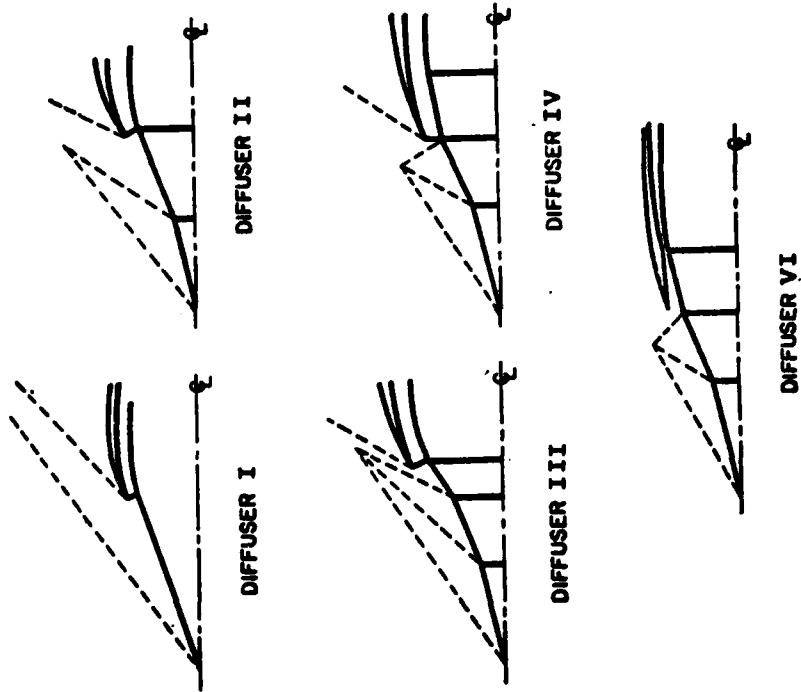


Figure 5. Different Conical Shock Supersonic Diffuser Configurations Tested by Oswatitsch. (Reproduced from Ref. 4, p. 247)

Specifically, the lens, which is required to focus the image of the target, is the stumbling block to an efficient ramjet design. A blunt nose cannot be used because of poor pressure recovery and large additive drag. Therefore, some type of an inlet using a spike must be used. The spike must also be a lens capable of forming an image on the GLM axis. The lens must have a large enough aperture and field of view to provide the GLM with sufficient data to maintain and accurately measure the line of sight.

This thesis is based on an inlet design by Brown [3] using data from Faro [7] shown in figure 2. The inlet is a 15° conical tip, axisymmetric, isentropic spike for a design Mach number of 3.0. The spike studied in the thesis is a cone having approximately the same length-to-diameter ratio as the inlet in figure 2 [3]. Hence, the first optical surface used for ray tracing is a cone with a 21° half-angle.

III. SECOND SURFACE GENERATION: DIRECT SOLUTION

The direct solution to designing a conical lens consists of solving Snell's Law at a point T shown in figures 6 and 7 along the refracted ray within the lens. Point T is located below the line QP in figure 6. When T is in this position relative to QP, the geometry is referred to as the low region. When T is in the position shown in figure 7, the geometry is referred to as the high region. When T is on the line QP, i.e. $\rho_1 = \beta$, the low region geometry is assumed.

The following discussion is the derivation of expressions for ρ_2 , the angle with respect to the GLM axis of the ray refracted at T which passes through the design focal point P, and α_2 , the angle which the tangent line at T makes with respect to the GLM axis. The derivation will only discuss the low region, because the procedure for the high region is identical and only the results for the high region will be given. The magnitude of a line segment is shown by stating the endpoints of the line segment in uppercase letters or by a single lower case letter.

Let $QP=l$, $QT=s$ and $OP=f$; then according to the law of sines $\sin\alpha/l = (\sin(\pi-[\alpha+|\beta|]))/f$. This relation simplifies to

$$l = \frac{f \sin\alpha}{\sin(\alpha+|\beta|)} \quad (1)$$

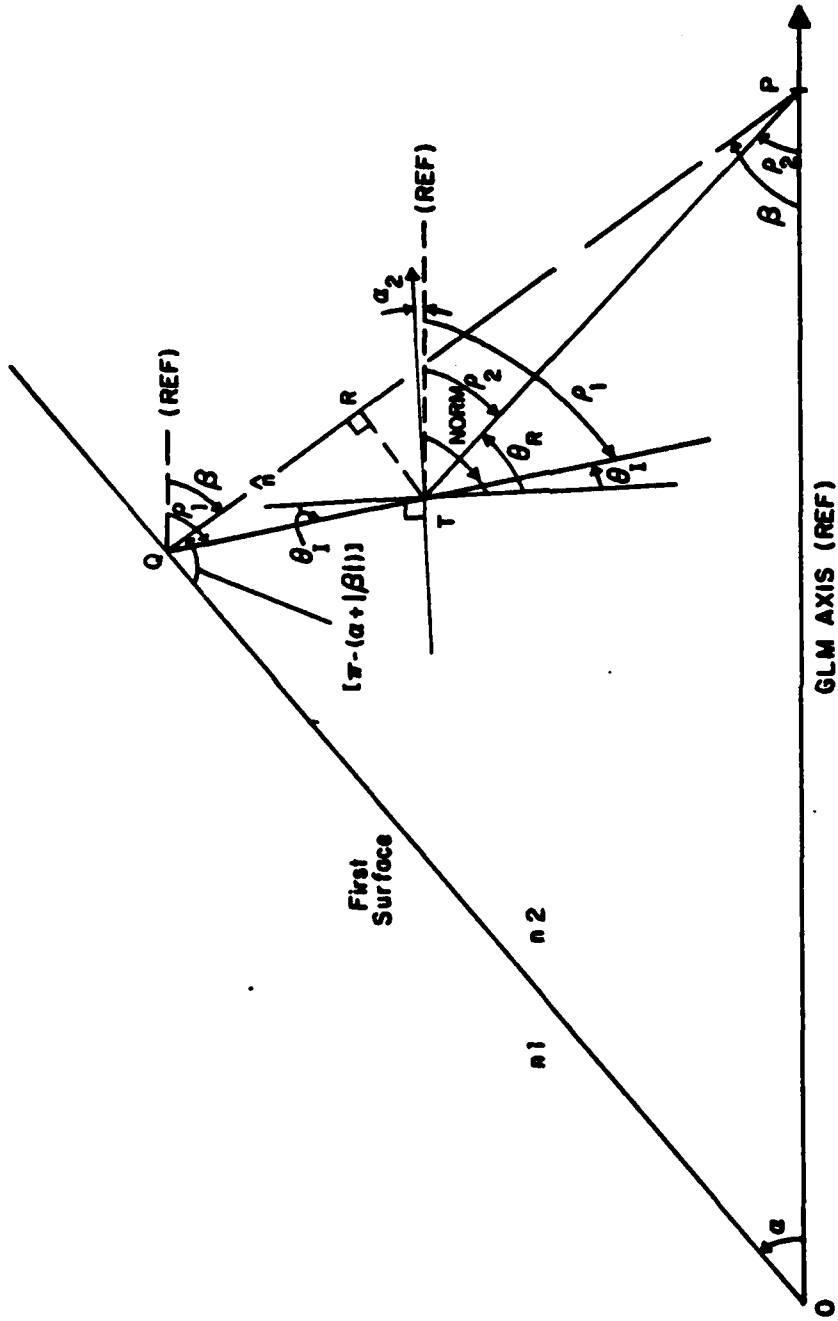


Figure 6. Direct Solution: Low Region Geometry for $n_2 > n_3$.

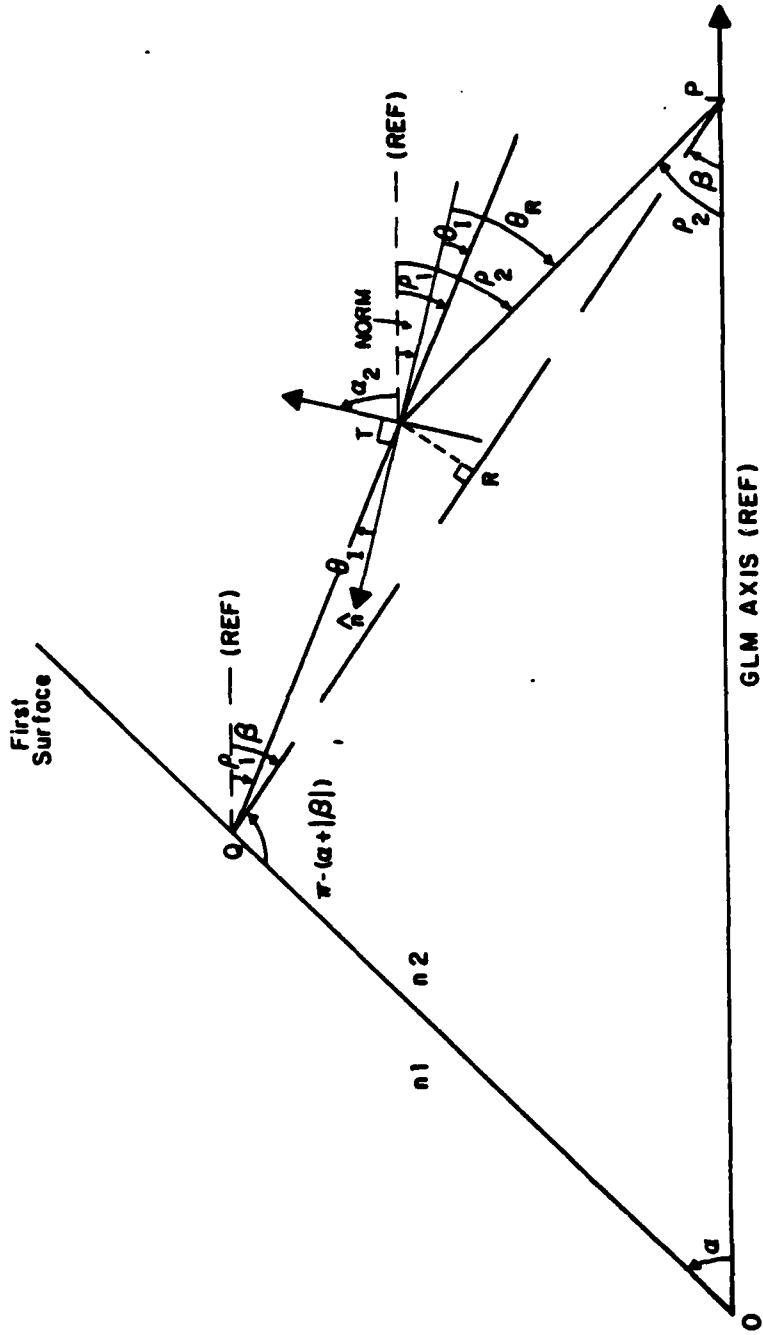


Figure 7. Direct Solution: High Region Geometry for $n_2 > n_3$.

Next, note that

$$RT = s \sin(|\rho_1| - |\beta|) \quad (2)$$

and

$$RT = (PQ-QR) \tan(|\beta| - |\rho_2|) \quad (3)$$

Now $PQ-QR = \ell - s \cos(|\rho_1| - |\beta|)$. Substituting this into equation (3) and solving for $\tan(|\beta| - |\rho_2|)$ yields

$$\tan(|\beta| - |\rho_2|) = \left\{ \frac{s \sin(|\rho_1| - |\beta|)}{\frac{\ell \sin \alpha}{\sin(\alpha + |\beta|)} - s \cos(|\rho_1| - |\beta|)} \right\} \quad (4)$$

Consequently the formula for $|\rho_2|$ becomes $|\beta| - \arctan\{\}$.

Using equation (4), ρ_1 , the angle with respect to the GLM axis of the ray refracted at Q, apply Snell's Law at T.

Thus, referring to figure 6

$$\sin \theta_R = \frac{n_2}{n_3} \sin \theta_I = n_{23} \sin \theta_I \quad (5)$$

where $\theta_R = |\text{NORM}| - |\rho_2|$ and $\theta_I = |\text{NORM}| - |\rho_1|$.

Substituting these expressions into equation (5) yields a relation involving the sine of two angles. Expanding the sine expressions and solving for $\tan|\text{NORM}|$ yields

$$\tan|\text{NORM}| = \left\{ \frac{\sin|\rho_2| - n_{23} \sin|\rho_1|}{\cos|\rho_2| - n_{23} \cos|\rho_1|} \right\} \quad (6)$$

and $|\text{NORM}| = \arctan\{\}$. Equation (6) must be greater than or equal to zero for the expression to be valid. Then

$$\alpha_2 = \frac{\pi}{2} - |\text{NORM}| \quad (7)$$

The result of the derivation for the high region yields

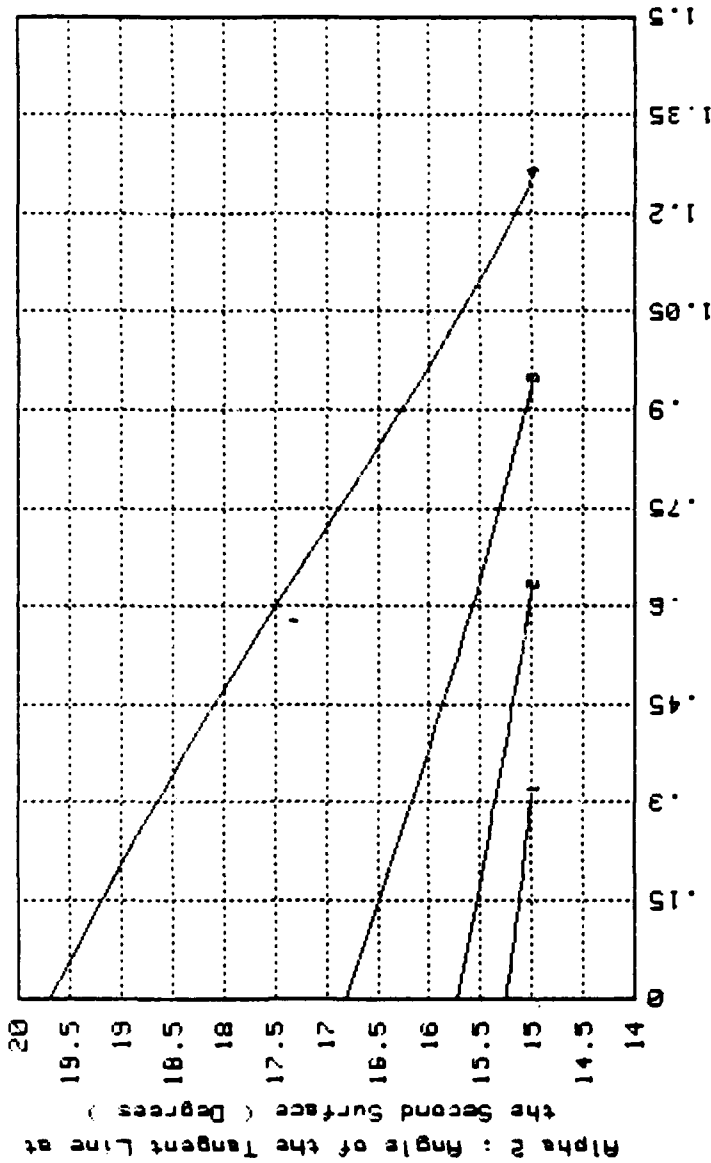
$$\tan(|\rho_2| - |\beta|) = \left\{ \frac{s \sin(|\beta| - |\rho_1|)}{\frac{f \sin \alpha}{\sin(\alpha + |\beta|)} - s \cos(|\beta| - |\rho_1|)} \right\} \quad (8)$$

$$\tan|\text{NORM}| = \frac{n_{23} \sin|\rho_1| - \sin|\rho_2|}{n_{23} \cos|\rho_1| - \cos|\rho_2|} \quad (9)$$

and solving for α_2 gives

$$\alpha_2 = \frac{\pi}{2} - |\text{NORM}| \quad (10)$$

Therefore, α_2 is a complicated relationship involving incident ray position, denoted by β , cone half angle α , design focal point P , the refractive indices n_1 , n_2 , and n_3 and position s along the ray within the lens. In order for a systematic study to be conducted, the parameters α , f , n_1 , n_2 and n_3 are assigned specific values. The parameter β is determined by the position of point Q on the first surface. The angle of ρ_1 , is determined by the incident ray angle with respect to the first surface, n_1 , and n_2 . Therefore, with the values for the parameters, either fixed or calculated, a design chart relating α_2 with the position along the ray in the lens s shown in figure 8 can be generated. The numbered curves correspond to numbered rays entering the lens. The rays are numbered consecutively beginning with the one nearest the GLM axis.



S : Distance Along Refracted Ray in the Lens (Inches)
 Design Focal Point : 6.00 inches
 Number of Rays : 4
 Alpha : 15.00 deg
 n2 : 1.00000

Figure 8. Sample Design Chart for a Conical Lens Design.

The actual design process involves selecting a starting point, T_1 , on a given ray and noting the magnitude of s_1 as shown in figure 9. With that value of s_1 , enter the design chart in figure 8 and read the value of α_{2_1} from curve number 1. Returning to figure 9 extend a line from T_1 using α_{2_1} until that line intercepts the next ray at T_2 . Measure the value of s_2 and enter figure 8 to obtain the value of α_{2_2} from curve number 2. Return to figure 9 and extend a line from T_2 to intercept the next ray, etc. This process continues until all of the rays are intercepted or the first surface is intercepted. Once the intercept point T and the angle of the tangent line α_2 is known, the ray can be refracted at T . Equations (4) and (7) for the low region and equations (8) and (10) for the high region accomplish the refraction. The result of each refraction by design result in a refracted ray through the focal point P as shown in figure 10.

The design procedure does not produce a single surface which can be used to refract light through the focal point. The surface designed depends on which ray was chosen as the initial ray and the value of s along that ray where T_1 is positioned. Thus, a small family of surfaces illustrated in figure 11 can easily be calculated to provide a choice of lens second surfaces to the optical engineer.

The lens designer must choose from the family of second surfaces generated by the design procedure. In order for a

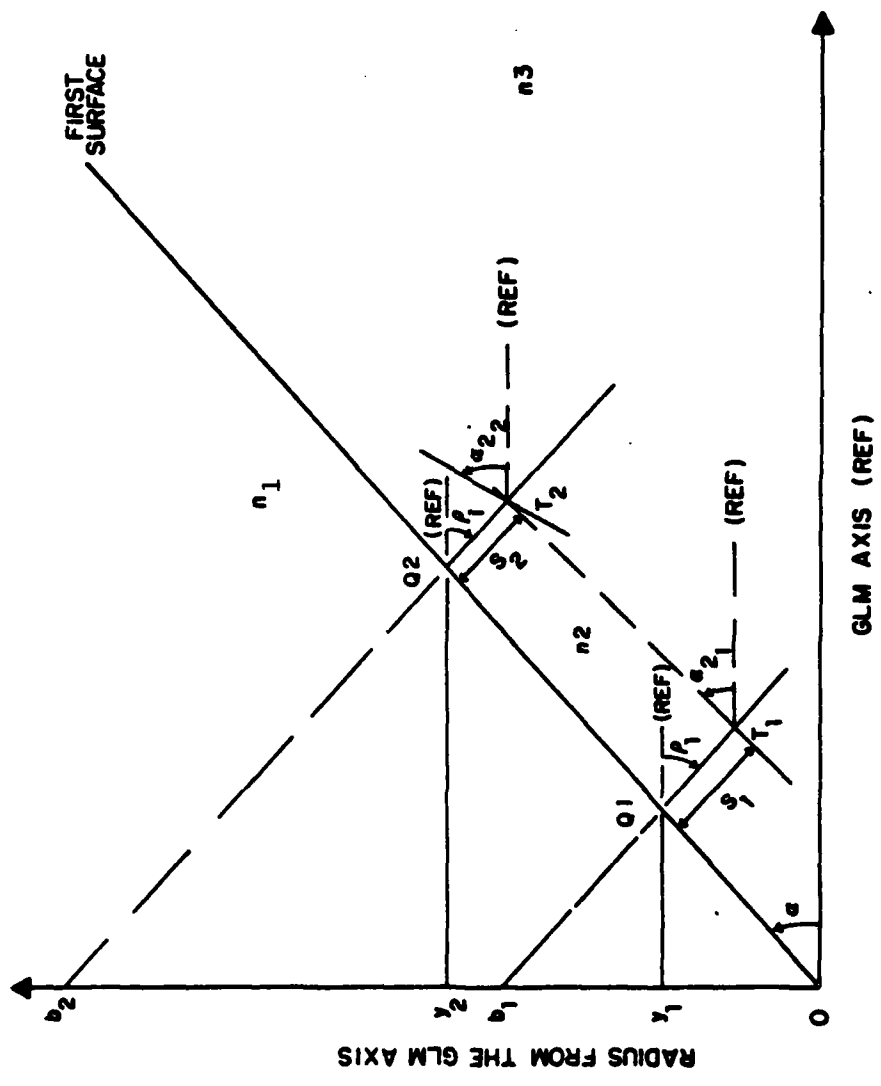


Figure 9. Geometric Relationship for the Calculation of α_2 versus s .

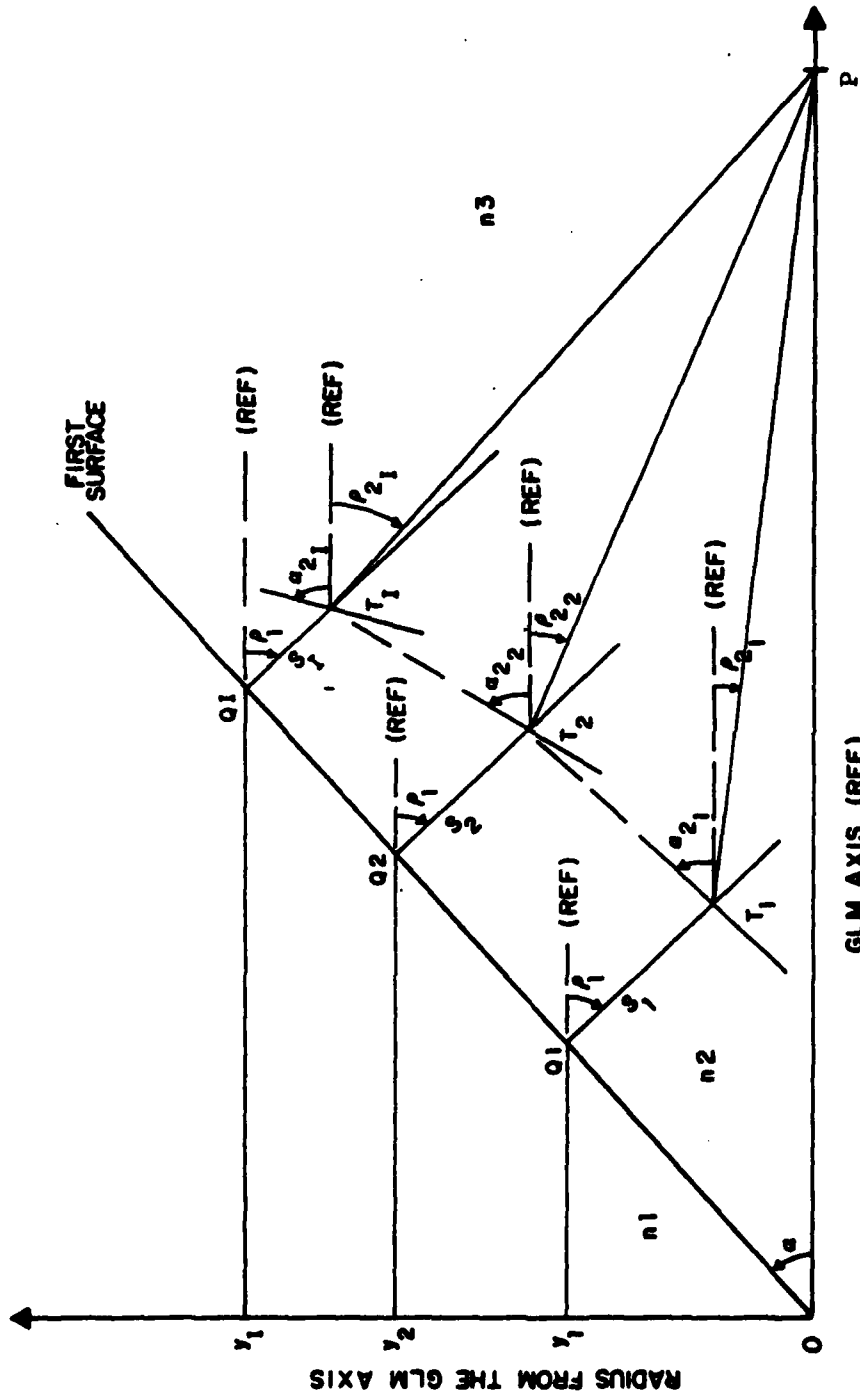
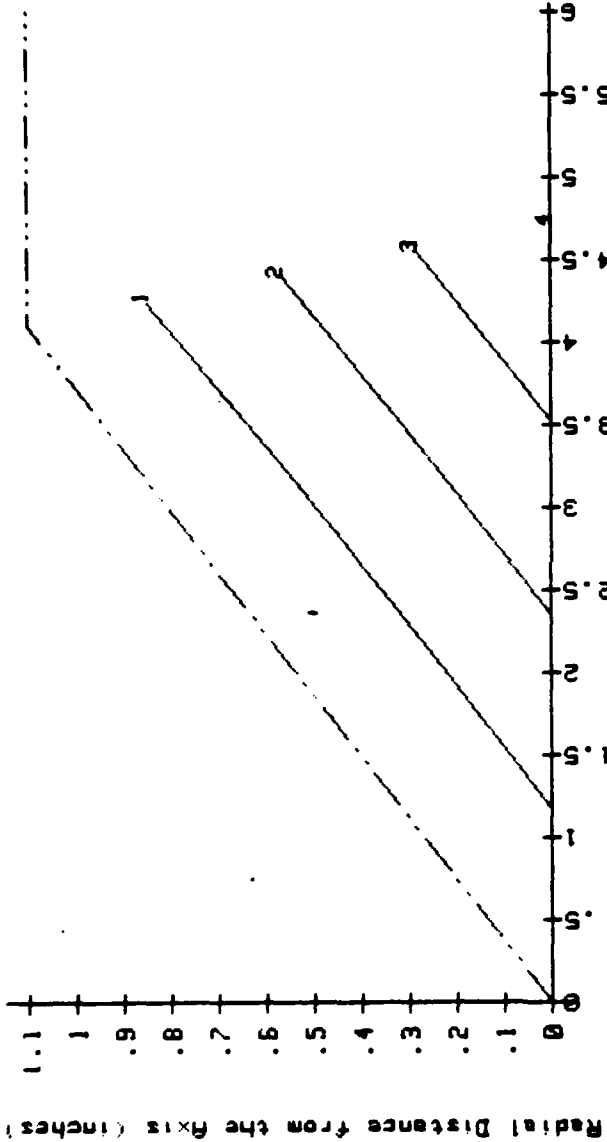


Figure 10. Light Rays Refracted Through the Design Focal Point.



Distance Along GLH Axis (inches)

FAMILY OF SURFACES

Design Focal Point : 6.00 inches Number of Rays : 4
 Alpha : 15.00 deg n2 : 4.00000

Figure 11. Example of a Family of Second Surfaces Calculated from the Design Chart in Figure 8. The Surfaces Numbers 1, 2, 3 and 4 are Correlated Between the Curve Numbers in this Figure and Figure 8.

consistent set of decisions to be made a set of design criteria for this thesis are:

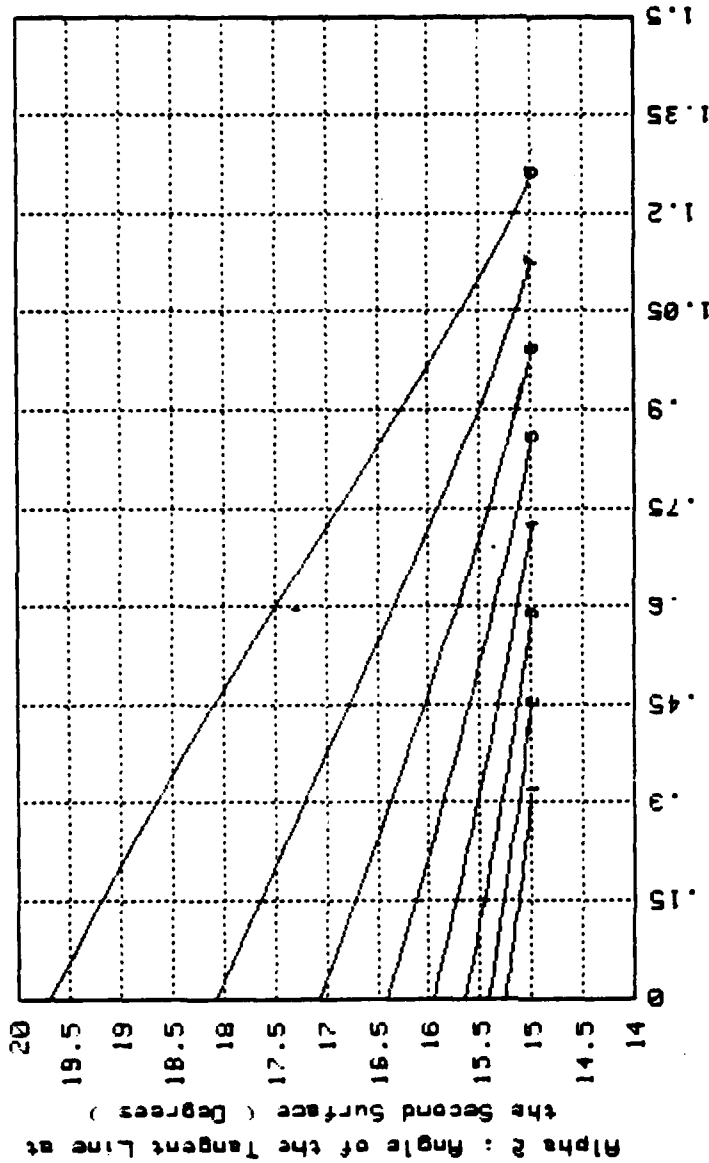
- 1) that the lens must be as thin as possible.
- 2) that the lens have as large an aperture as possible.

The aperture is defined to be the difference in radius between the maximum and minimum radii from the GLM axis at which light rays enter the lens and are refracted through the focal point.

- 3) that the focal length to diameter ratio, f/d , is a minimum and in no case greater than 4.

Using the stated design criteria, surface number 1 in figure 11 is the logical choice because it is the thinnest and has the maximum aperture of the 5 surfaces provided. All of the surfaces have the same f/d ratio of 2.73.

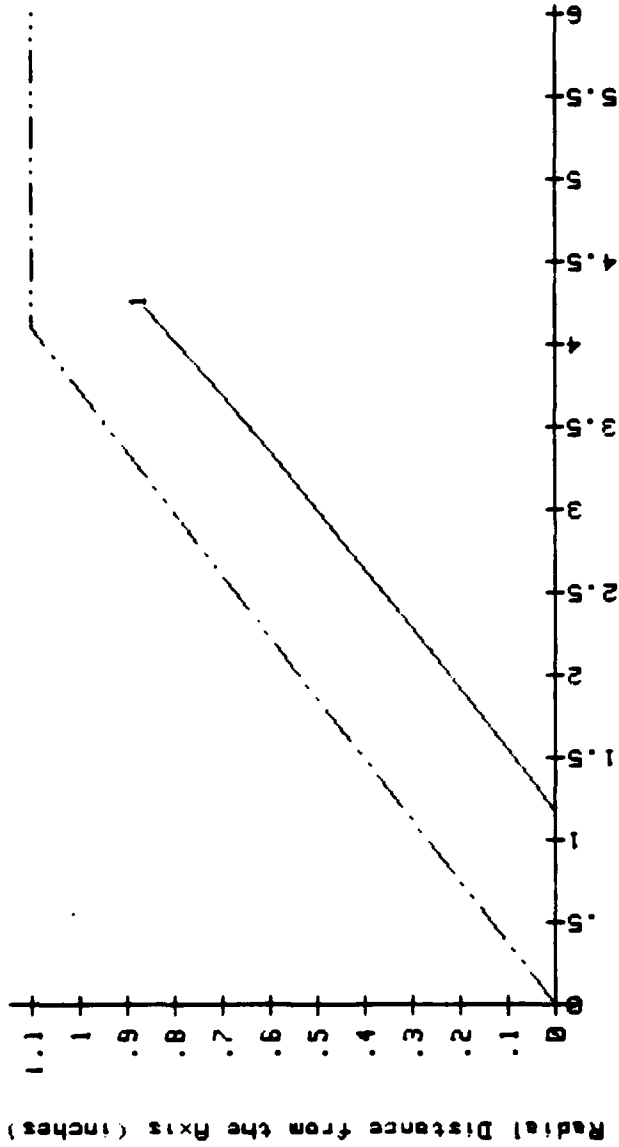
Each member of the family of surfaces is generated by using straight lines. Since a real surface will not be a series of flat surfaces but a smooth continuous surface with no discontinuities, an inherent error exists in the design. The error can be reduced substantially by using a large number of rays to provide a large number of line segments to approximate a continuous surface. The designer must now choose the number of rays to be used, repeat the design process and generate the design chart for the final lens design using, for example, 26 rays in figure 12. Using figure 12, the designer calculates the final lens design in figure 13 beginning with the starting point which is the



S : Distance Along Refracted Ray in the Lens (Inches)

Design Focal Point : 6.88 inches Number of Rays : 8
 Alpha : 15.00 deg n2 : 1.60000

Figure 12. Example Design Chart for the Final Design of the Second Surface Using a Particular Surface Chosen in Figure 11.



Distance Along GLM Axis (inches)

SURFACE NUMBER 1

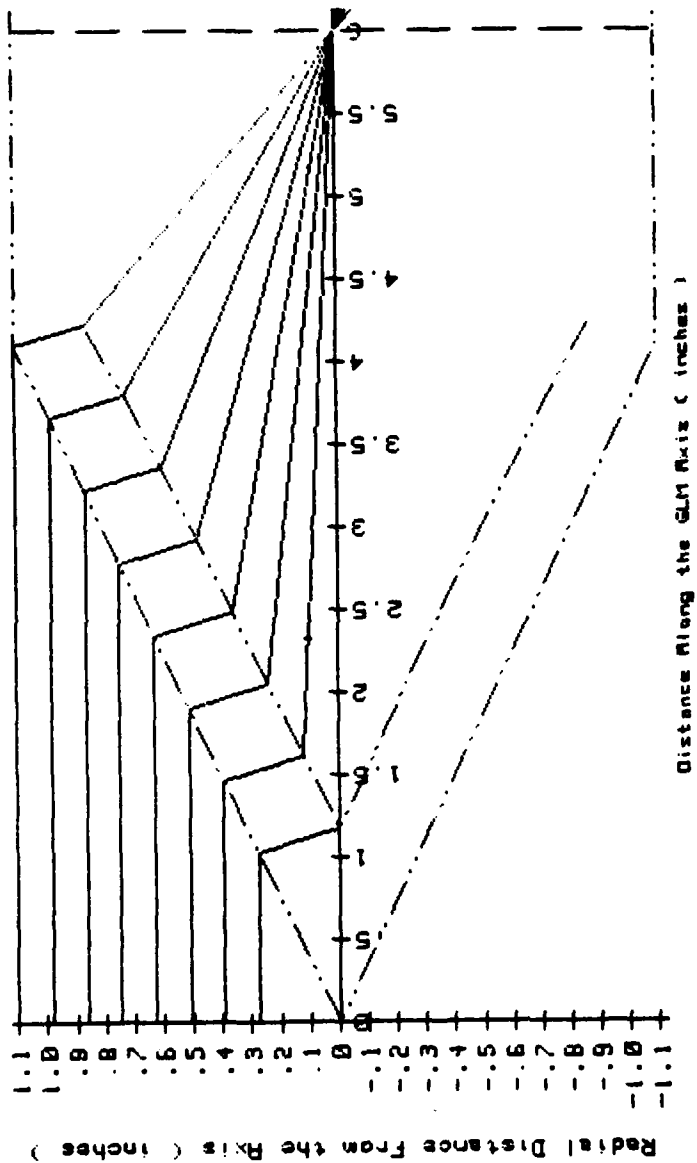
Design Focal Point : 6.00 inches Number of Rays : 8
 Alpha : 15.00 deg Aperture : .025 inch n2 : 1.00000

Figure 13. Example of the Final Design of the Second Surface for the Surface Chosen in Figure 11.

end of a curve number 1 in figure 12. Thus T_1 is near the GLM axis and $\alpha_2 = 21^\circ$.

A ray diagram shown in figure 14 illustrates the paths of the light rays through the lens generated using the design chart in figure 12. A histogram showing the distribution of light rays on the image plane reveals that the light rays do pass through one design focal point plus or minus an half-increment width. The width of an increment is defined as the maximum radius of the GLM divided by the desired number of intervals. For example, if the maximum radius of the GLM is 1.1 inch and 100 intervals from the GLM axis to a radius of 1.1 inch then the increment width is 0.011 inch. In order to position an interval on the origin, an increment is centered on the origin. The effect of this operation is to add a half-increment at the maximum value of the radius. Therefore, for the entire GLM a total of $2 \times 100 + 1 = 201$ increments are used to generate a histogram. The fact that all of the rays intersect the focal point shows the calculations are correct for this particular lens.

An automated computer algorithm, CHART, has been written to construct a design chart and calculate a family of surfaces from that design chart. CHART waits until the operator chooses a particular surface from the presentation and the number of rays desired to calculate a final surface. Next, CHART will compute the final surface and present it to the



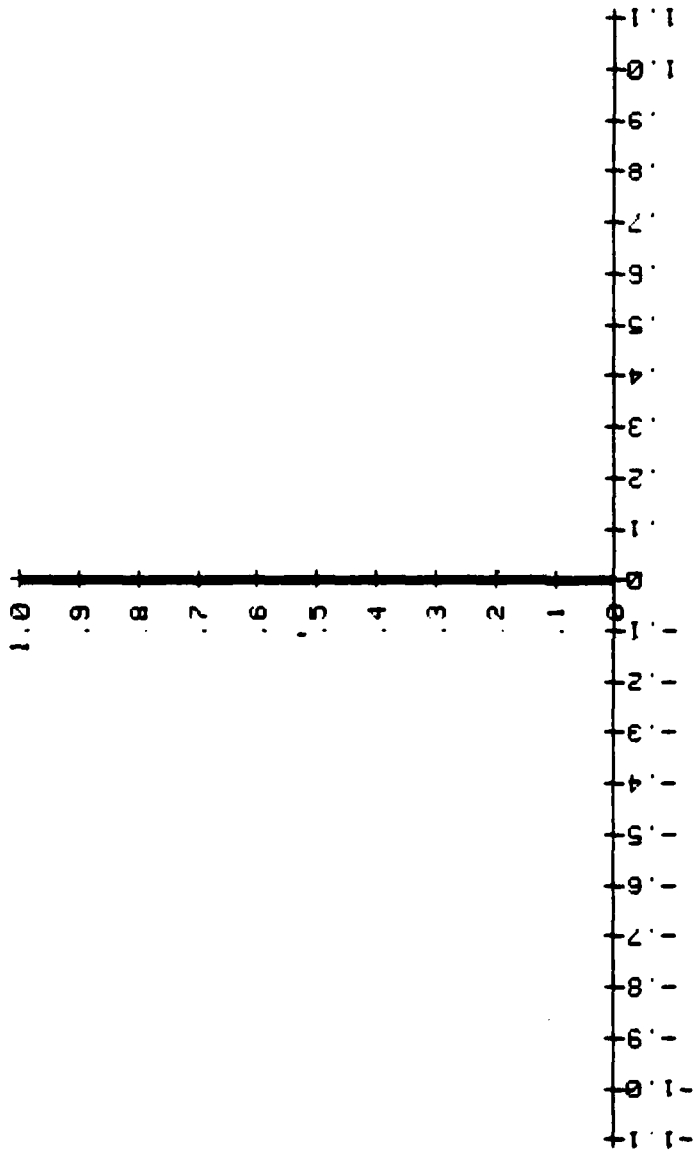
Incident Ray Angle : 0.00 deg
 Aperture : .025 inch
 Alpha : 15.00 deg

Number of Rays : 8
 n2 : 4.000000
 Image Plane : 5.00 inch

Figure 14. Example Ray Diagram Showing the Results of the Lens Design Procedure.

operator. The operator can choose to stop or draw a ray diagram to show the effectiveness of the design. If the ray diagram is chosen a histogram of ray distribution on the image plane is presented to the operator. If the operator wants to design a lens using another surface, the entire procedure must be repeated.

The following figures are a sample run of CHART to design a lens. Tables containing the initial parameter values and calculated data are located in Appendix A. The design chart in figure 16 was generated using the initial parameter information in Table A-II. The family of second surfaces in figures 18 and 19 were calculated using the end of each numbered curve in figure 16 as the starting point T_1 for each numbered second surface in figures 17 and 18. The information used to draw figures 17 and 18 is in Table A-III. The rays shown in figure 18 were used to generate the design chart and family of second surfaces figures 17 and 18. The maximum length of a ray in the lens is defined as QA , the distance from the intercept of the incident ray and the first surface to the GLM axis. The calculated information used to draw the family of second surfaces in figures 17 and 18 is found in Table A-IV. A comparison of QA and the value of s used as the starting point T_1 for each family, s_{max} , is found in Table A-V.



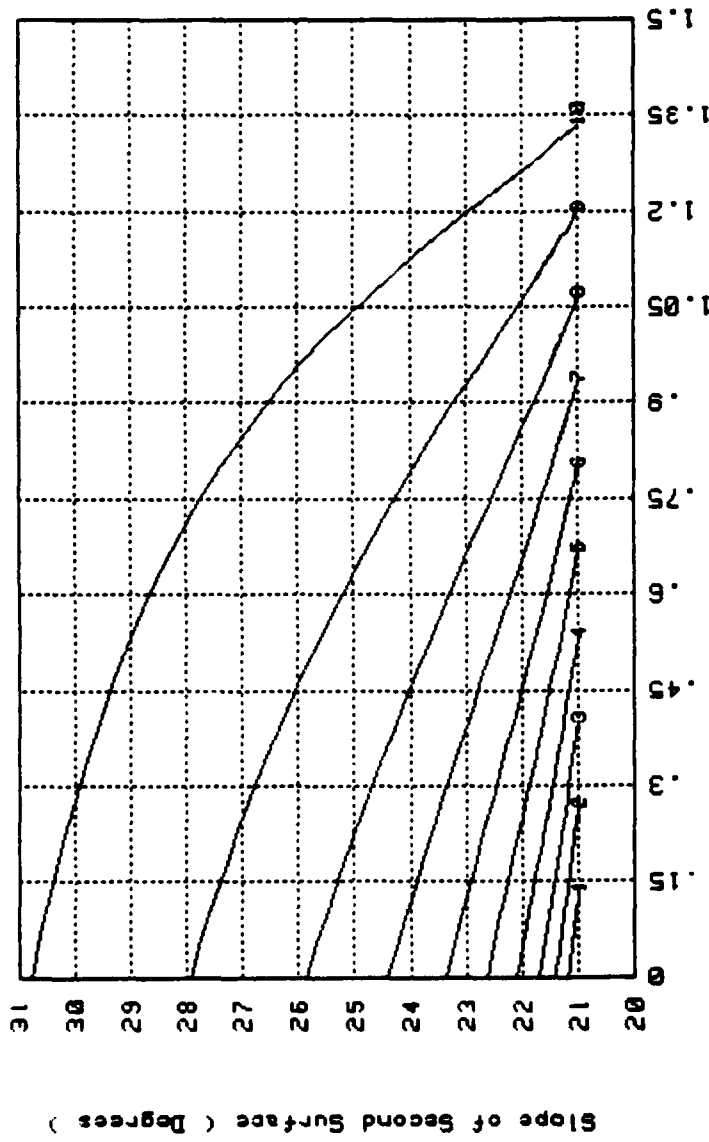
Normalized Number of Hits vs Distance from the GLM Axis

SURFACE NUMBER 1

Number of Hits on the Image Plane : 8 % of Rays to Image Plane : 100.00

Number of Increments (0.1.1) : 100 Image Plane : 6.00 inches

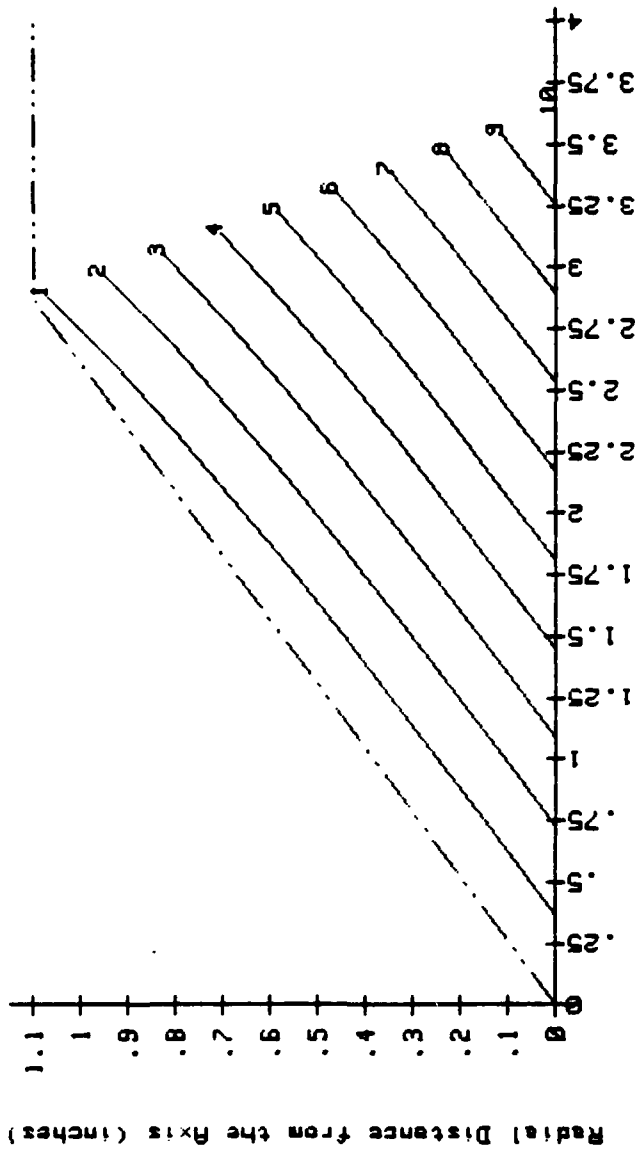
Figure 15. Example of the Histogram of the Ray Distribution on the Image Plane in Figure 10. Compare with Figures C-3, C-7, C-13 and C-14 of Appendix C.



Distance Along Refracted Ray in the Lens (Inches)

Design focal Point : 4.88 inches Number of Rays : 10
 Alpha : 21.00 deg n2 : 1.60000

Figure 16. Initial Design Chart Showing the Angle of the Tangent Line at the Second Surface, α_2 , as a Function of Distance Along the Ray in the Lens, s.

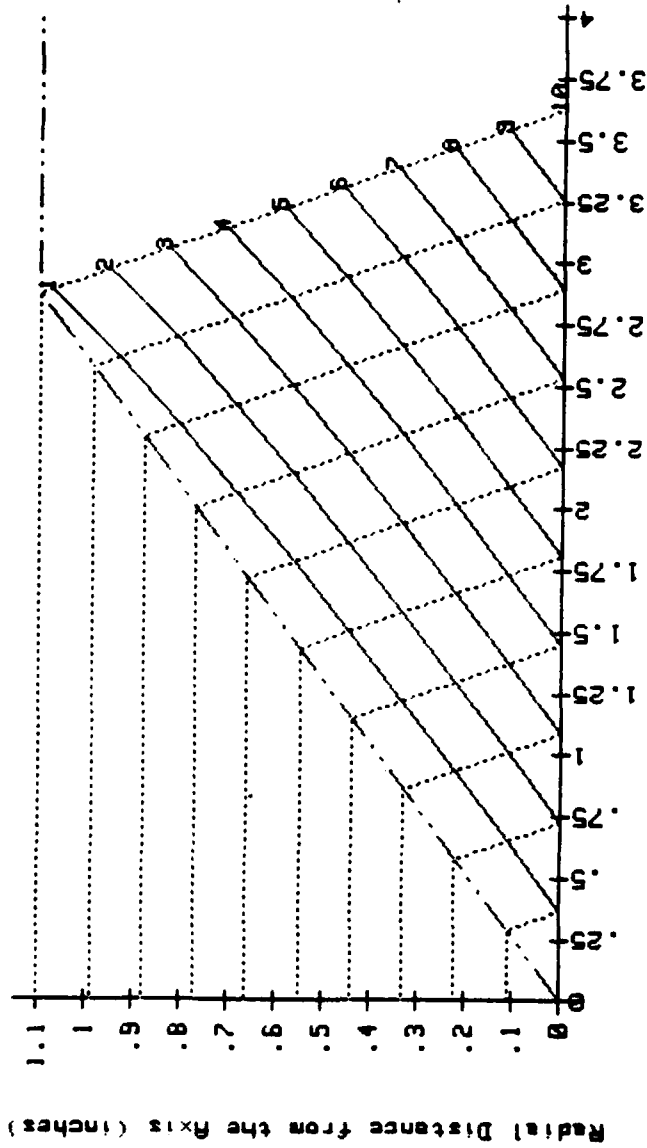


Distance Along GLM Axis (inches)

FAMILY OF SURFACES

Design Focal Point : 4.00 inches Number of Rays : 18
 Alpha : 21.00 deg n2 : 1.00000

Figure 17. Family of Second Surfaces Generated from the Design Chart in Figure 16.



Distance Along GLM Axis (inches)

FAMILY OF SURFACES

Design Focal Point : 4.00 inches

Number of Rays : 10

Alpha : 21.00 deg

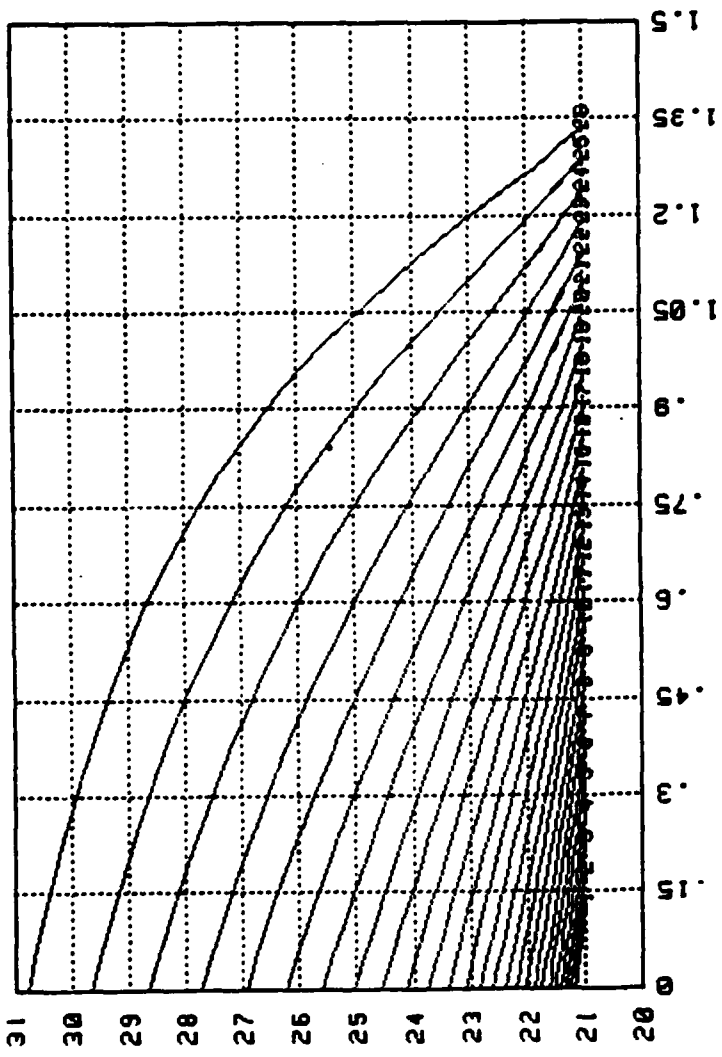
n2 : 1.00000

Figure 18. Family of Second Surfaces Generated from the Design Chart in Figure 16. The Rays are Included to Provide a Geometric Perspective.

Surface number 1 was chosen because the surface satisfied all of the design criteria. The final design chart shown in figure 19 was generated using 26 rays. The number of rays actually entered into the computer was 25, CHART then calculates the aperture of the lens using the chosen surface. If the lower limit of the aperture is not the GLM axis, CHART adds one ray to the number entered to use as the starting ray. This method insure a ray will be drawn at the maximum and minimum boundaries of the aperture. The calculated data used to generate the design chart in figure 19 is listed in Table A-VI.

The final lens design shown in figure 20 consists of a surface defined by 26 points rather than 10 with the initial design. The coordinate values for the final surface are found in Table A-VII. The refinement of the surface obtained by using 26 rays is illustrated by comparing the end points of the surfaces listed in Tables A-VII and A-IV. The changes in x , y are $(-0.009, 0.013)$ inch. The change in s is (-0.016) inch. Hence, the lens designer should be aware of the tendency of the final surface to move towards the first surface, possibly resulting in the design surface intercepting the first surface prior to the GLM wall at the maximum radius from the axis. This effect results in a decrease in aperture, a violation of the design criteria.

The final design surface is then drawn within an outline of the GLM shown in figure 21 illustrating the symmetry of

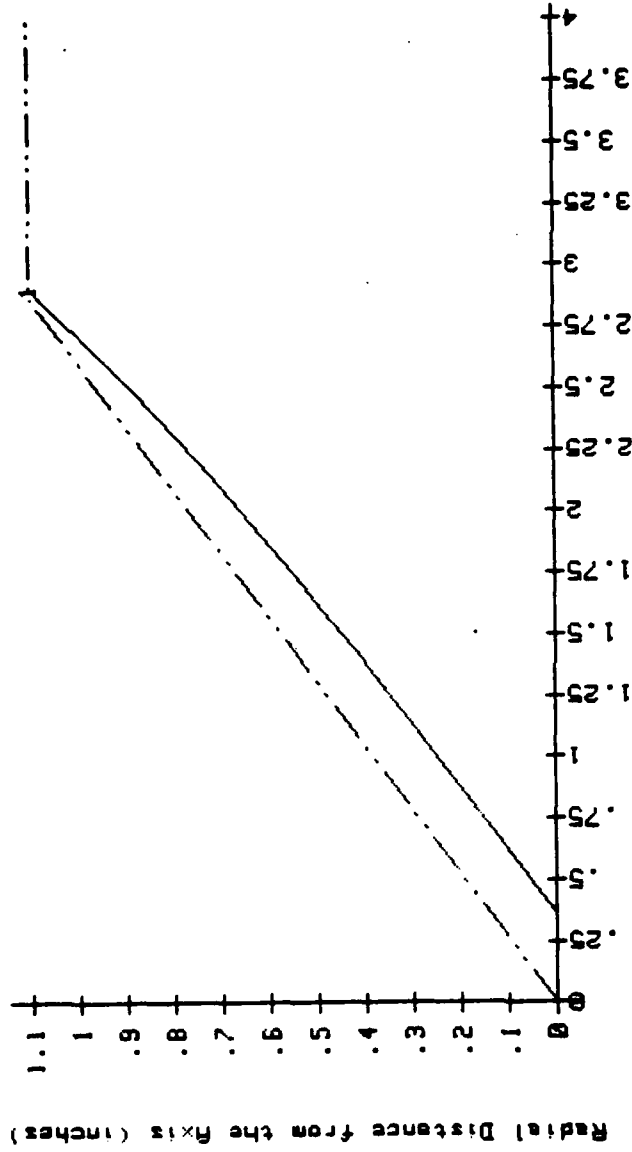


ALPHA2: Angle of the Tangent Line
at the Second Surface (Degrees)

Distance Along Refracted Ray in the Lens (Inches)

Design Focal Point : 4.88 inches Number of Rays : 26
Alpha : 21.00 deg n2 : 1.60000

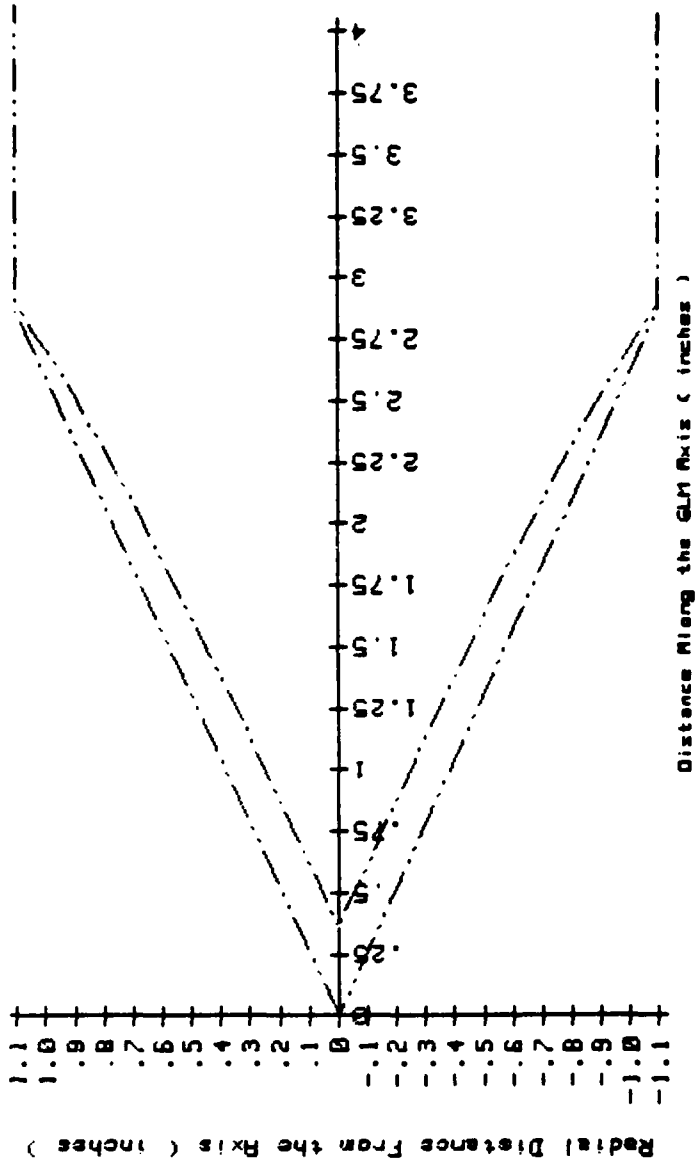
Figure 19. Final Design Chart Used to Calculate the Surface Number 1 in Figures 17 and 18.



SURFACE NUMBER 1

Design Focal Point : 4.00 inches Number of Rays : 26
 Alpha : 21.00 deg Aperture : .890 inch n2 : 1.00000

Figure 20. Final Design of the Second Surface of the Conical Lens Calculated from the Design Chart in Figure 19.



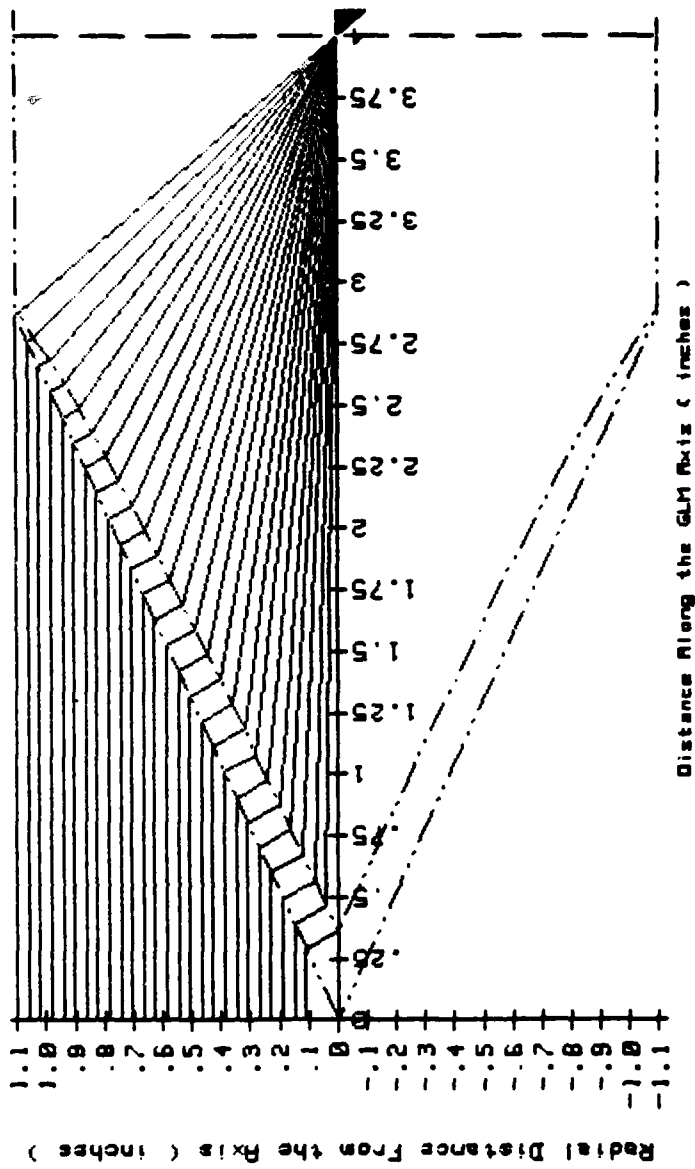
SURFACE NUMBER 1

Incident Ray Angle : 0.00 deg
 Aperture : .998 inch
 Alpha : 21.00 deg
 Number of Rays : 26
 n2 : 4.000000

Figure 21. Final Lens Design Illustrating the Symmetry and Position of the Lens in the GLM.

the design and the location of the lens within the missile.

A ray diagram using the final lens design shown in figure 22 with the distribution of the rays on the image plane shown in figure 23. The coordinate values used to draw the ray diagram in figure 22 are listed in Table A-VIII.

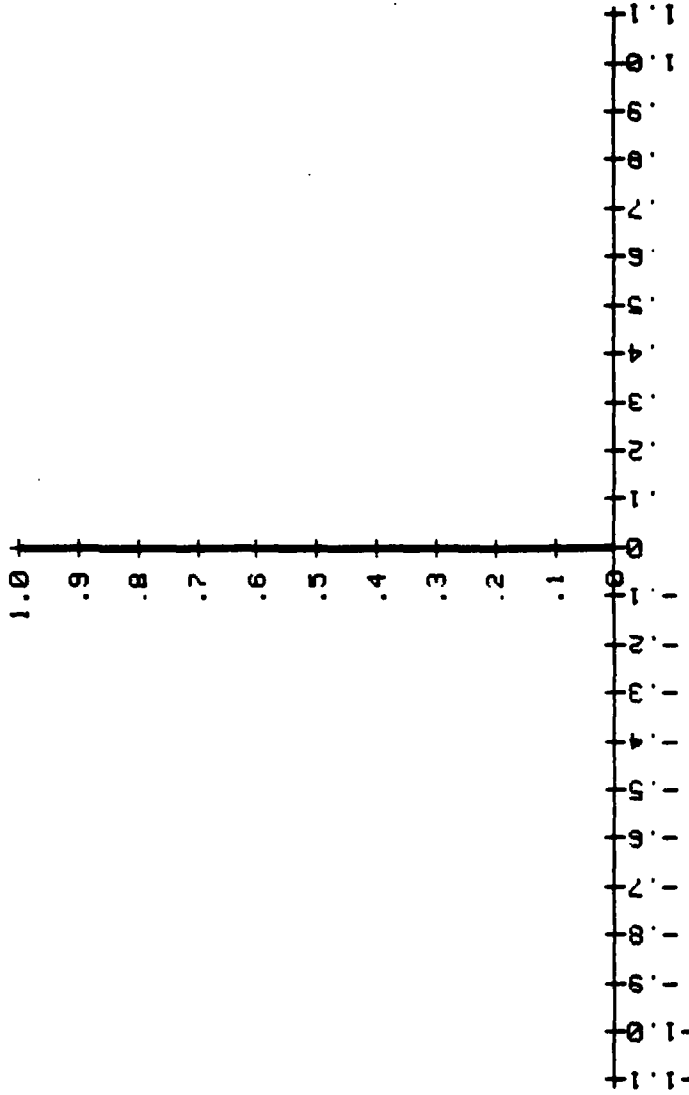


SURFACE NUMBER 1

Incident Ray Angle : 0.00 deg
 Aperture : .950 inch
 Alpha : 21.00 deg

Number of Rays : 26
 n2 : 4.000000
 Image Plane : 4.00 inch

Figure 22. Ray Diagram Showing the Trajectories of the Light Rays Through the Final Lens Design.



Normalized Number of Hits vs Distance from the GLM Axis

SURFACE NUMBER 1

Number of Rays : 26

Number of Hits on the Image Plane : 26 % of Rays to Image Plane : 100.00

Number of Increments (0,1,1) : 100

Image Plans : 1.00 inches

Figure 23. Histogram Showing the Distribution of Rays on the Image Plane in Figure 22.

IV. RECOMMENDATIONS FOR FUTURE WORK

This thesis investigated part of the properties of a conical lens. Future studies should investigate:

- a) the effect of skew rays on the image.
- b) the effect of total internal reflection on the image.
- c) the calculation of monochromatic and chromatic aberrations for the conical lens.
- d) the availability and applicability of materials to use for a lens.
- e) the effect on the incident rays of the shock wave in the air ahead of the GLM.
- f) the effect on the image of an object not on the lens axis.
- g) the effect on the image when the object is no longer in the far field and the curvature of the ray front must be taken into account.
- h) the ability of a conical lens to focus coherent and incoherent light.

V. CONCLUSIONS

The completed design of figure 22 indicates that a conical lens can focus incident light which is parallel to the GLM axis. The conical lens design is compatible with the aerodynamic requirements of high pressure recovery and low drag. The ability to provide optical guidance information to the GLM powered by an integral rocket ramjet may provide the battle group commander with an inexpensive ASMD weapon for shipboard use.

APPENDIX A

CHART SAMPLE OUTPUT AND PROGRAM LISTING

This appendix contains the program listing for CHART. The subroutines listed in Table A-I were copied or derived from the HP-9845 utilities library, cassette number 2, Ser. No. 09845-10205, program REGPLT.

Subroutines DRIVER, POLYNOMIAL and PLOT-CUBIC are not implemented in the present version of CHART because of time constraints. They are designed to be used to fit a polynomial of degree 3, a cubic, between four points to estimate the shape of the second surface. The requirement to fit a curve stems from the fact that the trajectory of a ray cannot be calculated if the ray does not coincide with a known ray trajectory. Hence, two options are open. The first is to calculate an infinite number of points on the second surface which is not practical. The second option is to estimate the actual shape of the second surface with an analytic expression, a cubic in this application. The error of the estimate can be reduced by designing a second surface with a large number of points. CHART has been written to design a lens with a maximum number of 250 points.

CHART, as implemented on the HP-9845T is a slow program. The design procedure described in chapter III requires approximately fifteen minutes for an experienced operator.

Therefore, if the initial and final design charts used more or less rays then the computation time should be scaled accordingly.

TABLE A-I

SUBROUTINES DERIVED FROM THE HP-9845B UTILITIES LIBRARY

<u>Name</u>	<u>Line Number</u>
Plot	3710
Laxes	5280
Driver	13910
Polynomial	14400
Plot-Cubic	14910
Min	21040
Max	21160

TABLE A-II

INITIAL PARAMETER VALUES

Alpha = 21.00 degrees	Rho-initial = 0.00
TAN(Alpha) = .38	TAN(RHO-INITIAL) = 0.00
RHO1 = -55.50 degrees	Theta(critical) = 14.40 degrees
GLN Radius = 1.10 inches	Yb = 1.10 inches
Aperture = 1.10 Ya = 0.00 inch	
n1 = 1.00000 n2 = 4.00000	n3 1.00000
Number of Rays = 10	
Design Focal Point = 4.00 inches	

TABLE A-III

CALCULATED DATA USED TO CONSTRUCT THE DESIGN CHART IN FIGURE 16.

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
1	-1.697	13.317	-68.820	0.000	21.180	-1.697
1	-1.697	13.326	-68.829	.007	21.171	-1.614
1	-1.697	13.335	-68.838	.013	21.162	-1.530
1	-1.697	13.344	-68.847	.020	21.153	-1.447
1	-1.697	13.354	-68.856	.027	21.144	-1.363
1	-1.697	13.363	-68.866	.033	21.134	-1.279
1	-1.697	13.372	-68.875	.040	21.125	-1.195
1	-1.697	13.381	-68.884	.047	21.116	-1.111
1	-1.697	13.390	-68.893	.053	21.107	-1.027
1	-1.697	13.399	-68.902	.060	21.098	-.942
1	-1.697	13.408	-68.911	.067	21.089	-.857
1	-1.697	13.417	-68.920	.073	21.080	-.772
1	-1.697	13.426	-68.929	.080	21.071	-.687
1	-1.697	13.435	-68.938	.087	21.062	-.602
1	-1.697	13.444	-68.947	.093	21.053	-.517
1	-1.697	13.453	-68.956	.100	21.044	-.431
1	-1.697	13.462	-68.965	.107	21.035	-.345
1	-1.697	13.471	-68.974	.113	21.026	-.259
1	-1.697	13.479	-68.982	.120	21.018	-.173
1	-1.697	13.488	-68.991	.127	21.009	-.087
1	-1.697	13.479	-68.982	.120	21.018	-.173
1	-1.697	13.480	-68.983	.121	21.017	-.164
1	-1.697	13.481	-68.984	.121	21.016	-.156
1	-1.697	13.482	-68.985	.122	21.015	-.147
1	-1.697	13.483	-68.986	.123	21.014	-.138
1	-1.697	13.484	-68.987	.123	21.013	-.130
1	-1.697	13.485	-68.988	.124	21.012	-.121
1	-1.697	13.486	-68.989	.125	21.011	-.112
1	-1.697	13.486	-68.989	.125	21.011	-.104
1	-1.697	13.487	-68.990	.126	21.010	-.095
1	-1.697	13.488	-68.991	.127	21.009	-.087
1	-1.697	13.489	-68.992	.127	21.008	-.078
1	-1.697	13.490	-68.993	.128	21.007	-.069
1	-1.697	13.491	-68.994	.129	21.006	-.061
1	-1.697	13.492	-68.995	.129	21.005	-.052
1	-1.697	13.493	-68.996	.130	21.004	-.043
1	-1.697	13.494	-68.996	.131	21.004	-.035
1	-1.697	13.494	-68.997	.131	21.003	-.026
1	-1.697	13.495	-68.998	.132	21.002	-.017
1	-1.697	13.496	-68.999	.133	21.001	-.009
1	-1.697	13.496	-68.999	.132	21.002	-.017
1	-1.697	13.495	-68.998	.132	21.002	-.016
1	-1.697	13.495	-68.998	.132	21.002	-.016
1	-1.697	13.496	-68.999	.132	21.001	-.015
1	-1.697	13.496	-68.999	.132	21.001	-.014
1	-1.697	13.496	-68.999	.132	21.001	-.013

TABLE A-III (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
2	-3.673	13.317	-68.828	.147	21.188	-1.696
2	-3.673	13.337	-68.840	.160	21.160	-1.511
2	-3.673	13.358	-68.861	.174	21.139	-1.325
2	-3.673	13.378	-68.881	.187	21.119	-1.139
2	-3.673	13.398	-68.901	.200	21.099	-.951
2	-3.673	13.418	-68.921	.214	21.079	-.763
2	-3.673	13.438	-68.941	.227	21.059	-.573
2	-3.673	13.458	-68.961	.240	21.039	-.383
2	-3.673	13.477	-68.980	.254	21.020	-.192
2	-3.673	13.498	-68.961	.240	21.039	-.383
2	-3.673	13.460	-68.963	.242	21.037	-.364
2	-3.673	13.462	-68.965	.243	21.035	-.345
2	-3.673	13.464	-68.967	.244	21.033	-.326
2	-3.673	13.466	-68.969	.246	21.031	-.307
2	-3.673	13.468	-68.971	.247	21.029	-.288
2	-3.673	13.470	-68.973	.248	21.027	-.268
2	-3.673	13.472	-68.975	.250	21.025	-.249
2	-3.673	13.474	-68.976	.251	21.024	-.230
2	-3.673	13.475	-68.978	.252	21.022	-.211
2	-3.673	13.477	-68.980	.254	21.020	-.192
2	-3.673	13.479	-68.982	.255	21.018	-.173
2	-3.673	13.481	-68.984	.256	21.016	-.154
2	-3.673	13.483	-68.986	.258	21.014	-.134
2	-3.673	13.485	-68.988	.259	21.012	-.115
2	-3.673	13.487	-68.990	.260	21.010	-.096
2	-3.673	13.489	-68.992	.262	21.008	-.077
2	-3.673	13.491	-68.994	.263	21.006	-.058
2	-3.673	13.493	-68.996	.264	21.004	-.038
2	-3.673	13.495	-68.998	.266	21.002	-.019
2	-3.673	13.493	-68.996	.264	21.004	-.038
2	-3.673	13.493	-68.996	.264	21.004	-.037
2	-3.673	13.494	-68.996	.265	21.004	-.035
2	-3.673	13.494	-68.997	.265	21.003	-.033
2	-3.673	13.494	-68.997	.265	21.003	-.031
2	-3.673	13.494	-68.997	.265	21.003	-.029
2	-3.673	13.494	-68.997	.265	21.003	-.027
2	-3.673	13.494	-68.997	.265	21.003	-.025
2	-3.673	13.493	-68.998	.265	21.002	-.023
2	-3.673	13.493	-68.998	.265	21.002	-.021
2	-3.673	13.493	-68.998	.266	21.002	-.019
2	-3.673	13.493	-68.998	.266	21.002	-.017
2	-3.673	13.493	-68.998	.266	21.002	-.015
2	-3.673	13.496	-68.999	.266	21.001	-.013
2	-3.673	13.496	-68.999	.266	21.001	-.012
2	-3.673	13.496	-68.999	.266	21.001	-.010
2	-3.673	13.496	-68.999	.266	21.001	-.008

TABLE A-III (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
3	-5.999	12.862	-68.365	.040	21.635	-5.442
3	-5.999	12.899	-68.402	.060	21.598	-5.160
3	-5.999	12.936	-68.439	.080	21.561	-4.876
3	-5.999	12.972	-68.475	.100	21.525	-4.589
3	-5.999	13.009	-68.512	.120	21.488	-4.300
3	-5.999	13.045	-68.548	.140	21.452	-4.009
3	-5.999	13.081	-68.584	.160	21.416	-3.715
3	-5.999	13.117	-68.620	.180	21.380	-3.419
3	-5.999	13.153	-68.656	.200	21.344	-3.120
3	-5.999	13.189	-68.692	.220	21.308	-2.819
3	-5.999	13.224	-68.727	.240	21.273	-2.516
3	-5.999	13.259	-68.762	.260	21.238	-2.210
3	-5.999	13.294	-68.797	.280	21.203	-1.902
3	-5.999	13.329	-68.831	.300	21.169	-1.591
3	-5.999	13.363	-68.866	.320	21.134	-1.278
3	-5.999	13.397	-68.900	.340	21.100	-.962
3	-5.999	13.431	-68.933	.360	21.067	-.644
3	-5.999	13.464	-68.967	.380	21.033	-.323
3	-5.999	13.497	-69.000	.400	21.000	-.000
3	-5.999	13.464	-68.967	.380	21.033	-.323
3	-5.999	13.467	-68.970	.382	21.030	-.291
3	-5.999	13.471	-68.974	.384	21.026	-.259
3	-5.999	13.474	-68.977	.386	21.023	-.227
3	-5.999	13.477	-68.980	.388	21.020	-.194
3	-5.999	13.481	-68.983	.390	21.017	-.162
3	-5.999	13.484	-68.987	.392	21.013	-.130
3	-5.999	13.487	-68.990	.394	21.010	-.097
3	-5.999	13.490	-68.993	.396	21.007	-.065
3	-5.999	13.494	-68.997	.398	21.003	-.032
3	-5.999	13.497	-69.000	.400	21.000	-.000
3	-5.999	13.494	-68.997	.398	21.003	-.032
3	-5.999	13.494	-68.997	.399	21.003	-.029
3	-5.999	13.494	-68.997	.399	21.003	-.026
3	-5.999	13.495	-68.998	.399	21.002	-.023
3	-5.999	13.495	-68.998	.399	21.002	-.019
3	-5.999	13.495	-68.998	.399	21.002	-.016
3	-5.999	13.496	-68.999	.400	21.001	-.013
3	-5.999	13.496	-68.999	.400	21.001	-.010
3	-5.999	13.496	-68.999	.400	21.001	-.006
3	-5.999	13.497	-69.000	.400	21.000	-.003
3	-5.999	13.497	-69.000	.400	21.000	-.000
3	-5.999	13.497	-69.000	.400	21.000	-.003
3	-5.999	13.497	-69.000	.400	21.000	-.003
3	-5.999	13.497	-69.000	.400	21.000	-.003
3	-5.999	13.497	-69.000	.400	21.000	-.002
3	-5.999	13.497	-69.000	.400	21.000	-.002

TABLE A-III (CONT)

RAY	BETA	THETA(CRAY)	NORMAL	S	ALPHA2	RHO 2
3	-5.999	13.497	-69.000	.400	21.000	-.002
3	-5.999	13.497	-69.000	.400	21.000	-.001
3	-5.999	13.497	-69.000	.400	21.000	-.001
3	-5.999	13.497	-69.000	.400	21.000	-.001
3	-5.999	13.497	-69.000	.400	21.000	-.000
3	-5.999	13.497	-69.000	.400	21.000	-.000
3	-5.999	13.497	-69.000	.400	21.000	-.000
3	-5.999	13.497	-69.000	.400	21.000	-.000
3	-5.999	13.497	-69.000	.400	21.000	-.000
3	-5.999	13.497	-69.000	.400	21.000	-.000
3	-5.999	13.497	-69.000	.400	21.000	-.000
3	-5.999	13.497	-69.000	.400	21.000	-.000
3	-5.999	13.497	-69.000	.400	21.000	-.000
3	-5.999	13.497	-69.000	.400	21.000	-.000
3	-5.999	13.497	-69.000	.400	21.000	-.000
4	-8.765	12.391	-67.894	0.000	22.106	-8.765
4	-8.765	12.449	-67.952	.027	22.048	-8.377
4	-8.765	12.507	-68.010	.053	21.990	-7.984
4	-8.765	12.565	-68.068	.080	21.932	-7.586
4	-8.765	12.623	-68.126	.107	21.874	-7.182
4	-8.765	12.681	-68.184	.133	21.816	-6.774
4	-8.765	12.738	-68.241	.160	21.759	-6.361
4	-8.765	12.795	-68.298	.187	21.702	-5.942
4	-8.765	12.852	-68.355	.214	21.645	-5.518
4	-8.765	12.908	-68.411	.240	21.589	-5.089
4	-8.765	12.964	-68.467	.267	21.533	-4.654
4	-8.765	13.020	-68.523	.294	21.477	-4.214
4	-8.765	13.075	-68.578	.320	21.422	-3.768
4	-8.765	13.130	-68.633	.347	21.367	-3.317
4	-8.765	13.184	-68.687	.374	21.313	-2.860
4	-8.765	13.238	-68.741	.400	21.259	-2.398
4	-8.765	13.291	-68.794	.427	21.206	-1.930
4	-8.765	13.343	-68.846	.454	21.154	-1.456
4	-8.765	13.395	-68.898	.480	21.102	-.976
4	-8.765	13.447	-68.949	.507	21.051	-.491
4	-8.765	13.447	-68.949	.507	21.051	-.491
4	-8.765	13.452	-68.955	.510	21.045	-.442
4	-8.765	13.457	-68.960	.513	21.040	-.393
4	-8.765	13.462	-68.965	.515	21.035	-.344
4	-8.765	13.467	-68.970	.518	21.030	-.295
4	-8.765	13.472	-68.975	.521	21.025	-.246
4	-8.765	13.477	-68.980	.523	21.020	-.197
4	-8.765	13.482	-68.985	.526	21.015	-.148

TABLE A-III (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
4	-0.765	13.487	-68.998	.529	21.010	-.099
4	-0.765	13.492	-68.995	.531	21.005	-.049
4	-0.765	13.492	-68.995	.531	21.005	-.049
4	-0.765	13.493	-68.995	.531	21.005	-.044
4	-0.765	13.493	-68.996	.532	21.004	-.040
4	-0.765	13.494	-68.996	.532	21.004	-.035
4	-0.765	13.494	-68.997	.532	21.003	-.030
4	-0.765	13.495	-68.997	.533	21.003	-.025
4	-0.765	13.495	-68.998	.533	21.002	-.020
4	-0.765	13.496	-68.998	.533	21.002	-.015
4	-0.765	13.496	-68.999	.533	21.001	-.010
4	-0.765	13.497	-68.999	.534	21.001	-.005
4	-0.765	13.497	-68.999	.534	21.001	-.005
4	-0.765	13.497	-69.000	.534	21.000	-.004
4	-0.765	13.497	-69.000	.534	21.000	-.004
4	-0.765	13.497	-69.000	.534	21.000	-.003
4	-0.765	13.497	-69.000	.534	21.000	-.003
4	-0.765	13.497	-69.000	.534	21.000	-.002
4	-0.765	13.497	-69.000	.534	21.000	-.002
4	-0.765	13.497	-69.000	.534	21.000	-.001
4	-0.765	13.497	-69.000	.534	21.000	-.001
4	-0.765	13.497	-69.000	.534	21.000	-.000
4	-0.765	13.497	-69.000	.534	21.000	-.000
4	-0.765	13.497	-69.000	.534	21.000	-.000
4	-0.765	13.497	-69.000	.534	21.000	-.000
4	-0.765	13.497	-69.000	.534	21.000	-.000
4	-0.765	13.497	-69.000	.534	21.000	-.000
4	-0.765	13.497	-69.000	.534	21.000	-.000
4	-0.765	13.497	-69.000	.534	21.000	-.000
4	-0.765	13.497	-69.000	.534	21.000	-.000
5	-12.092	11.956	-67.359	0.000	22.641	-12.092
5	-12.092	11.941	-67.444	.033	22.556	-11.507
5	-12.092	12.027	-67.530	.067	22.470	-11.073
5	-12.092	12.112	-67.615	.100	22.385	-10.549
5	-12.092	12.197	-67.700	.133	22.300	-10.015
5	-12.092	12.283	-67.786	.167	22.214	-9.471
5	-12.092	12.368	-67.871	.200	22.129	-8.917
5	-12.092	12.453	-67.956	.234	22.044	-8.353
5	-12.092	12.537	-68.040	.267	21.960	-7.778
5	-12.092	12.622	-68.125	.300	21.875	-7.192
5	-12.092	12.705	-68.200	.334	21.792	-6.596
5	-12.092	12.789	-68.292	.367	21.700	-5.999
5	-12.092	12.871	-68.374	.400	21.626	-5.370

TABLE A-III (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
5	-12.092	12.959	-68.456	.434	21.544	-4.740
5	-12.092	13.034	-68.537	.467	21.463	-4.099
5	-12.092	13.114	-68.617	.501	21.383	-3.446
5	-12.092	13.193	-68.696	.534	21.304	-2.781
5	-12.092	13.271	-68.774	.567	21.226	-2.104
5	-12.092	13.348	-68.851	.601	21.149	-1.415
5	-12.092	13.423	-68.926	.634	21.074	-.714
5	-12.092	13.348	-68.851	.601	21.149	-1.415
5	-12.092	13.355	-68.858	.604	21.142	-1.345
5	-12.092	13.363	-68.866	.607	21.134	-1.275
5	-12.092	13.371	-68.874	.611	21.126	-1.206
5	-12.092	13.378	-68.881	.614	21.119	-1.136
5	-12.092	13.386	-68.889	.617	21.111	-1.066
5	-12.092	13.393	-68.896	.621	21.104	-.995
5	-12.092	13.401	-68.904	.624	21.096	-.925
5	-12.092	13.408	-68.911	.627	21.089	-.855
5	-12.092	13.416	-68.919	.631	21.081	-.784
5	-12.092	13.423	-68.926	.634	21.074	-.714
5	-12.092	13.431	-68.934	.637	21.066	-.643
5	-12.092	13.438	-68.941	.641	21.059	-.572
5	-12.092	13.446	-68.948	.644	21.052	-.501
5	-12.092	13.453	-68.956	.647	21.044	-.430
5	-12.092	13.460	-68.963	.651	21.037	-.358
5	-12.092	13.468	-68.971	.654	21.029	-.287
5	-12.092	13.475	-68.978	.657	21.022	-.215
5	-12.092	13.482	-68.985	.661	21.015	-.144
5	-12.092	13.490	-68.993	.664	21.007	-.072
5	-12.092	13.482	-68.985	.661	21.015	-.144
5	-12.092	13.483	-68.986	.661	21.014	-.137
5	-12.092	13.484	-68.987	.661	21.013	-.129
5	-12.092	13.485	-68.988	.662	21.012	-.122
5	-12.092	13.485	-68.988	.662	21.012	-.115
5	-12.092	13.486	-68.989	.662	21.011	-.108
5	-12.092	13.487	-68.990	.663	21.010	-.101
5	-12.092	13.488	-68.990	.663	21.010	-.093
5	-12.092	13.488	-68.991	.663	21.009	-.086
5	-12.092	13.489	-68.992	.664	21.008	-.079
5	-12.092	13.490	-68.993	.664	21.007	-.072
5	-12.092	13.490	-68.993	.664	21.007	-.065
5	-12.092	13.491	-68.994	.665	21.006	-.058
5	-12.092	13.492	-68.995	.665	21.005	-.050
5	-12.092	13.493	-68.996	.665	21.004	-.043
5	-12.092	13.493	-68.996	.666	21.004	-.036
5	-12.092	13.494	-68.997	.666	21.003	-.029
5	-12.092	13.495	-68.998	.666	21.002	-.022
5	-12.092	13.496	-68.999	.667	21.001	-.014

TABLE A-III (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
5	-12.092	13.496	-68.999	.667	21.001	-.007
5	-12.092	13.497	-69.000	.667	21.000	-.000
5	-12.092	13.496	-68.999	.667	21.001	-.007
5	-12.092	13.496	-68.999	.667	21.001	-.006
5	-12.092	13.496	-68.999	.667	21.001	-.006
5	-12.092	13.497	-68.999	.667	21.001	-.005
5	-12.092	13.497	-69.000	.667	21.000	-.004
5	-12.092	13.497	-69.000	.667	21.000	-.004
5	-12.092	13.497	-69.000	.667	21.000	-.003
5	-12.092	13.497	-69.000	.667	21.000	-.002
5	-12.092	13.497	-69.000	.667	21.000	-.001
5	-12.092	13.497	-69.000	.667	21.000	-.001
5	-12.092	13.497	-69.000	.667	21.000	-.000
5	-12.092	13.497	-69.000	.667	21.000	-.001
5	-12.092	13.497	-69.000	.667	21.000	-.001
5	-12.092	13.497	-69.000	.667	21.000	-.000
5	-12.092	13.497	-69.000	.667	21.000	-.000
5	-12.092	13.497	-69.000	.667	21.000	-.000
5	-12.092	13.497	-69.000	.667	21.000	-.000
5	-12.092	13.497	-69.000	.667	21.000	-.000
5	-12.092	13.497	-69.000	.667	21.000	-.000
5	-12.092	13.497	-69.000	.667	21.000	-.000
5	-12.092	13.497	-69.000	.667	21.000	-.000
5	-12.092	13.497	-69.000	.667	21.000	-.000
6	-16.140	11.120	-66.623	0.000	23.377	-16.140
6	-16.140	11.239	-66.742	.040	23.250	-15.519
6	-16.140	11.359	-66.862	.080	23.130	-14.882
6	-16.140	11.479	-66.982	.120	23.010	-14.227
6	-16.140	11.601	-67.104	.160	22.896	-13.556
6	-16.140	11.723	-67.226	.200	22.774	-12.866
6	-16.140	11.845	-67.348	.240	22.652	-12.157
6	-16.140	11.968	-67.471	.280	22.529	-11.430
6	-16.140	12.090	-67.593	.320	22.407	-10.683
6	-16.140	12.213	-67.716	.360	22.284	-9.916
6	-16.140	12.336	-67.839	.400	22.161	-9.128
6	-16.140	12.458	-67.961	.440	22.039	-8.319
6	-16.140	12.579	-68.082	.480	21.918	-7.480
6	-16.140	12.700	-68.203	.521	21.797	-6.635
6	-16.140	12.819	-68.322	.561	21.678	-5.759
6	-16.140	12.938	-68.441	.601	21.559	-4.860
6	-16.140	13.054	-68.557	.641	21.443	-3.937
6	-16.140	13.169	-68.672	.681	21.328	-2.990
6	-16.140	13.281	-68.784	.721	21.216	-2.019
6	-16.140	13.390	-68.893	.761	21.107	-1.022
6	-16.140	13.281	-68.784	.721	21.216	-2.019

TABLE A-III (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
6	-16.140	13.292	-68.795	.725	21.205	-1.920
6	-16.140	13.303	-68.806	.729	21.194	-1.821
6	-16.140	13.314	-68.817	.733	21.183	-1.722
6	-16.140	13.325	-68.828	.737	21.172	-1.623
6	-16.140	13.336	-68.839	.741	21.161	-1.524
6	-16.140	13.347	-68.850	.745	21.150	-1.424
6	-16.140	13.358	-68.861	.749	21.139	-1.324
6	-16.140	13.369	-68.872	.753	21.128	-1.223
6	-16.140	13.380	-68.883	.757	21.117	-1.123
6	-16.140	13.390	-68.893	.761	21.107	-1.022
6	-16.140	13.401	-68.904	.765	21.096	-.921
6	-16.140	13.412	-68.915	.769	21.085	-.820
6	-16.140	13.423	-68.926	.773	21.074	-.718
6	-16.140	13.433	-68.936	.777	21.064	-.616
6	-16.140	13.444	-68.947	.781	21.053	-.514
6	-16.140	13.455	-68.958	.785	21.042	-.412
6	-16.140	13.465	-68.968	.789	21.032	-.309
6	-16.140	13.476	-68.979	.793	21.021	-.206
6	-16.140	13.487	-68.989	.797	21.011	-.103
6	-16.140	13.476	-68.979	.793	21.021	-.206
6	-16.140	13.477	-68.980	.793	21.020	-.196
6	-16.140	13.478	-68.981	.794	21.019	-.186
6	-16.140	13.479	-68.982	.794	21.018	-.176
6	-16.140	13.480	-68.983	.794	21.017	-.165
6	-16.140	13.481	-68.984	.795	21.016	-.155
6	-16.140	13.482	-68.985	.795	21.015	-.145
6	-16.140	13.483	-68.986	.796	21.014	-.134
6	-16.140	13.484	-68.987	.796	21.013	-.124
6	-16.140	13.485	-68.988	.796	21.012	-.114
6	-16.140	13.487	-68.989	.797	21.011	-.103
6	-16.140	13.488	-68.991	.797	21.009	-.093
6	-16.140	13.489	-68.992	.798	21.008	-.083
6	-16.140	13.490	-68.993	.798	21.007	-.072
6	-16.140	13.491	-68.994	.798	21.006	-.062
6	-16.140	13.492	-68.995	.799	21.005	-.052
6	-16.140	13.493	-68.996	.799	21.004	-.041
6	-16.140	13.494	-68.997	.800	21.003	-.031
6	-16.140	13.495	-68.998	.800	21.002	-.021
6	-16.140	13.496	-68.999	.800	21.001	-.010
6	-16.140	13.495	-68.998	.800	21.002	-.021
6	-16.140	13.495	-68.998	.800	21.002	-.019
6	-16.140	13.495	-68.998	.800	21.002	-.018
6	-16.140	13.495	-68.998	.800	21.002	-.017
6	-16.140	13.495	-68.998	.800	21.002	-.016
6	-16.140	13.496	-68.999	.800	21.001	-.014

TABLE A-III (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
6	-16.140	13.496	-68.999	.800	21.001	-.013
6	-16.140	13.496	-68.999	.800	21.001	-.012
6	-16.140	13.496	-68.999	.800	21.001	-.011
6	-16.140	13.496	-68.999	.800	21.001	-.010
6	-16.140	13.496	-68.999	.800	21.001	-.009
6	-16.140	13.496	-68.999	.800	21.001	-.008
6	-16.140	13.496	-68.999	.801	21.001	-.007
6	-16.140	13.496	-68.999	.801	21.001	-.006
6	-16.140	13.497	-68.999	.801	21.001	-.005
6	-16.140	13.497	-69.000	.801	21.000	-.004
6	-16.140	13.497	-69.000	.801	21.000	-.003
6	-16.140	13.497	-69.000	.801	21.000	-.002
6	-16.140	13.497	-69.000	.801	21.000	-.001
6	-16.140	13.497	-69.000	.801	21.000	-.000
7	-21.114	10.008	-65.591	0.000	24.409	-21.114
7	-21.114	10.246	-65.749	.047	24.251	-20.394
7	-21.114	10.406	-65.909	.093	24.091	-19.647
7	-21.114	10.570	-66.073	.140	23.927	-18.872
7	-21.114	10.736	-66.239	.187	23.761	-18.068
7	-21.114	10.905	-66.408	.234	23.592	-17.233
7	-21.114	11.076	-66.579	.280	23.421	-16.366
7	-21.114	11.249	-66.752	.327	23.248	-15.466
7	-21.114	11.424	-66.926	.374	23.074	-14.531
7	-21.114	11.600	-67.103	.420	22.897	-13.560
7	-21.114	11.778	-67.280	.467	22.720	-12.550
7	-21.114	11.956	-67.459	.514	22.541	-11.500
7	-21.114	12.135	-67.637	.561	22.363	-10.410
7	-21.114	12.313	-67.816	.607	22.184	-9.276
7	-21.114	12.491	-67.994	.654	22.006	-8.097
7	-21.114	12.667	-68.170	.701	21.830	-6.872
7	-21.114	12.841	-68.344	.747	21.656	-5.599
7	-21.114	13.012	-68.515	.794	21.485	-4.277
7	-21.114	13.179	-68.682	.841	21.318	-2.904
7	-21.114	13.341	-68.844	.888	21.156	-1.479
7	-21.114	13.179	-68.682	.841	21.318	-2.904
7	-21.114	13.195	-68.690	.846	21.302	-2.764
7	-21.114	13.212	-68.715	.850	21.285	-2.623
7	-21.114	13.228	-68.731	.855	21.269	-2.482
7	-21.114	13.244	-68.747	.860	21.253	-2.340
7	-21.114	13.260	-68.763	.864	21.237	-2.198
7	-21.114	13.277	-68.780	.869	21.220	-2.055
7	-21.114	13.293	-68.796	.874	21.204	-1.912
7	-21.114	13.309	-68.812	.878	21.188	-1.768
7	-21.114	13.325	-68.828	.883	21.172	-1.624
7	-21.114	13.341	-68.844	.888	21.156	-1.479

TABLE A-III (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
7	-21.114	13.357	-68.868	.892	21.148	-1.333
7	-21.114	13.373	-68.876	.897	21.124	-1.187
7	-21.114	13.388	-68.891	.902	21.109	-1.041
7	-21.114	13.404	-68.907	.906	21.093	-.894
7	-21.114	13.420	-68.923	.911	21.077	-.746
7	-21.114	13.435	-68.938	.916	21.062	-.598
7	-21.114	13.451	-68.954	.920	21.046	-.449
7	-21.114	13.466	-68.969	.925	21.031	-.300
7	-21.114	13.482	-68.985	.930	21.015	-.150
7	-21.114	13.497	-69.000	.934	21.000	-.000
8	-27.265	8.626	-64.129	0.000	25.871	-27.265
8	-27.265	8.820	-64.323	.053	25.677	-26.493
8	-27.265	9.021	-64.524	.107	25.476	-25.681
8	-27.265	9.229	-64.732	.160	25.268	-24.827
8	-27.265	9.444	-64.947	.214	25.053	-23.928
8	-27.265	9.665	-65.168	.267	24.832	-22.980
8	-27.265	9.894	-65.397	.320	24.603	-21.981
8	-27.265	10.129	-65.632	.374	24.368	-20.926
8	-27.265	10.371	-65.874	.427	24.126	-19.812
8	-27.265	10.620	-66.122	.480	23.878	-18.634
8	-27.265	10.874	-66.377	.534	23.623	-17.387
8	-27.265	11.134	-66.637	.587	23.363	-16.067
8	-27.265	11.398	-66.901	.641	23.099	-14.669
8	-27.265	11.666	-67.169	.694	22.831	-13.188
8	-27.265	11.936	-67.439	.747	22.561	-11.617
8	-27.265	12.208	-67.711	.801	22.289	-9.951
8	-27.265	12.478	-67.981	.854	22.019	-8.184
8	-27.265	12.745	-68.248	.908	21.752	-6.311
8	-27.265	13.006	-68.509	.961	21.491	-4.326
8	-27.265	13.258	-68.761	1.014	21.239	-2.224
8	-27.265	13.006	-68.509	.961	21.491	-4.326
8	-27.265	13.031	-68.534	.966	21.466	-4.121
8	-27.265	13.057	-68.560	.972	21.440	-3.915
8	-27.265	13.082	-68.585	.977	21.415	-3.708
8	-27.265	13.108	-68.611	.982	21.389	-3.500
8	-27.265	13.133	-68.636	.988	21.364	-3.290
8	-27.265	13.158	-68.661	.993	21.339	-3.079
8	-27.265	13.183	-68.686	.998	21.314	-2.867
8	-27.265	13.208	-68.711	1.004	21.289	-2.654
8	-27.265	13.233	-68.736	1.009	21.264	-2.440
8	-27.265	13.258	-68.761	1.014	21.239	-2.224
8	-27.265	13.282	-68.785	1.020	21.215	-2.007
8	-27.265	13.307	-68.810	1.025	21.190	-1.789
8	-27.265	13.331	-68.834	1.030	21.166	-1.570
8	-27.265	13.355	-68.858	1.036	21.142	-1.349

TABLE A-III (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
0	-27.265	13.379	-68.882	1.041	21.118	-1.127
0	-27.265	13.403	-68.906	1.046	21.094	-.984
0	-27.265	13.427	-68.930	1.052	21.070	-.680
0	-27.265	13.450	-68.953	1.057	21.047	-.455
0	-27.265	13.474	-68.977	1.062	21.023	-.228
0	-27.265	13.498	-68.953	1.057	21.047	-.455
0	-27.265	13.453	-68.956	1.058	21.044	-.432
0	-27.265	13.455	-68.958	1.058	21.042	-.409
0	-27.265	13.457	-68.960	1.059	21.040	-.387
0	-27.265	13.460	-68.963	1.059	21.037	-.364
0	-27.265	13.462	-68.965	1.060	21.035	-.341
0	-27.265	13.464	-68.967	1.060	21.033	-.319
0	-27.265	13.467	-68.970	1.061	21.030	-.296
0	-27.265	13.469	-68.972	1.061	21.028	-.273
0	-27.265	13.471	-68.974	1.062	21.026	-.251
0	-27.265	13.474	-68.977	1.062	21.023	-.228
0	-27.265	13.476	-68.979	1.063	21.021	-.205
0	-27.265	13.478	-68.981	1.063	21.019	-.182
0	-27.265	13.481	-68.984	1.064	21.016	-.160
0	-27.265	13.483	-68.986	1.065	21.014	-.137
0	-27.265	13.485	-68.988	1.065	21.012	-.114
0	-27.265	13.488	-68.991	1.066	21.009	-.091
0	-27.265	13.490	-68.993	1.066	21.007	-.069
0	-27.265	13.492	-68.995	1.067	21.005	-.046
0	-27.265	13.495	-68.998	1.067	21.002	-.023
0	-27.265	13.492	-68.995	1.067	21.005	-.046
0	-27.265	13.493	-68.996	1.067	21.004	-.043
0	-27.265	13.493	-68.996	1.067	21.004	-.041
0	-27.265	13.493	-68.996	1.067	21.004	-.039
0	-27.265	13.493	-68.996	1.067	21.004	-.037
0	-27.265	13.494	-68.997	1.067	21.003	-.034
0	-27.265	13.494	-68.997	1.067	21.003	-.032
0	-27.265	13.494	-68.997	1.067	21.003	-.030
0	-27.265	13.494	-68.997	1.067	21.003	-.027
0	-27.265	13.494	-68.997	1.067	21.003	-.025
0	-27.265	13.495	-68.998	1.067	21.002	-.023
0	-27.265	13.495	-68.998	1.067	21.002	-.021
0	-27.265	13.495	-68.998	1.067	21.002	-.018
0	-27.265	13.495	-68.998	1.067	21.002	-.016
0	-27.265	13.496	-68.999	1.067	21.001	-.014
0	-27.265	13.496	-68.999	1.067	21.001	-.011
0	-27.265	13.496	-68.999	1.068	21.001	-.009
0	-27.265	13.496	-68.999	1.068	21.001	-.007
0	-27.265	13.497	-69.000	1.068	21.000	-.005
0	-27.265	13.497	-69.000	1.068	21.000	-.002
0	-27.265	13.497	-69.000	1.068	21.000	-.005

TABLE A-III (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
8	-27.265	13.497	-69.000	1.068	21.000	-.004
8	-27.265	13.497	-69.000	1.068	21.000	-.004
8	-27.265	13.497	-69.000	1.068	21.000	-.004
8	-27.265	13.497	-69.000	1.068	21.000	-.004
8	-27.265	13.497	-69.000	1.068	21.000	-.003
8	-27.265	13.497	-69.000	1.068	21.000	-.003
8	-27.265	13.497	-69.000	1.068	21.000	-.003
8	-27.265	13.497	-69.000	1.068	21.000	-.003
8	-27.265	13.497	-69.000	1.068	21.000	-.003
8	-27.265	13.497	-69.000	1.068	21.000	-.002
8	-27.265	13.497	-69.000	1.068	21.000	-.002
8	-27.265	13.497	-69.000	1.068	21.000	-.002
8	-27.265	13.497	-69.000	1.068	21.000	-.002
8	-27.265	13.497	-69.000	1.068	21.000	-.001
8	-27.265	13.497	-69.000	1.068	21.000	-.001
8	-27.265	13.497	-69.000	1.068	21.000	-.001
8	-27.265	13.497	-69.000	1.068	21.000	-.000
8	-27.265	13.497	-69.000	1.068	21.000	-.000
9	-34.865	6.562	-62.065	0.000	27.935	-34.865
9	-34.865	6.769	-62.272	.060	27.728	-34.142
9	-34.865	6.989	-62.492	.120	27.508	-33.368
9	-34.865	7.221	-62.724	.180	27.276	-32.539
9	-34.865	7.467	-62.970	.240	27.030	-31.649
9	-34.865	7.728	-63.231	.300	26.769	-30.693
9	-34.865	8.004	-63.507	.360	26.493	-29.661
9	-34.865	8.296	-63.799	.420	26.201	-28.547
9	-34.865	8.606	-64.109	.480	25.891	-27.341
9	-34.865	8.935	-64.437	.541	25.563	-26.032
9	-34.865	9.282	-64.785	.601	25.215	-24.608
9	-34.865	9.648	-65.151	.661	24.849	-23.054
9	-34.865	10.034	-65.537	.721	24.463	-21.356
9	-34.865	10.439	-65.942	.781	24.058	-19.495
9	-34.865	10.861	-66.364	.841	23.636	-17.452
9	-34.865	11.298	-66.801	.901	23.199	-15.204
9	-34.865	11.747	-67.250	.961	22.750	-12.727
9	-34.865	12.201	-67.704	1.021	22.296	-9.994
9	-34.865	12.652	-68.155	1.081	21.845	-6.980
9	-34.865	13.089	-68.592	1.141	21.400	-3.656
9	-34.865	12.652	-68.155	1.081	21.845	-6.980
9	-34.865	12.696	-68.199	1.087	21.801	-6.662
9	-34.865	12.741	-68.244	1.093	21.756	-6.341
9	-34.865	12.785	-68.288	1.099	21.712	-6.016
9	-34.865	12.829	-68.332	1.105	21.668	-5.689
9	-34.865	12.873	-68.376	1.111	21.624	-5.358

TABLE A-III (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
9	-34.865	12.916	-68.419	1.117	21.581	-5.824
9	-34.865	12.960	-68.463	1.123	21.537	-4.687
9	-34.865	13.003	-68.506	1.129	21.494	-4.347
9	-34.865	13.046	-68.549	1.135	21.451	-4.003
9	-34.865	13.089	-68.592	1.141	21.408	-3.656
9	-34.865	13.131	-68.634	1.147	21.366	-3.306
9	-34.865	13.173	-68.676	1.153	21.324	-2.952
9	-34.865	13.215	-68.718	1.159	21.282	-2.595
9	-34.865	13.256	-68.759	1.165	21.241	-2.235
9	-34.865	13.297	-68.800	1.171	21.200	-1.871
9	-34.865	13.338	-68.841	1.177	21.159	-1.504
9	-34.865	13.378	-68.881	1.183	21.119	-1.133
9	-34.865	13.418	-68.921	1.189	21.079	-.759
9	-34.865	13.458	-68.961	1.195	21.039	-.381
9	-34.865	13.418	-68.921	1.189	21.079	-.759
9	-34.865	13.422	-68.925	1.190	21.075	-.721
9	-34.865	13.426	-68.929	1.190	21.071	-.684
9	-34.865	13.430	-68.933	1.191	21.067	-.646
9	-34.865	13.434	-68.937	1.192	21.063	-.608
9	-34.865	13.438	-68.941	1.192	21.059	-.570
9	-34.865	13.442	-68.945	1.193	21.055	-.533
9	-34.865	13.446	-68.949	1.193	21.051	-.495
9	-34.865	13.450	-68.953	1.194	21.047	-.457
9	-34.865	13.454	-68.957	1.195	21.043	-.419
9	-34.865	13.458	-68.961	1.195	21.039	-.381
9	-34.865	13.462	-68.965	1.196	21.035	-.343
9	-34.865	13.466	-68.969	1.196	21.031	-.305
9	-34.865	13.470	-68.973	1.197	21.027	-.267
9	-34.865	13.474	-68.977	1.198	21.023	-.229
9	-34.865	13.478	-68.981	1.198	21.019	-.191
9	-34.865	13.481	-68.984	1.199	21.016	-.153
9	-34.865	13.485	-68.988	1.199	21.012	-.115
9	-34.865	13.489	-68.992	1.200	21.008	-.077
9	-34.865	13.493	-68.996	1.201	21.004	-.038
9	-34.865	13.489	-68.992	1.200	21.008	-.077
9	-34.865	13.490	-68.993	1.200	21.007	-.073
9	-34.865	13.490	-68.993	1.200	21.007	-.069
9	-34.865	13.490	-68.993	1.200	21.007	-.065
9	-34.865	13.491	-68.994	1.200	21.006	-.061
9	-34.865	13.491	-68.994	1.200	21.006	-.057
9	-34.865	13.492	-68.995	1.200	21.005	-.054
9	-34.865	13.492	-68.995	1.200	21.005	-.050
9	-34.865	13.492	-68.995	1.201	21.005	-.046
9	-34.865	13.493	-68.996	1.201	21.004	-.042
9	-34.865	13.493	-68.996	1.201	21.004	-.038
9	-34.865	13.494	-68.997	1.201	21.003	-.034

TABLE A-III (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
9	-34.865	13.494	-68.997	1.201	21.003	-.031
9	-34.865	13.494	-68.997	1.201	21.003	-.027
9	-34.865	13.495	-68.998	1.201	21.002	-.023
9	-34.865	13.495	-68.998	1.201	21.002	-.019
9	-34.865	13.495	-68.998	1.201	21.002	-.015
9	-34.865	13.496	-68.999	1.201	21.001	-.011
9	-34.865	13.496	-68.999	1.201	21.001	-.008
9	-34.865	13.497	-69.000	1.201	21.000	-.004
9	-34.865	13.496	-68.999	1.201	21.001	-.008
9	-34.865	13.496	-68.999	1.201	21.001	-.007
9	-34.865	13.496	-68.999	1.201	21.001	-.007
9	-34.865	13.496	-68.999	1.201	21.001	-.006
9	-34.865	13.496	-68.999	1.201	21.001	-.006
9	-34.865	13.496	-68.999	1.201	21.001	-.005
9	-34.865	13.497	-69.000	1.201	21.001	-.005
9	-34.865	13.497	-69.000	1.201	21.000	-.004
9	-34.865	13.497	-69.000	1.201	21.000	-.004
9	-34.865	13.497	-69.000	1.201	21.000	-.003
9	-34.865	13.497	-69.000	1.201	21.000	-.003
9	-34.865	13.497	-69.000	1.201	21.000	-.003
9	-34.865	13.497	-69.000	1.201	21.000	-.002
9	-34.865	13.497	-69.000	1.201	21.000	-.002
9	-34.865	13.497	-69.000	1.201	21.000	-.002
9	-34.865	13.497	-69.000	1.201	21.000	-.001
9	-34.865	13.497	-69.000	1.201	21.000	-.001
9	-34.865	13.497	-69.000	1.201	21.000	-.000
10	-44.118	3.740	-55.243	0.000	30.757	-44.118
10	-44.118	3.899	-59.402	.067	30.598	-43.620
10	-44.118	4.071	-59.574	.133	30.426	-43.076
10	-44.118	4.259	-59.762	.200	30.238	-42.482
10	-44.118	4.463	-59.966	.267	30.034	-41.829
10	-44.118	4.688	-60.191	.334	29.809	-41.109
10	-44.118	4.935	-60.438	.400	29.562	-40.310
10	-44.118	5.200	-60.711	.467	29.289	-39.420
10	-44.118	5.511	-61.014	.534	28.986	-38.423
10	-44.118	5.848	-61.351	.601	28.649	-37.298
10	-44.118	6.226	-61.729	.667	28.271	-36.021
10	-44.118	6.650	-62.153	.734	27.847	-34.559
10	-44.118	7.120	-62.631	.801	27.369	-32.873
10	-44.118	7.669	-63.172	.868	26.828	-30.909
10	-44.118	8.283	-63.786	.934	26.214	-28.600
10	-44.118	8.978	-64.481	1.001	25.519	-25.856
10	-44.118	9.763	-65.266	1.068	24.734	-22.556

TABLE A-III (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
10	-44.118	10.638	-66.141	1.134	23.859	-18.544
10	-44.118	11.590	-67.092	1.201	22.908	-13.618
10	-44.118	12.574	-68.077	1.268	21.923	-7.527
10	-44.118	11.590	-67.092	1.201	22.908	-13.618
10	-44.118	11.688	-67.191	1.208	22.809	-13.066
10	-44.118	11.786	-67.289	1.215	22.711	-12.501
10	-44.118	11.884	-67.387	1.221	22.613	-11.925
10	-44.118	11.983	-67.486	1.228	22.514	-11.336
10	-44.118	12.082	-67.585	1.235	22.415	-10.735
10	-44.118	12.181	-67.684	1.241	22.316	-10.120
10	-44.118	12.279	-67.782	1.248	22.218	-9.492
10	-44.118	12.378	-67.881	1.255	22.119	-8.851
10	-44.118	12.476	-67.979	1.261	22.021	-8.196
10	-44.118	12.574	-68.077	1.268	21.923	-7.527
10	-44.118	12.671	-68.174	1.275	21.826	-6.843
10	-44.118	12.767	-68.270	1.281	21.730	-6.145
10	-44.118	12.863	-68.366	1.288	21.634	-5.431
10	-44.118	12.958	-68.461	1.295	21.539	-4.703
10	-44.118	13.051	-68.554	1.301	21.446	-3.959
10	-44.118	13.144	-68.647	1.308	21.353	-3.199
10	-44.118	13.235	-68.738	1.315	21.262	-2.424
10	-44.118	13.324	-68.827	1.321	21.173	-1.632
10	-44.118	13.411	-68.914	1.328	21.086	-0.824
10	-44.118	13.324	-68.827	1.321	21.173	-1.632
10	-44.118	13.333	-68.836	1.322	21.164	-1.552
10	-44.118	13.342	-68.845	1.323	21.155	-1.472
10	-44.118	13.350	-68.853	1.323	21.147	-1.392
10	-44.118	13.359	-68.862	1.324	21.138	-1.311
10	-44.118	13.368	-68.871	1.325	21.129	-1.230
10	-44.118	13.377	-68.880	1.325	21.120	-1.149
10	-44.118	13.385	-68.888	1.326	21.112	-1.068
10	-44.118	13.394	-68.897	1.327	21.103	-0.987
10	-44.118	13.403	-68.906	1.327	21.094	-0.906
10	-44.118	13.411	-68.914	1.328	21.086	-0.824
10	-44.118	13.420	-68.923	1.329	21.077	-0.743
10	-44.118	13.429	-68.932	1.329	21.068	-0.661
10	-44.118	13.437	-68.940	1.330	21.060	-0.579
10	-44.118	13.446	-68.949	1.331	21.051	-0.497
10	-44.118	13.455	-68.957	1.331	21.043	-0.414
10	-44.118	13.463	-68.966	1.332	21.034	-0.332
10	-44.118	13.472	-68.975	1.333	21.025	-0.249
10	-44.118	13.480	-68.983	1.333	21.017	-0.166
10	-44.118	13.489	-68.992	1.334	21.008	-0.083
10	-44.118	13.488	-68.983	1.333	21.017	-0.166
10	-44.118	13.481	-68.984	1.333	21.016	-0.158
10	-44.118	13.482	-68.985	1.333	21.015	-0.150

TABLE A-III (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
10	-44.118	13.483	-68.986	1.334	21.014	-.141
10	-44.118	13.483	-68.986	1.334	21.014	-.133
10	-44.118	13.484	-68.987	1.334	21.013	-.125
10	-44.118	13.485	-68.988	1.334	21.012	-.116
10	-44.118	13.486	-68.989	1.334	21.011	-.108
10	-44.118	13.487	-68.990	1.334	21.010	-.100
10	-44.118	13.488	-68.991	1.334	21.009	-.091
10	-44.118	13.489	-68.992	1.334	21.008	-.083
10	-44.118	13.489	-68.992	1.334	21.008	-.075
10	-44.118	13.490	-68.993	1.334	21.007	-.067
10	-44.118	13.491	-68.994	1.334	21.006	-.058
10	-44.118	13.492	-68.995	1.334	21.005	-.050
10	-44.118	13.493	-68.996	1.334	21.004	-.042
10	-44.118	13.494	-68.997	1.334	21.003	-.033
10	-44.118	13.495	-68.997	1.334	21.003	-.025
10	-44.118	13.495	-68.998	1.335	21.002	-.017
10	-44.118	13.496	-68.999	1.335	21.001	-.008
10	-44.118	13.496	-68.999	1.335	21.001	-.008
10	-44.118	13.496	-68.999	1.335	21.001	-.007
10	-44.118	13.496	-68.999	1.335	21.001	-.007
10	-44.118	13.496	-68.999	1.335	21.001	-.006
10	-44.118	13.497	-68.999	1.335	21.001	-.005
10	-44.118	13.497	-69.000	1.335	21.000	-.004
10	-44.118	13.497	-69.000	1.335	21.000	-.003
10	-44.118	13.497	-69.000	1.335	21.000	-.002
10	-44.118	13.497	-69.000	1.335	21.000	-.002
10	-44.118	13.497	-69.000	1.335	21.000	-.001

TABLE A-IV

SECOND SURFACE COORDINATE (X,Y) VALUES, S, ALPHA2 AND RHO2 FOR THE FAMILY OF SURFACES IN FIGURES 17 AND 18. THE COLUMN LABELED BEGIN RAY CORRESPONDS TO THE FAMILY MEMBER.

Begin RAY	Next RAY	Xsurf (next)	Ysurf (next)	S (next)	Alpha2 (next)	RHO 2 (next)
1	1	.362	.000	.133	21.000	-.000
1	2	.649	.110	.133	21.201	-1.000
1	3	.935	.221	.132	21.466	-4.122
1	4	1.220	.333	.130	21.824	-6.831
1	5	1.504	.447	.125	22.321	-10.147
1	6	1.786	.563	.118	23.024	-14.262
1	7	2.067	.682	.107	24.043	-19.425
1	8	2.344	.805	.090	25.538	-25.934
1	9	2.616	.936	.066	27.707	-34.070
1	10	2.882	1.076	.030	30.668	-43.901
2	2	.724	.000	.267	21.201	-.000
2	3	1.010	.111	.266	21.220	-2.125
2	4	1.296	.222	.265	21.538	-4.693
2	5	1.581	.334	.262	21.973	-7.870
2	6	1.865	.449	.256	22.603	-11.868
2	7	2.146	.566	.248	23.542	-16.978
2	8	2.425	.687	.234	24.971	-23.577
2	9	2.699	.815	.212	27.147	-32.074
2	10	2.967	.953	.179	30.300	-42.677
3	3	1.006	.000	.400	21.220	-.000
3	4	1.372	.111	.399	21.262	-2.420
3	5	1.658	.222	.398	21.633	-5.420
3	6	1.943	.335	.394	22.180	-9.251
3	7	2.226	.450	.388	23.021	-14.243
3	8	2.506	.570	.377	24.354	-20.865
3	9	2.782	.695	.358	26.502	-29.695
3	10	3.052	.829	.329	29.826	-41.164
4	4	1.449	.000	.534	21.262	-.000
4	5	1.734	.111	.532	21.307	-2.810
4	6	2.020	.223	.531	21.766	-6.414
4	7	2.304	.336	.527	22.493	-11.208
4	8	2.586	.453	.518	23.690	-17.757
4	9	2.864	.575	.504	25.766	-26.849
4	10	3.136	.706	.478	29.242	-39.260
5	5	1.811	.000	.667	21.307	-.000
5	6	2.096	.111	.666	21.371	-3.349
5	7	2.382	.223	.664	21.970	-7.849
5	8	2.665	.337	.658	23.011	-14.109
5	9	2.946	.457	.647	24.932	-23.412
5	10	3.220	.584	.626	28.510	-36.832
6	6	2.173	.000	.801	21.371	-.000

TABLE A-IV (CONT)

Begin Surf	Next Surf	Xsurf (next)	Ysurf (next)	S (next)	Alpha2 (next)	RHO 2 (next)
6	7	2.458	.112	.799	21.469	-4.143
6	8	2.743	.224	.796	22.313	-10.099
6	9	3.026	.340	.789	24.002	-19.227
6	10	3.303	.463	.773	27.578	-33.615
7	7	2.535	.000	.934	21.469	-.000
7	8	2.820	.112	.932	21.634	-5.429
7	9	3.105	.225	.928	22.996	-14.107
7	10	3.385	.344	.917	26.378	-29.225
8	8	2.897	.000	1.068	21.634	-.000
8	9	3.182	.113	1.064	21.971	-7.855
8	10	3.465	.227	1.059	24.843	-23.029
9	9	3.259	.000	1.201	21.971	-.000
9	10	3.543	.114	1.196	22.986	-14.051
10	10	3.622	.000	1.335	22.986	-.001

TABLE A-V

COMPARISON OF THE MAXIMUM ALLOWED LENGTH OF THE RAY IN THE LENS QA AND THE ACTUAL VALUE USED S_{MAX} FOR EACH SURFACE IN FIGURES 17 AND 18. ALPHA2 AND RHO2 ARE THE VALUES AT S_{MAX} .

RAY	QA	Smax	Alpha2	RHO 2
1	.133	.133	21.000	-.000
2	.267	.267	21.201	-.000
3	.400	.400	21.220	-.000
4	.534	.534	21.262	-.000
5	.667	.667	21.307	-.000
6	.801	.801	21.371	-.000
7	.934	.934	21.469	-.000
8	1.068	1.068	21.634	-.000
9	1.201	1.201	21.971	-.000
10	1.335	1.335	22.986	-.001

TABLE A-VI

CALCULATED VALUES OF S AND ALPHA2 USED TO CONSTRUCT THE DESIGN CHART IN FIGURE 19 FOR THE FINAL DESIGN OF SURFACE NUMBER 1 in FIGURE 20.

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
1	-1.697	13.317	-68.828	0.000	21.180	-1.697
1	-1.697	13.326	-68.829	.007	21.171	-1.614
1	-1.697	13.335	-68.838	.013	21.162	-1.530
1	-1.697	13.344	-68.847	.020	21.153	-1.447
1	-1.697	13.354	-68.856	.027	21.144	-1.363
1	-1.697	13.363	-68.866	.033	21.134	-1.279
1	-1.697	13.372	-68.875	.040	21.125	-1.195
1	-1.697	13.381	-68.884	.047	21.116	-1.111
1	-1.697	13.390	-68.893	.053	21.107	-1.027
1	-1.697	13.399	-68.902	.060	21.098	-.942
1	-1.697	13.408	-68.911	.067	21.089	-.857
1	-1.697	13.417	-68.920	.073	21.080	-.772
1	-1.697	13.426	-68.929	.080	21.071	-.687
1	-1.697	13.435	-68.938	.087	21.062	-.602
1	-1.697	13.444	-68.947	.093	21.053	-.517
1	-1.697	13.453	-68.956	.100	21.044	-.431
1	-1.697	13.462	-68.965	.107	21.035	-.345
1	-1.697	13.471	-68.974	.113	21.026	-.259
1	-1.697	13.479	-68.982	.120	21.018	-.173
1	-1.697	13.488	-68.991	.127	21.009	-.087
1	-1.697	13.479	-68.982	.120	21.018	-.173
1	-1.697	13.488	-68.983	.121	21.017	-.164
1	-1.697	13.481	-68.984	.121	21.016	-.156
1	-1.697	13.482	-68.985	.122	21.015	-.147
1	-1.697	13.483	-68.986	.123	21.014	-.139
1	-1.697	13.484	-68.987	.123	21.013	-.130
1	-1.697	13.485	-68.988	.124	21.012	-.121
1	-1.697	13.486	-68.989	.125	21.011	-.112
1	-1.697	13.486	-68.989	.125	21.011	-.104
1	-1.697	13.487	-68.990	.126	21.010	-.095
1	-1.697	13.488	-68.991	.127	21.009	-.087
1	-1.697	13.489	-68.992	.127	21.008	-.078
1	-1.697	13.490	-68.993	.128	21.007	-.069
1	-1.697	13.491	-68.994	.129	21.006	-.061
1	-1.697	13.492	-68.995	.129	21.005	-.052
1	-1.697	13.493	-68.996	.130	21.004	-.043
1	-1.697	13.494	-68.996	.131	21.004	-.035
1	-1.697	13.494	-68.997	.131	21.003	-.026
1	-1.697	13.495	-68.998	.132	21.002	-.017
1	-1.697	13.496	-68.999	.133	21.001	-.009
1	-1.697	13.495	-68.998	.132	21.002	-.017
1	-1.697	13.495	-68.998	.132	21.002	-.016
1	-1.697	13.496	-68.999	.132	21.001	-.015
1	-1.697	13.496	-68.999	.132	21.001	-.014
1	-1.697	13.496	-68.999	.132	21.001	-.013

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
1	-1.697	13.496	-68.999	.133	21.001	-.012
1	-1.697	13.496	-68.999	.133	21.001	-.011
1	-1.697	13.496	-68.999	.133	21.001	-.010
1	-1.697	13.496	-68.999	.133	21.001	-.010
1	-1.697	13.496	-68.999	.133	21.001	-.009
1	-1.697	13.496	-68.999	.133	21.001	-.008
1	-1.697	13.496	-68.999	.133	21.001	-.007
1	-1.697	13.496	-68.999	.133	21.001	-.006
1	-1.697	13.497	-68.999	.133	21.001	-.005
1	-1.697	13.497	-69.000	.133	21.000	-.004
1	-1.697	13.497	-69.000	.133	21.000	-.003
1	-1.697	13.497	-69.000	.133	21.000	-.003
1	-1.697	13.497	-69.000	.133	21.000	-.002
1	-1.697	13.497	-69.000	.133	21.000	-.002
1	-1.697	13.497	-69.000	.133	21.000	-.002
1	-1.697	13.497	-69.000	.133	21.000	-.002
1	-1.697	13.497	-69.000	.133	21.000	-.001
1	-1.697	13.497	-69.000	.133	21.000	-.001
1	-1.697	13.497	-69.000	.133	21.000	-.001
1	-1.697	13.497	-69.000	.133	21.000	-.001
1	-1.697	13.497	-69.000	.133	21.000	-.001
1	-1.697	13.497	-69.000	.133	21.000	-.001
1	-1.697	13.497	-69.000	.133	21.000	-.001
1	-1.697	13.497	-69.000	.133	21.000	-.001
1	-1.697	13.497	-69.000	.133	21.000	-.001
1	-1.697	13.497	-69.000	.133	21.000	-.001
1	-1.697	13.497	-69.000	.133	21.000	-.001
1	-1.697	13.497	-69.000	.133	21.000	-.001
1	-1.697	13.497	-69.000	.133	21.000	-.001
1	-1.697	13.497	-69.000	.133	21.000	-.001
1	-1.697	13.497	-69.000	.133	21.000	-.001
1	-1.697	13.497	-69.000	.133	21.000	-.001
1	-1.697	13.497	-69.000	.133	21.000	-.001
1	-1.697	13.497	-69.000	.133	21.000	-.001
2	-2.373	13.241	-68.743	0.000	21.257	-2.373
2	-2.373	13.254	-68.757	.009	21.243	-2.258
2	-2.373	13.267	-68.770	.018	21.230	-2.142
2	-2.373	13.280	-68.783	.027	21.217	-2.026
2	-2.373	13.293	-68.796	.036	21.204	-1.910
2	-2.373	13.306	-68.809	.045	21.191	-1.793
2	-2.373	13.319	-68.822	.054	21.178	-1.676
2	-2.373	13.332	-68.835	.064	21.165	-1.558
2	-2.373	13.345	-68.848	.073	21.152	-1.441
2	-2.373	13.358	-68.861	.082	21.139	-1.323
2	-2.373	13.371	-68.874	.091	21.126	-1.204

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
2	-2.373	13.384	-68.887	.100	21.113	-1.085
2	-2.373	13.396	-68.899	.109	21.101	-.966
2	-2.373	13.409	-68.912	.118	21.088	-.847
2	-2.373	13.422	-68.925	.127	21.075	-.727
2	-2.373	13.434	-68.937	.136	21.063	-.606
2	-2.373	13.447	-68.950	.145	21.050	-.486
2	-2.373	13.460	-68.963	.154	21.037	-.365
2	-2.373	13.472	-68.975	.163	21.025	-.244
2	-2.373	13.485	-68.988	.172	21.012	-.122
2	-2.373	13.497	-69.000	.182	21.000	-.000
2	-2.373	13.485	-68.988	.172	21.012	-.122
2	-2.373	13.486	-68.989	.173	21.011	-.110
2	-2.373	13.487	-68.990	.174	21.010	-.098
2	-2.373	13.488	-68.991	.175	21.009	-.085
2	-2.373	13.490	-68.993	.176	21.007	-.073
2	-2.373	13.491	-68.994	.177	21.006	-.061
2	-2.373	13.492	-68.995	.178	21.005	-.049
2	-2.373	13.493	-68.996	.179	21.004	-.037
2	-2.373	13.495	-68.998	.180	21.002	-.024
2	-2.373	13.496	-68.999	.181	21.001	-.012
2	-2.373	13.497	-69.000	.182	21.000	-.000
2	-2.373	13.496	-68.999	.181	21.001	-.012
2	-2.373	13.496	-68.999	.181	21.001	-.011
2	-2.373	13.496	-68.999	.181	21.001	-.010
2	-2.373	13.496	-68.999	.181	21.001	-.009
2	-2.373	13.496	-68.999	.181	21.001	-.007
2	-2.373	13.496	-68.999	.181	21.001	-.006
2	-2.373	13.497	-69.000	.181	21.000	-.005
2	-2.373	13.497	-69.000	.181	21.000	-.004
2	-2.373	13.497	-69.000	.181	21.000	-.002
2	-2.373	13.497	-69.000	.181	21.000	-.001
2	-2.373	13.497	-69.000	.182	21.000	-.000
2	-2.373	13.497	-69.000	.181	21.000	-.001
2	-2.373	13.497	-69.000	.181	21.000	-.001
2	-2.373	13.497	-69.000	.181	21.000	-.001
2	-2.373	13.497	-69.000	.181	21.000	-.001
2	-2.373	13.497	-69.000	.181	21.000	-.001
2	-2.373	13.497	-69.000	.181	21.000	-.001
2	-2.373	13.497	-69.000	.181	21.000	-.000
2	-2.373	13.497	-69.000	.181	21.000	-.000
2	-2.373	13.497	-69.000	.182	21.000	-.000
2	-2.373	13.497	-69.000	.182	21.000	-.000
3	-3.000	13.157	-68.660	0.000	21.340	-3.000
3	-3.000	13.175	-68.678	.011	21.322	-2.939
3	-3.000	13.192	-68.695	.023	21.305	-2.790

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
3	-3.000	13.210	-68.713	.034	21.287	-2.640
3	-3.000	13.227	-68.730	.046	21.270	-2.490
3	-3.000	13.244	-68.747	.057	21.253	-2.339
3	-3.000	13.262	-68.765	.069	21.235	-2.187
3	-3.000	13.279	-68.782	.080	21.218	-2.035
3	-3.000	13.296	-68.799	.092	21.201	-1.882
3	-3.000	13.313	-68.816	.103	21.184	-1.728
3	-3.000	13.330	-68.833	.115	21.167	-1.574
3	-3.000	13.347	-68.850	.126	21.150	-1.420
3	-3.000	13.364	-68.867	.138	21.133	-1.264
3	-3.000	13.381	-68.884	.149	21.116	-1.108
3	-3.000	13.398	-68.901	.161	21.099	-.952
3	-3.000	13.415	-68.918	.172	21.082	-.795
3	-3.000	13.431	-68.934	.184	21.066	-.637
3	-3.000	13.448	-68.951	.195	21.049	-.479
3	-3.000	13.464	-68.967	.207	21.033	-.320
3	-3.000	13.481	-68.984	.218	21.016	-.160
3	-3.000	13.497	-69.000	.230	21.000	-.000
3	-3.000	13.481	-68.984	.218	21.016	-.160
3	-3.000	13.482	-68.985	.219	21.015	-.144
3	-3.000	13.484	-68.987	.220	21.013	-.128
3	-3.000	13.486	-68.989	.222	21.011	-.112
3	-3.000	13.487	-68.990	.223	21.010	-.096
3	-3.000	13.489	-68.992	.224	21.008	-.080
3	-3.000	13.491	-68.993	.225	21.007	-.064
3	-3.000	13.492	-68.995	.226	21.005	-.048
3	-3.000	13.494	-68.997	.227	21.003	-.032
3	-3.000	13.495	-68.998	.228	21.002	-.016
3	-3.000	13.495	-68.998	.228	21.002	-.016
3	-3.000	13.496	-68.999	.229	21.001	-.014
3	-3.000	13.496	-68.999	.229	21.001	-.013
3	-3.000	13.496	-68.999	.229	21.001	-.011
3	-3.000	13.496	-68.999	.229	21.001	-.010
3	-3.000	13.496	-68.999	.229	21.001	-.008
3	-3.000	13.496	-68.999	.229	21.001	-.006
3	-3.000	13.497	-69.000	.229	21.000	-.005
3	-3.000	13.497	-69.000	.229	21.000	-.003
3	-3.000	13.497	-69.000	.229	21.000	-.002
3	-3.000	13.497	-69.000	.230	21.000	-.000
3	-3.000	13.497	-69.000	.229	21.000	-.002
3	-3.000	13.497	-69.000	.229	21.000	-.001
3	-3.000	13.497	-69.000	.229	21.000	-.001
3	-3.000	13.497	-69.000	.229	21.000	-.001
3	-3.000	13.497	-69.000	.230	21.000	-.001
3	-3.000	13.497	-69.000	.230	21.000	-.001

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
3	-3.000	13.497	-69.000	.230	21.000	-.000
3	-3.000	13.497	-69.000	.230	21.000	-.000
3	-3.000	13.497	-69.000	.230	21.000	-.000
3	-3.000	13.497	-69.000	.230	21.000	-.000
3	-3.000	13.497	-69.000	.230	21.000	-.000
3	-3.000	13.497	-69.000	.230	21.000	-.000
3	-3.000	13.497	-69.000	.230	21.000	-.000
3	-3.000	13.497	-69.000	.230	21.000	-.000
3	-3.000	13.497	-69.000	.230	21.000	-.000
3	-3.000	13.497	-69.000	.230	21.000	-.000
3	-3.000	13.497	-69.000	.230	21.000	-.000
3	-3.000	13.497	-69.000	.230	21.000	-.000
3	-3.000	13.497	-69.000	.230	21.000	-.000
3	-3.000	13.497	-69.000	.230	21.000	-.000
4	-3.845	13.065	-68.568	0.000	21.432	-3.845
4	-3.845	13.088	-68.591	.014	21.409	-3.662
4	-3.845	13.110	-68.613	.028	21.387	-3.478
4	-3.845	13.133	-68.636	.042	21.364	-3.293
4	-3.845	13.155	-68.658	.056	21.342	-3.107
4	-3.845	13.177	-68.680	.069	21.320	-2.920
4	-3.845	13.199	-68.702	.083	21.298	-2.732
4	-3.845	13.221	-68.724	.097	21.276	-2.543
4	-3.845	13.243	-68.746	.111	21.254	-2.353
4	-3.845	13.265	-68.768	.125	21.232	-2.162
4	-3.845	13.286	-68.789	.139	21.211	-1.970
4	-3.845	13.308	-68.811	.153	21.189	-1.778
4	-3.845	13.329	-68.832	.167	21.168	-1.584
4	-3.845	13.351	-68.854	.180	21.146	-1.389
4	-3.845	13.372	-68.875	.194	21.125	-1.194
4	-3.845	13.393	-68.896	.208	21.104	-.997
4	-3.845	13.414	-68.917	.222	21.083	-.799
4	-3.845	13.435	-68.938	.236	21.062	-.601
4	-3.845	13.456	-68.959	.250	21.041	-.402
4	-3.845	13.476	-68.979	.264	21.021	-.201
4	-3.845	13.476	-68.979	.264	21.021	-.201
4	-3.845	13.479	-68.982	.265	21.018	-.181
4	-3.845	13.481	-68.984	.267	21.016	-.161
4	-3.845	13.483	-68.986	.268	21.014	-.141
4	-3.845	13.485	-68.988	.269	21.012	-.121
4	-3.845	13.487	-68.990	.271	21.010	-.101
4	-3.845	13.489	-68.992	.272	21.008	-.081
4	-3.845	13.491	-68.994	.273	21.006	-.061
4	-3.845	13.493	-68.996	.275	21.004	-.040
4	-3.845	13.495	-68.998	.276	21.002	-.020
4	-3.845	13.495	-68.998	.276	21.002	-.020

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
4	-3.845	13.495	-68.998	.276	21.002	-.019
4	-3.845	13.495	-68.998	.277	21.002	-.016
4	-3.845	13.496	-68.999	.277	21.001	-.014
4	-3.845	13.496	-68.999	.277	21.001	-.012
4	-3.845	13.496	-68.999	.277	21.001	-.010
4	-3.845	13.496	-68.999	.277	21.001	-.008
4	-3.845	13.496	-68.999	.277	21.001	-.006
4	-3.845	13.497	-69.000	.277	21.000	-.004
4	-3.845	13.497	-69.000	.277	21.000	-.002
4	-3.845	13.497	-69.000	.277	21.000	-.002
4	-3.845	13.497	-69.000	.277	21.000	-.002
4	-3.845	13.497	-69.000	.278	21.000	-.002
4	-3.845	13.497	-69.000	.278	21.000	-.001
4	-3.845	13.497	-69.000	.278	21.000	-.001
4	-3.845	13.497	-69.000	.278	21.000	-.001
4	-3.845	13.497	-69.000	.278	21.000	-.001
4	-3.845	13.497	-69.000	.278	21.000	-.001
4	-3.845	13.497	-69.000	.278	21.000	-.001
4	-3.845	13.497	-69.000	.278	21.000	-.000
4	-3.845	13.497	-69.000	.278	21.000	-.000
4	-3.845	13.497	-69.000	.278	21.000	-.000
4	-3.845	13.497	-69.000	.278	21.000	-.000
4	-3.845	13.497	-69.000	.278	21.000	-.000
4	-3.845	13.497	-69.000	.278	21.000	-.000
4	-3.845	13.497	-69.000	.278	21.000	-.000
4	-3.845	13.497	-69.000	.278	21.000	-.000
4	-3.845	13.497	-69.000	.278	21.000	-.000
4	-3.845	13.497	-69.000	.278	21.000	-.000
4	-3.845	13.497	-69.000	.278	21.000	-.000
5	-4.649	12.965	-68.468	0.000	21.532	-4.649
5	-4.649	12.993	-68.496	.016	21.504	-4.430
5	-4.649	13.020	-68.523	.033	21.477	-4.209
5	-4.649	13.048	-68.551	.049	21.449	-3.987
5	-4.649	13.075	-68.578	.065	21.422	-3.764
5	-4.649	13.103	-68.606	.081	21.394	-3.539
5	-4.649	13.130	-68.633	.098	21.367	-3.313
5	-4.649	13.157	-68.660	.114	21.340	-3.086
5	-4.649	13.184	-68.687	.130	21.313	-2.857
5	-4.649	13.211	-68.714	.147	21.286	-2.627
5	-4.649	13.238	-68.741	.163	21.259	-2.395
5	-4.649	13.265	-68.768	.179	21.232	-2.162
5	-4.649	13.291	-68.794	.195	21.206	-1.927
5	-4.649	13.317	-68.820	.212	21.180	-1.692
5	-4.649	13.344	-68.847	.228	21.153	-1.454
5	-4.649	13.370	-68.873	.244	21.127	-1.216

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
U	-4.649	13.395	-68.898	.261	21.102	-.975
U	-4.649	13.421	-68.924	.277	21.076	-.734
U	-4.649	13.447	-68.950	.293	21.050	-.491
U	-4.649	13.472	-68.975	.309	21.025	-.246
U	-4.649	13.472	-68.975	.309	21.025	-.246
U	-4.649	13.474	-68.977	.311	21.023	-.221
U	-4.649	13.477	-68.980	.313	21.020	-.197
U	-4.649	13.479	-68.982	.314	21.018	-.172
U	-4.649	13.482	-68.985	.316	21.015	-.148
U	-4.649	13.484	-68.987	.318	21.013	-.123
U	-4.649	13.487	-68.990	.319	21.010	-.099
U	-4.649	13.490	-68.992	.321	21.008	-.074
U	-4.649	13.492	-68.995	.322	21.005	-.049
U	-4.649	13.495	-68.997	.324	21.003	-.025
U	-4.649	13.492	-68.995	.322	21.005	-.049
U	-4.649	13.492	-68.995	.323	21.005	-.047
U	-4.649	13.493	-68.995	.323	21.005	-.044
U	-4.649	13.493	-68.996	.323	21.004	-.042
U	-4.649	13.493	-68.996	.323	21.004	-.039
U	-4.649	13.493	-68.996	.323	21.004	-.037
U	-4.649	13.494	-68.996	.323	21.004	-.035
U	-4.649	13.494	-68.997	.324	21.003	-.032
U	-4.649	13.494	-68.997	.324	21.003	-.030
U	-4.649	13.494	-68.997	.324	21.003	-.027
U	-4.649	13.495	-68.997	.324	21.003	-.025
U	-4.649	13.495	-68.998	.324	21.002	-.022
U	-4.649	13.495	-68.998	.324	21.002	-.020
U	-4.649	13.495	-68.998	.325	21.002	-.017
U	-4.649	13.496	-68.998	.325	21.002	-.015
U	-4.649	13.496	-68.999	.325	21.001	-.012
U	-4.649	13.496	-68.999	.325	21.001	-.010
U	-4.649	13.496	-68.999	.325	21.001	-.007
U	-4.649	13.497	-68.999	.325	21.001	-.005
U	-4.649	13.497	-69.000	.326	21.000	-.002
U	-4.649	13.497	-69.000	.326	21.000	-.002
U	-4.649	13.497	-69.000	.326	21.000	-.002
U	-4.649	13.497	-69.000	.326	21.000	-.002
U	-4.649	13.497	-69.000	.326	21.000	-.001
U	-4.649	13.497	-69.000	.326	21.000	-.001
U	-4.649	13.497	-69.000	.326	21.000	-.001
U	-4.649	13.497	-69.000	.326	21.000	-.000
U	-4.649	13.497	-69.000	.326	21.000	-.000
U	-4.649	13.497	-69.000	.326	21.000	-.000
U	-4.649	13.497	-69.000	.326	21.000	-.000

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
5	-4.649	13.497	-69.000	.326	21.000	-.000
5	-4.649	13.497	-69.000	.326	21.000	-.000
5	-4.649	13.497	-69.000	.326	21.000	-.000
5	-4.649	13.497	-69.000	.326	21.000	-.000
5	-4.649	13.497	-69.000	.326	21.000	-.000
5	-4.649	13.497	-69.000	.326	21.000	-.000
5	-4.649	13.497	-69.000	.326	21.000	-.000
5	-4.649	13.497	-69.000	.326	21.000	-.000
5	-4.649	13.497	-69.000	.326	21.000	-.000
5	-4.649	13.497	-69.000	.326	21.000	-.000
5	-4.649	13.497	-69.000	.326	21.000	-.000
5	-4.649	13.497	-69.000	.326	21.000	-.000
5	-4.649	13.497	-69.000	.326	21.000	-.000
5	-4.649	13.497	-69.000	.326	21.000	-.000
5	-4.649	13.497	-69.000	.326	21.000	-.000
5	-4.649	13.497	-69.000	.326	21.000	-.000
5	-4.649	13.497	-69.000	.326	21.000	-.000
5	-4.649	13.497	-69.000	.326	21.000	-.000
5	-4.649	13.497	-69.000	.326	21.000	-.000
5	-4.649	13.497	-69.000	.326	21.000	-.000
6	-5.502	12.854	-68.357	0.000	21.643	-5.502
6	-5.502	12.888	-68.390	.019	21.610	-5.246
6	-5.502	12.921	-68.424	.037	21.576	-4.987
6	-5.502	12.955	-68.458	.056	21.542	-4.727
6	-5.502	12.988	-68.491	.075	21.509	-4.465
6	-5.502	13.021	-68.524	.093	21.476	-4.201
6	-5.502	13.054	-68.557	.112	21.443	-3.935
6	-5.502	13.087	-68.590	.131	21.410	-3.667
6	-5.502	13.120	-68.623	.149	21.377	-3.397
6	-5.502	13.153	-68.656	.168	21.344	-3.125
6	-5.502	13.185	-68.688	.187	21.312	-2.851
6	-5.502	13.217	-68.720	.206	21.280	-2.576
6	-5.502	13.249	-68.752	.224	21.248	-2.298
6	-5.502	13.281	-68.784	.243	21.216	-2.018
6	-5.502	13.313	-68.815	.262	21.185	-1.736
6	-5.502	13.344	-68.847	.280	21.153	-1.451
6	-5.502	13.375	-68.878	.299	21.122	-1.165
6	-5.502	13.406	-68.909	.318	21.091	-.877
6	-5.502	13.437	-68.939	.336	21.061	-.587
6	-5.502	13.467	-68.970	.355	21.030	-.294
6	-5.502	13.437	-68.939	.336	21.061	-.587
6	-5.502	13.440	-68.943	.338	21.057	-.558
6	-5.502	13.443	-68.946	.340	21.054	-.529
6	-5.502	13.446	-68.949	.342	21.051	-.499
6	-5.502	13.449	-68.952	.344	21.048	-.470
6	-5.502	13.452	-68.955	.346	21.045	-.441
6	-5.502	13.455	-68.958	.348	21.042	-.412

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
6	-5.502	13.458	-68.961	.349	21.039	-.382
6	-5.502	13.461	-68.964	.351	21.036	-.353
6	-5.502	13.464	-68.967	.353	21.033	-.324
6	-5.502	13.467	-68.970	.355	21.030	-.294
6	-5.502	13.470	-68.973	.357	21.027	-.265
6	-5.502	13.473	-68.976	.359	21.024	-.236
6	-5.502	13.476	-68.979	.361	21.021	-.206
6	-5.502	13.479	-68.982	.363	21.018	-.177
6	-5.502	13.482	-68.985	.364	21.015	-.147
6	-5.502	13.485	-68.988	.366	21.012	-.118
6	-5.502	13.488	-68.991	.368	21.009	-.089
6	-5.502	13.491	-68.994	.370	21.006	-.059
6	-5.502	13.494	-68.997	.372	21.003	-.030
6	-5.502	13.491	-68.994	.370	21.006	-.059
6	-5.502	13.491	-68.994	.370	21.006	-.056
6	-5.502	13.492	-68.995	.370	21.005	-.053
6	-5.502	13.492	-68.995	.371	21.005	-.050
6	-5.502	13.492	-68.995	.371	21.005	-.047
6	-5.502	13.493	-68.995	.371	21.005	-.044
6	-5.502	13.493	-68.996	.371	21.004	-.041
6	-5.502	13.493	-68.996	.371	21.004	-.038
6	-5.502	13.493	-68.996	.371	21.004	-.035
6	-5.502	13.494	-68.997	.372	21.003	-.032
6	-5.502	13.494	-68.997	.372	21.003	-.030
6	-5.502	13.494	-68.997	.372	21.003	-.027
6	-5.502	13.495	-68.998	.372	21.002	-.024
6	-5.502	13.495	-68.998	.372	21.002	-.021
6	-5.502	13.495	-68.998	.373	21.002	-.018
6	-5.502	13.496	-68.999	.373	21.001	-.015
6	-5.502	13.496	-68.999	.373	21.001	-.012
6	-5.502	13.496	-68.999	.373	21.001	-.009
6	-5.502	13.496	-68.999	.373	21.001	-.006
6	-5.502	13.497	-69.000	.374	21.000	-.003
6	-5.502	13.496	-68.999	.373	21.001	-.006
6	-5.502	13.496	-68.999	.373	21.001	-.006
6	-5.502	13.496	-68.999	.373	21.001	-.006
6	-5.502	13.496	-68.999	.373	21.001	-.005
6	-5.502	13.497	-68.999	.373	21.001	-.005
6	-5.502	13.497	-69.000	.373	21.000	-.005
6	-5.502	13.497	-69.000	.373	21.000	-.004
6	-5.502	13.497	-69.000	.373	21.000	-.004
6	-5.502	13.497	-69.000	.373	21.000	-.004
6	-5.502	13.497	-69.000	.373	21.000	-.004
6	-5.502	13.497	-69.000	.374	21.000	-.003
6	-5.502	13.497	-69.000	.374	21.000	-.003
6	-5.502	13.497	-69.000	.374	21.000	-.003
6	-5.502	13.497	-69.000	.374	21.000	-.002

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
7	-6.409	13.389	-68.892	.359	21.100	-1.033
7	-6.409	13.426	-68.928	.360	21.072	-.692
7	-6.409	13.461	-68.964	.401	21.036	-.347
7	-6.409	13.426	-68.920	.380	21.072	-.692
7	-6.409	13.429	-68.932	.382	21.068	-.657
7	-6.409	13.433	-68.936	.384	21.064	-.623
7	-6.409	13.436	-68.939	.386	21.061	-.589
7	-6.409	13.440	-68.943	.388	21.057	-.554
7	-6.409	13.444	-68.946	.390	21.054	-.520
7	-6.409	13.447	-68.950	.392	21.050	-.485
7	-6.409	13.451	-68.954	.394	21.046	-.451
7	-6.409	13.454	-68.957	.396	21.043	-.416
7	-6.409	13.458	-68.961	.399	21.039	-.382
7	-6.409	13.461	-68.964	.401	21.036	-.347
7	-6.409	13.465	-68.968	.403	21.032	-.313
7	-6.409	13.469	-68.972	.405	21.028	-.278
7	-6.409	13.472	-68.975	.407	21.025	-.243
7	-6.409	13.476	-68.979	.409	21.021	-.209
7	-6.409	13.479	-68.982	.411	21.018	-.174
7	-6.409	13.483	-68.986	.413	21.014	-.139
7	-6.409	13.486	-68.989	.415	21.011	-.104
7	-6.409	13.490	-68.993	.418	21.007	-.070
7	-6.409	13.493	-68.996	.420	21.004	-.035
7	-6.409	13.490	-68.993	.418	21.007	-.070
7	-6.409	13.490	-68.993	.418	21.007	-.066
7	-6.409	13.491	-68.994	.418	21.006	-.063
7	-6.409	13.491	-68.994	.418	21.006	-.059
7	-6.409	13.491	-68.994	.418	21.006	-.056
7	-6.409	13.492	-68.995	.419	21.005	-.052
7	-6.409	13.492	-68.995	.419	21.005	-.049
7	-6.409	13.492	-68.995	.419	21.005	-.045
7	-6.409	13.493	-68.996	.419	21.004	-.042
7	-6.409	13.493	-68.996	.419	21.004	-.038
7	-6.409	13.493	-68.996	.420	21.004	-.035
7	-6.409	13.494	-68.997	.420	21.003	-.031
7	-6.409	13.494	-68.997	.420	21.003	-.028
7	-6.409	13.495	-68.998	.420	21.002	-.024
7	-6.409	13.495	-68.998	.420	21.002	-.021
7	-6.409	13.495	-68.998	.421	21.002	-.017
7	-6.409	13.496	-68.999	.421	21.001	-.014
7	-6.409	13.496	-68.999	.421	21.001	-.010
7	-6.409	13.496	-68.999	.421	21.001	-.007
7	-6.409	13.497	-69.000	.422	21.000	-.003
7	-6.409	13.496	-68.999	.421	21.001	-.007
7	-6.409	13.496	-68.999	.421	21.001	-.007
7	-6.409	13.496	-68.999	.421	21.001	-.006

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
0	-7.375	13.413	-68.916	.423	21.004	-.806
0	-7.375	13.455	-68.950	.446	21.042	-.405
0	-7.375	13.413	-68.916	.423	21.004	-.806
0	-7.375	13.418	-68.921	.425	21.079	-.766
0	-7.375	13.422	-68.925	.428	21.075	-.726
0	-7.375	13.426	-68.929	.430	21.071	-.686
0	-7.375	13.430	-68.933	.432	21.067	-.646
0	-7.375	13.435	-68.937	.435	21.063	-.606
0	-7.375	13.439	-68.942	.437	21.059	-.566
0	-7.375	13.443	-68.946	.439	21.054	-.526
0	-7.375	13.447	-68.950	.442	21.050	-.486
0	-7.375	13.451	-68.954	.444	21.046	-.445
0	-7.375	13.455	-68.958	.446	21.042	-.405
0	-7.375	13.460	-68.963	.449	21.037	-.365
0	-7.375	13.464	-68.967	.451	21.033	-.324
0	-7.375	13.468	-68.971	.453	21.029	-.284
0	-7.375	13.472	-68.975	.456	21.025	-.244
0	-7.375	13.476	-68.979	.458	21.021	-.203
0	-7.375	13.480	-68.983	.460	21.017	-.162
0	-7.375	13.485	-68.988	.463	21.012	-.122
0	-7.375	13.489	-68.992	.465	21.008	-.081
0	-7.375	13.493	-68.996	.467	21.004	-.041
0	-7.375	13.489	-68.992	.465	21.000	-.001
0	-7.375	13.489	-68.992	.465	21.000	-.077
0	-7.375	13.490	-68.993	.466	21.007	-.073
0	-7.375	13.490	-68.993	.466	21.007	-.069
0	-7.375	13.490	-68.993	.466	21.007	-.065
0	-7.375	13.491	-68.994	.466	21.006	-.061
0	-7.375	13.491	-68.994	.467	21.006	-.057
0	-7.375	13.492	-68.995	.467	21.005	-.053
0	-7.375	13.492	-68.995	.467	21.005	-.049
0	-7.375	13.492	-68.995	.467	21.005	-.045
0	-7.375	13.493	-68.996	.467	21.004	-.041
0	-7.375	13.493	-68.996	.468	21.004	-.037
0	-7.375	13.494	-68.997	.468	21.003	-.033
0	-7.375	13.494	-68.997	.468	21.003	-.028
0	-7.375	13.495	-68.998	.468	21.002	-.024
0	-7.375	13.495	-68.998	.469	21.002	-.020
0	-7.375	13.495	-68.998	.469	21.002	-.016
0	-7.375	13.496	-68.999	.469	21.001	-.012
0	-7.375	13.496	-68.999	.469	21.001	-.008
0	-7.375	13.497	-69.000	.470	21.000	-.004
0	-7.375	13.496	-68.999	.469	21.001	-.000
0	-7.375	13.496	-68.999	.469	21.001	-.000
0	-7.375	13.496	-68.999	.469	21.001	-.007
0	-7.375	13.496	-68.999	.469	21.001	-.007

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
8	-7.375	13.496	-68.999	.469	21.001	-.007
8	-7.375	13.496	-68.999	.469	21.001	-.006
8	-7.375	13.496	-68.999	.469	21.001	-.006
8	-7.375	13.497	-68.999	.470	21.001	-.005
8	-7.375	13.497	-69.000	.470	21.000	-.005
8	-7.375	13.497	-69.000	.470	21.000	-.004
8	-7.375	13.497	-69.000	.470	21.000	-.004
8	-7.375	13.497	-69.000	.470	21.000	-.003
8	-7.375	13.497	-69.000	.470	21.000	-.003
8	-7.375	13.497	-69.000	.470	21.000	-.002
8	-7.375	13.497	-69.000	.470	21.000	-.002
8	-7.375	13.497	-69.000	.470	21.000	-.002
8	-7.375	13.497	-69.000	.470	21.000	-.001
8	-7.375	13.497	-69.000	.470	21.000	-.001
8	-7.375	13.497	-69.000	.470	21.000	-.000
8	-7.375	13.497	-69.000	.470	21.000	-.001
8	-7.375	13.497	-69.000	.470	21.000	-.001
8	-7.375	13.497	-69.000	.470	21.000	-.001
8	-7.375	13.497	-69.000	.470	21.000	-.001
8	-7.375	13.497	-69.000	.470	21.000	-.001
8	-7.375	13.497	-69.000	.470	21.000	-.001
8	-7.375	13.497	-69.000	.470	21.000	-.001
8	-7.375	13.497	-69.000	.470	21.000	-.000
8	-7.375	13.497	-69.000	.470	21.000	-.000
8	-7.375	13.497	-69.000	.470	21.000	-.000
8	-7.375	13.497	-69.000	.470	21.000	-.000
8	-7.375	13.497	-69.000	.470	21.000	-.000
8	-7.375	13.497	-69.000	.470	21.000	-.000
8	-7.375	13.497	-69.000	.470	21.000	-.000
8	-7.375	13.497	-69.000	.470	21.000	-.000
8	-7.375	13.497	-69.000	.470	21.000	-.000
8	-7.375	13.497	-69.000	.470	21.000	-.000
9	-8.486	12.445	-67.948	0.000	22.052	-8.486
9	-8.486	12.500	-68.003	.026	21.997	-8.032
9	-8.486	12.556	-68.059	.052	21.941	-7.653
9	-8.486	12.611	-68.114	.078	21.886	-7.269
9	-8.486	12.666	-68.169	.104	21.831	-6.881
9	-8.486	12.720	-68.223	.129	21.777	-6.488
9	-8.486	12.775	-68.278	.155	21.722	-6.090
9	-8.486	12.829	-68.332	.181	21.668	-5.688
9	-8.486	12.883	-68.386	.207	21.614	-5.280

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
9	-8.486	13.497	-69.800	.518	21.000	-.000
9	-8.486	13.497	-69.800	.518	21.000	-.000
9	-8.486	13.497	-69.800	.518	21.000	-.000
9	-8.486	13.497	-69.800	.518	21.000	-.000
9	-8.486	13.497	-69.800	.518	21.000	-.000
10	-9.507	12.277	-67.788	0.000	22.220	-9.507
10	-9.507	12.341	-67.844	.028	22.156	-9.091
10	-9.507	12.405	-67.908	.057	22.092	-8.670
10	-9.507	12.469	-67.972	.085	22.028	-8.242
10	-9.507	12.533	-68.036	.113	21.964	-7.808
10	-9.507	12.596	-68.099	.141	21.901	-7.369
10	-9.507	12.660	-68.163	.170	21.837	-6.923
10	-9.507	12.723	-68.226	.198	21.774	-6.471
10	-9.507	12.785	-68.288	.226	21.712	-6.013
10	-9.507	12.848	-68.351	.255	21.649	-5.548
10	-9.507	12.910	-68.412	.283	21.588	-5.077
10	-9.507	12.971	-68.474	.311	21.526	-4.600
10	-9.507	13.032	-68.535	.340	21.465	-4.116
10	-9.507	13.092	-68.595	.368	21.405	-3.625
10	-9.507	13.152	-68.655	.396	21.345	-3.128
10	-9.507	13.212	-68.715	.424	21.285	-2.624
10	-9.507	13.270	-68.773	.453	21.227	-2.113
10	-9.507	13.328	-68.831	.481	21.169	-1.595
10	-9.507	13.385	-68.888	.509	21.112	-1.070
10	-9.507	13.442	-68.945	.538	21.055	-.539
10	-9.507	13.385	-68.888	.509	21.112	-1.070
10	-9.507	13.391	-68.894	.512	21.106	-1.017
10	-9.507	13.397	-68.900	.515	21.100	-.965
10	-9.507	13.402	-68.905	.518	21.095	-.912
10	-9.507	13.408	-68.911	.521	21.089	-.858
10	-9.507	13.414	-68.916	.523	21.084	-.805
10	-9.507	13.419	-68.922	.526	21.078	-.752
10	-9.507	13.425	-68.928	.529	21.072	-.699
10	-9.507	13.430	-68.933	.532	21.067	-.646
10	-9.507	13.436	-68.939	.535	21.061	-.592
10	-9.507	13.442	-68.945	.538	21.055	-.539
10	-9.507	13.447	-68.950	.540	21.050	-.485
10	-9.507	13.453	-68.956	.543	21.044	-.431
10	-9.507	13.458	-68.961	.546	21.039	-.378
10	-9.507	13.464	-68.967	.549	21.033	-.324
10	-9.507	13.469	-68.972	.552	21.028	-.270
10	-9.507	13.475	-68.978	.555	21.022	-.216
10	-9.507	13.480	-68.983	.557	21.017	-.162
10	-9.507	13.486	-68.989	.560	21.011	-.108
10	-9.507	13.492	-68.994	.563	21.006	-.054

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
10	-9.507	13.492	-68.994	.563	21.006	-.054
10	-9.507	13.492	-68.995	.563	21.005	-.049
10	-9.507	13.493	-68.996	.564	21.004	-.043
10	-9.507	13.493	-68.996	.564	21.004	-.038
10	-9.507	13.494	-68.997	.564	21.003	-.033
10	-9.507	13.494	-68.997	.564	21.003	-.027
10	-9.507	13.495	-68.998	.565	21.002	-.022
10	-9.507	13.495	-68.998	.565	21.002	-.016
10	-9.507	13.496	-68.999	.565	21.001	-.011
10	-9.507	13.496	-68.999	.566	21.001	-.005
10	-9.507	13.496	-68.999	.566	21.001	-.005
10	-9.507	13.497	-69.000	.566	21.000	-.005
10	-9.507	13.497	-69.000	.566	21.000	-.004
10	-9.507	13.497	-69.000	.566	21.000	-.004
10	-9.507	13.497	-69.000	.566	21.000	-.003
10	-9.507	13.497	-69.000	.566	21.000	-.003
10	-9.507	13.497	-69.000	.566	21.000	-.002
10	-9.507	13.497	-69.000	.566	21.000	-.002
10	-9.507	13.497	-69.000	.566	21.000	-.002
10	-9.507	13.497	-69.000	.566	21.000	-.001
10	-9.507	13.497	-69.000	.566	21.000	-.001
10	-9.507	13.497	-69.000	.566	21.000	-.001
10	-9.507	13.497	-69.000	.566	21.000	-.000
10	-9.507	13.497	-69.000	.566	21.000	-.000
10	-9.507	13.497	-69.000	.566	21.000	-.000
10	-9.507	13.497	-69.000	.566	21.000	-.000
10	-9.507	13.497	-69.000	.566	21.000	-.000
10	-9.507	13.497	-69.000	.566	21.000	-.000
10	-9.507	13.497	-69.000	.566	21.000	-.000
10	-9.507	13.497	-69.000	.566	21.000	-.000
10	-9.507	13.497	-69.000	.566	21.000	-.000
11	-10.605	12.090	-67.593	0.000	22.407	-10.605
11	-10.605	12.164	-67.667	.031	22.333	-10.227
11	-10.605	12.237	-67.740	.061	22.260	-9.762
11	-10.605	12.311	-67.814	.092	22.186	-9.299
11	-10.605	12.384	-67.887	.123	22.113	-8.809
11	-10.605	12.458	-67.961	.153	22.039	-8.320
11	-10.605	12.531	-68.034	.184	21.966	-7.825
11	-10.605	12.603	-68.106	.215	21.894	-7.321
11	-10.605	12.676	-68.179	.246	21.821	-6.809
11	-10.605	12.748	-68.251	.276	21.749	-6.289
11	-10.605	12.819	-68.322	.307	21.678	-5.760
11	-10.605	12.890	-68.393	.330	21.607	-5.224
11	-10.605	12.961	-68.464	.360	21.536	-4.679
11	-10.605	13.031	-68.534	.399	21.466	-4.125
11	-10.605	13.100	-68.603	.430	21.397	-3.562

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
11	-10.685	13.169	-68.671	.460	21.329	-2.991
11	-10.685	13.236	-68.739	.491	21.261	-2.411
11	-10.685	13.303	-68.806	.522	21.194	-1.822
11	-10.685	13.369	-68.872	.553	21.128	-1.224
11	-10.685	13.433	-68.936	.583	21.064	-.616
11	-10.685	13.369	-68.872	.553	21.128	-1.224
11	-10.685	13.375	-68.878	.556	21.122	-1.163
11	-10.685	13.382	-68.885	.559	21.115	-1.103
11	-10.685	13.388	-68.891	.562	21.109	-1.042
11	-10.685	13.395	-68.898	.565	21.102	-.982
11	-10.685	13.401	-68.904	.568	21.096	-.921
11	-10.685	13.408	-68.911	.571	21.089	-.860
11	-10.685	13.414	-68.917	.574	21.083	-.800
11	-10.685	13.421	-68.924	.577	21.076	-.739
11	-10.685	13.427	-68.930	.580	21.070	-.678
11	-10.685	13.433	-68.936	.583	21.064	-.616
11	-10.685	13.440	-68.943	.586	21.057	-.555
11	-10.685	13.446	-68.949	.589	21.051	-.494
11	-10.685	13.453	-68.956	.592	21.044	-.432
11	-10.685	13.459	-68.962	.596	21.038	-.371
11	-10.685	13.465	-68.968	.599	21.032	-.309
11	-10.685	13.472	-68.975	.602	21.025	-.248
11	-10.685	13.478	-68.981	.605	21.019	-.186
11	-10.685	13.484	-68.987	.608	21.013	-.124
11	-10.685	13.491	-68.994	.611	21.006	-.062
11	-10.685	13.484	-68.987	.608	21.013	-.124
11	-10.685	13.485	-68.988	.608	21.012	-.118
11	-10.685	13.486	-68.989	.608	21.011	-.112
11	-10.685	13.486	-68.989	.609	21.011	-.105
11	-10.685	13.487	-68.990	.609	21.010	-.099
11	-10.685	13.488	-68.991	.609	21.009	-.093
11	-10.685	13.488	-68.991	.610	21.009	-.087
11	-10.685	13.489	-68.992	.610	21.008	-.081
11	-10.685	13.489	-68.992	.610	21.008	-.074
11	-10.685	13.490	-68.993	.611	21.007	-.068
11	-10.685	13.491	-68.994	.611	21.006	-.062
11	-10.685	13.491	-68.994	.611	21.006	-.056
11	-10.685	13.492	-68.995	.612	21.005	-.050
11	-10.685	13.493	-68.996	.612	21.004	-.043
11	-10.685	13.493	-68.996	.612	21.004	-.037
11	-10.685	13.494	-68.997	.612	21.003	-.031
11	-10.685	13.495	-68.997	.613	21.003	-.025
11	-10.685	13.495	-68.998	.613	21.002	-.019
11	-10.685	13.496	-68.999	.613	21.001	-.012
11	-10.685	13.496	-68.999	.614	21.001	-.006
11	-10.685	13.496	-68.999	.613	21.001	-.012

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
12	-11.947	12.385	-67.888	.199	22.112	-8.803
12	-11.947	12.469	-67.972	.232	22.028	-8.245
12	-11.947	12.552	-68.055	.265	21.945	-7.677
12	-11.947	12.635	-68.138	.298	21.862	-7.098
12	-11.947	12.717	-68.220	.331	21.780	-6.508
12	-11.947	12.799	-68.302	.364	21.698	-5.908
12	-11.947	12.881	-68.384	.397	21.616	-5.297
12	-11.947	12.961	-68.464	.430	21.536	-4.675
12	-11.947	13.041	-68.544	.463	21.456	-4.042
12	-11.947	13.120	-68.623	.497	21.377	-3.398
12	-11.947	13.198	-68.701	.530	21.299	-2.742
12	-11.947	13.275	-68.778	.563	21.222	-2.074
12	-11.947	13.350	-68.853	.596	21.147	-1.395
12	-11.947	13.424	-68.927	.629	21.073	-.703
12	-11.947	13.497	-69.000	.662	21.000	-.000
12	-11.947	13.424	-68.927	.629	21.073	-.703
12	-11.947	13.432	-68.935	.632	21.065	-.633
12	-11.947	13.439	-68.942	.636	21.058	-.564
12	-11.947	13.446	-68.949	.639	21.051	-.494
12	-11.947	13.454	-68.957	.642	21.043	-.423
12	-11.947	13.461	-68.964	.645	21.036	-.353
12	-11.947	13.468	-68.971	.649	21.029	-.283
12	-11.947	13.475	-68.978	.652	21.022	-.212
12	-11.947	13.483	-68.986	.655	21.014	-.142
12	-11.947	13.490	-68.993	.659	21.007	-.071
12	-11.947	13.497	-69.000	.662	21.000	-.000
12	-11.947	13.490	-68.993	.659	21.007	-.071
12	-11.947	13.491	-68.994	.659	21.006	-.064
12	-11.947	13.491	-68.994	.659	21.006	-.057
12	-11.947	13.492	-68.995	.660	21.005	-.050
12	-11.947	13.493	-68.996	.660	21.004	-.043
12	-11.947	13.493	-68.996	.660	21.004	-.035
12	-11.947	13.494	-68.997	.661	21.003	-.028
12	-11.947	13.495	-68.998	.661	21.002	-.021
12	-11.947	13.496	-68.999	.661	21.001	-.014
12	-11.947	13.496	-68.999	.662	21.001	-.007
12	-11.947	13.497	-69.000	.662	21.000	-.000
12	-11.947	13.496	-68.999	.662	21.001	-.007
12	-11.947	13.496	-68.999	.662	21.001	-.006
12	-11.947	13.496	-68.999	.662	21.001	-.006
12	-11.947	13.497	-68.999	.662	21.001	-.005
12	-11.947	13.497	-69.000	.662	21.000	-.004
12	-11.947	13.497	-69.000	.662	21.000	-.004
12	-11.947	13.497	-69.000	.662	21.000	-.003
12	-11.947	13.497	-69.000	.662	21.000	-.002
12	-11.947	13.497	-69.000	.662	21.000	-.001

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
12	-11.947	13.497	-69.000	.662	21.000	-.001
12	-11.947	13.497	-69.000	.662	21.000	-.000
12	-11.947	13.497	-69.000	.662	21.000	-.001
12	-11.947	13.497	-69.000	.662	21.000	-.001
12	-11.947	13.497	-69.000	.662	21.000	-.001
12	-11.947	13.497	-69.000	.662	21.000	-.000
12	-11.947	13.497	-69.000	.662	21.000	-.000
12	-11.947	13.497	-69.000	.662	21.000	-.000
12	-11.947	13.497	-69.000	.662	21.000	-.000
12	-11.947	13.497	-69.000	.662	21.000	-.000
12	-11.947	13.497	-69.000	.662	21.000	-.000
12	-11.947	13.497	-69.000	.662	21.000	-.000
12	-11.947	13.497	-69.000	.662	21.000	-.000
12	-11.947	13.497	-69.000	.662	21.000	-.000
12	-11.947	13.497	-69.000	.662	21.000	-.000
13	-13.300	11.646	-67.149	0.000	22.851	-13.300
13	-13.300	11.741	-67.244	.036	22.756	-12.758
13	-13.300	11.837	-67.340	.071	22.660	-12.203
13	-13.300	11.933	-67.436	.107	22.564	-11.630
13	-13.300	12.029	-67.532	.142	22.468	-11.060
13	-13.300	12.125	-67.628	.178	22.372	-10.478
13	-13.300	12.221	-67.724	.213	22.276	-9.868
13	-13.300	12.316	-67.819	.249	22.181	-9.253
13	-13.300	12.412	-67.915	.284	22.085	-8.626
13	-13.300	12.507	-68.010	.320	21.990	-7.993
13	-13.300	12.602	-68.105	.355	21.895	-7.331
13	-13.300	12.696	-68.199	.391	21.801	-6.653
13	-13.300	12.790	-68.293	.426	21.707	-5.981
13	-13.300	12.882	-68.385	.462	21.615	-5.283
13	-13.300	12.974	-68.477	.497	21.523	-4.575
13	-13.300	13.065	-68.568	.533	21.432	-3.859
13	-13.300	13.154	-68.657	.568	21.343	-3.110
13	-13.300	13.242	-68.745	.604	21.255	-2.356
13	-13.300	13.329	-68.832	.639	21.168	-1.586
13	-13.300	13.414	-68.917	.675	21.083	-.801
13	-13.300	13.329	-68.832	.639	21.168	-1.586
13	-13.300	13.338	-68.841	.643	21.159	-1.588
13	-13.300	13.346	-68.849	.646	21.151	-1.438
13	-13.300	13.355	-68.858	.650	21.142	-1.352
13	-13.300	13.363	-68.866	.653	21.134	-1.274
13	-13.300	13.372	-68.875	.657	21.125	-1.195
13	-13.300	13.380	-68.883	.660	21.117	-1.117
13	-13.300	13.389	-68.892	.664	21.108	-1.038
13	-13.300	13.397	-68.900	.667	21.100	-.959
13	-13.300	13.406	-68.909	.671	21.091	-.880
13	-13.300	13.414	-68.917	.675	21.083	-.801
13	-13.300	13.422	-68.925	.678	21.075	-.721

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
13	-13.300	13.431	-68.934	.682	21.066	-.642
13	-13.300	13.439	-68.942	.685	21.058	-.562
13	-13.300	13.447	-68.950	.689	21.050	-.482
13	-13.300	13.456	-68.959	.692	21.041	-.402
13	-13.300	13.464	-68.967	.696	21.033	-.322
13	-13.300	13.472	-68.975	.699	21.025	-.242
13	-13.300	13.481	-68.984	.703	21.016	-.161
13	-13.300	13.489	-68.992	.707	21.008	-.081
13	-13.300	13.481	-68.984	.703	21.016	-.161
13	-13.300	13.481	-68.984	.703	21.016	-.153
13	-13.300	13.482	-68.985	.704	21.015	-.145
13	-13.300	13.483	-68.986	.704	21.014	-.137
13	-13.300	13.484	-68.987	.704	21.013	-.129
13	-13.300	13.485	-68.988	.705	21.012	-.121
13	-13.300	13.486	-68.988	.705	21.012	-.113
13	-13.300	13.486	-68.989	.705	21.011	-.105
13	-13.300	13.487	-68.990	.706	21.010	-.097
13	-13.300	13.488	-68.991	.706	21.009	-.089
13	-13.300	13.489	-68.992	.707	21.008	-.081
13	-13.300	13.490	-68.993	.707	21.007	-.073
13	-13.300	13.490	-68.993	.707	21.007	-.065
13	-13.300	13.491	-68.994	.708	21.006	-.057
13	-13.300	13.492	-68.995	.708	21.005	-.048
13	-13.300	13.493	-68.996	.708	21.004	-.040
13	-13.300	13.494	-68.997	.709	21.003	-.032
13	-13.300	13.495	-68.998	.709	21.002	-.024
13	-13.300	13.495	-68.998	.709	21.002	-.016
13	-13.300	13.496	-68.999	.710	21.001	-.008
13	-13.300	13.495	-68.998	.709	21.002	-.016
13	-13.300	13.495	-68.998	.709	21.002	-.013
13	-13.300	13.496	-68.999	.709	21.001	-.015
13	-13.300	13.496	-68.999	.709	21.001	-.014
13	-13.300	13.496	-68.999	.709	21.001	-.013
13	-13.300	13.496	-68.999	.710	21.001	-.012
13	-13.300	13.496	-68.999	.710	21.001	-.011
13	-13.300	13.496	-68.999	.710	21.001	-.011
13	-13.300	13.496	-68.999	.710	21.001	-.010
13	-13.300	13.496	-68.999	.710	21.001	-.009
13	-13.300	13.496	-68.999	.710	21.001	-.008
13	-13.300	13.496	-68.999	.710	21.001	-.007
13	-13.300	13.496	-68.999	.710	21.001	-.006
13	-13.300	13.496	-68.999	.710	21.001	-.006
13	-13.300	13.497	-69.000	.710	21.000	-.005
13	-13.300	13.497	-69.000	.710	21.000	-.004
13	-13.300	13.497	-69.000	.710	21.000	-.003
13	-13.300	13.497	-69.000	.710	21.000	-.002

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
14	-14.755	13.431	-68.934	.732	21.066	-.640
14	-14.755	13.440	-68.943	.735	21.057	-.549
14	-14.755	13.450	-68.953	.739	21.047	-.458
14	-14.755	13.459	-68.962	.743	21.038	-.367
14	-14.755	13.469	-68.972	.747	21.028	-.275
14	-14.755	13.478	-68.981	.751	21.019	-.184
14	-14.755	13.488	-68.991	.754	21.009	-.092
14	-14.755	13.488	-68.991	.754	21.009	-.092
14	-14.755	13.489	-68.992	.755	21.008	-.083
14	-14.755	13.490	-68.993	.755	21.007	-.074
14	-14.755	13.490	-68.993	.755	21.007	-.064
14	-14.755	13.491	-68.994	.756	21.006	-.055
14	-14.755	13.492	-68.995	.756	21.005	-.046
14	-14.755	13.493	-68.996	.757	21.004	-.037
14	-14.755	13.494	-68.997	.757	21.003	-.028
14	-14.755	13.495	-68.998	.757	21.002	-.018
14	-14.755	13.496	-68.999	.758	21.001	-.009
14	-14.755	13.496	-68.999	.758	21.001	-.009
14	-14.755	13.496	-68.999	.758	21.001	-.008
14	-14.755	13.496	-68.999	.758	21.001	-.007
14	-14.755	13.496	-68.999	.758	21.001	-.006
14	-14.755	13.496	-68.999	.758	21.001	-.006
14	-14.755	13.497	-69.000	.758	21.000	-.005
14	-14.755	13.497	-69.000	.758	21.000	-.004
14	-14.755	13.497	-69.000	.758	21.000	-.003
14	-14.755	13.497	-69.000	.758	21.000	-.002
14	-14.755	13.497	-69.000	.758	21.000	-.001
14	-14.755	13.497	-69.000	.758	21.000	-.001
14	-14.755	13.497	-69.000	.758	21.000	-.001
14	-14.755	13.497	-69.000	.758	21.000	-.001
14	-14.755	13.497	-69.000	.758	21.000	-.001
14	-14.755	13.497	-69.000	.758	21.000	-.001
14	-14.755	13.497	-69.000	.758	21.000	-.000
14	-14.755	13.497	-69.000	.758	21.000	-.000
14	-14.755	13.497	-69.000	.758	21.000	-.000
14	-14.755	13.497	-69.000	.758	21.000	-.000
14	-14.755	13.497	-69.000	.758	21.000	-.000
14	-14.755	13.497	-69.000	.758	21.000	-.000
15	-16.320	11.005	-66.500	0.000	23.412	-16.320
15	-16.320	11.205	-66.700	.040	23.292	-15.694
15	-16.320	11.327	-66.830	.081	23.170	-15.052
15	-16.320	11.449	-66.952	.121	23.048	-14.393
15	-16.320	11.572	-67.075	.161	22.925	-13.715
15	-16.320	11.696	-67.199	.202	22.801	-13.019
15	-16.320	11.820	-67.323	.242	22.677	-12.305
15	-16.320	11.944	-67.447	.282	22.553	-11.570

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
15	-16.320	12.069	-67.572	.322	22.428	-10.816
15	-16.320	12.193	-67.696	.363	22.304	-10.841
15	-16.320	12.318	-67.821	.403	22.179	-9.245
15	-16.320	12.442	-67.945	.443	22.055	-8.427
15	-16.320	12.565	-68.068	.484	21.932	-7.587
15	-16.320	12.688	-68.191	.524	21.809	-6.724
15	-16.320	12.809	-68.312	.564	21.688	-5.838
15	-16.320	12.929	-68.432	.605	21.568	-4.927
15	-16.320	13.047	-68.558	.645	21.450	-3.992
15	-16.320	13.164	-68.667	.685	21.333	-3.033
15	-16.320	13.278	-68.790	.726	21.220	-2.048
15	-16.320	13.389	-68.892	.766	21.108	-1.037
15	-16.320	13.278	-68.788	.726	21.220	-2.048
15	-16.320	13.289	-68.792	.730	21.208	-1.948
15	-16.320	13.300	-68.803	.734	21.197	-1.848
15	-16.320	13.311	-68.814	.738	21.186	-1.747
15	-16.320	13.322	-68.825	.742	21.175	-1.646
15	-16.320	13.334	-68.836	.746	21.164	-1.546
15	-16.320	13.345	-68.848	.750	21.152	-1.444
15	-16.320	13.356	-68.859	.754	21.141	-1.343
15	-16.320	13.367	-68.870	.758	21.130	-1.241
15	-16.320	13.378	-68.881	.762	21.119	-1.139
15	-16.320	13.389	-68.892	.766	21.108	-1.037
15	-16.320	13.400	-68.903	.770	21.097	-.934
15	-16.320	13.411	-68.914	.774	21.086	-.832
15	-16.320	13.422	-68.925	.778	21.075	-.729
15	-16.320	13.432	-68.935	.782	21.065	-.625
15	-16.320	13.443	-68.946	.786	21.054	-.522
15	-16.320	13.454	-68.957	.790	21.043	-.418
15	-16.320	13.465	-68.968	.794	21.032	-.314
15	-16.320	13.476	-68.979	.798	21.021	-.209
15	-16.320	13.486	-68.989	.802	21.011	-.105
15	-16.320	13.486	-68.989	.802	21.011	-.105
15	-16.320	13.487	-68.990	.803	21.010	-.094
15	-16.320	13.489	-68.991	.803	21.009	-.084
15	-16.320	13.490	-68.993	.803	21.007	-.073
15	-16.320	13.491	-68.994	.804	21.006	-.063
15	-16.320	13.492	-68.995	.804	21.005	-.052
15	-16.320	13.493	-68.996	.805	21.004	-.042
15	-16.320	13.494	-68.997	.805	21.003	-.031
15	-16.320	13.495	-68.998	.805	21.002	-.021
15	-16.320	13.496	-68.999	.806	21.001	-.010
15	-16.320	13.496	-68.999	.806	21.001	-.009
15	-16.320	13.496	-68.999	.806	21.001	-.008
15	-16.320	13.496	-68.999	.806	21.001	-.007

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
15	-16.320	13.496	-68.999	.806	21.001	-.006
15	-16.320	13.497	-68.999	.806	21.001	-.005
15	-16.320	13.497	-69.000	.806	21.000	-.004
15	-16.320	13.497	-69.000	.806	21.000	-.003
15	-16.320	13.497	-69.000	.806	21.000	-.002
15	-16.320	13.497	-69.000	.806	21.000	-.001
15	-16.320	13.497	-69.000	.806	21.000	-.001
15	-16.320	13.497	-69.000	.806	21.000	-.001
15	-16.320	13.497	-69.000	.806	21.000	-.001
15	-16.320	13.497	-69.000	.806	21.000	-.001
15	-16.320	13.497	-69.000	.806	21.000	-.001
15	-16.320	13.497	-69.000	.806	21.000	-.001
15	-16.320	13.497	-69.000	.806	21.000	-.000
15	-16.320	13.497	-69.000	.806	21.000	-.000
15	-16.320	13.497	-69.000	.806	21.000	-.000
15	-16.320	13.497	-69.000	.806	21.000	-.000
15	-16.320	13.497	-69.000	.806	21.000	-.000
15	-16.320	13.497	-69.000	.806	21.000	-.000
15	-16.320	13.497	-69.000	.806	21.000	-.000
16	-18.005	10.749	-66.252	0.800	23.748	-18.005
16	-18.005	10.883	-66.386	.803	23.614	-17.341
16	-18.005	11.019	-66.522	.805	23.478	-16.657
16	-18.005	11.156	-66.659	.808	23.341	-15.952
16	-18.005	11.294	-66.797	.811	23.203	-15.226
16	-18.005	11.434	-66.937	.814	23.063	-14.477
16	-18.005	11.574	-67.077	.816	22.923	-13.704
16	-18.005	11.713	-67.218	.819	22.782	-12.908
16	-18.005	11.857	-67.360	.822	22.640	-12.087
16	-18.005	11.999	-67.502	.824	22.498	-11.240
16	-18.005	12.141	-67.644	.827	22.356	-10.367
16	-18.005	12.283	-67.786	.830	22.214	-9.467
16	-18.005	12.425	-67.928	.833	22.072	-8.538
16	-18.005	12.566	-68.069	.835	21.931	-7.580
16	-18.005	12.706	-68.209	.838	21.791	-6.593
16	-18.005	12.844	-68.347	.841	21.653	-5.575
16	-18.005	12.980	-68.483	.843	21.517	-4.525
16	-18.005	13.114	-68.617	.846	21.383	-3.444
16	-18.005	13.245	-68.748	.849	21.252	-2.329
16	-18.005	13.373	-68.876	.851	21.124	-1.182
16	-18.005	13.245	-68.748	.849	21.252	-2.329
16	-18.005	13.258	-68.761	.849	21.239	-2.216
16	-18.005	13.271	-68.774	.849	21.226	-2.103
16	-18.005	13.284	-68.787	.849	21.213	-1.989
16	-18.005	13.297	-68.800	.849	21.200	-1.874
16	-18.005	13.310	-68.813	.849	21.187	-1.760
16	-18.005	13.323	-68.826	.849	21.174	-1.645
16	-18.005	13.335	-68.838	.849	21.162	-1.530
16	-18.005	13.348	-68.851	.849	21.149	-1.414

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
16	-18.005	13.361	-68.864	.807	21.136	-1.298
16	-18.005	13.373	-68.876	.811	21.124	-1.182
16	-18.005	13.386	-68.889	.816	21.111	-1.065
16	-18.005	13.398	-68.901	.820	21.099	-.948
16	-18.005	13.411	-68.914	.824	21.086	-.831
16	-18.005	13.423	-68.926	.829	21.074	-.713
16	-18.005	13.436	-68.939	.833	21.061	-.595
16	-18.005	13.448	-68.951	.837	21.049	-.477
16	-18.005	13.460	-68.963	.841	21.037	-.358
16	-18.005	13.473	-68.976	.846	21.024	-.239
16	-18.005	13.485	-68.988	.850	21.012	-.120
16	-18.005	13.473	-68.976	.846	21.024	-.239
16	-18.005	13.474	-68.977	.846	21.023	-.227
16	-18.005	13.475	-68.978	.847	21.022	-.215
16	-18.005	13.476	-68.979	.847	21.021	-.203
16	-18.005	13.478	-68.980	.847	21.020	-.191
16	-18.005	13.479	-68.982	.848	21.018	-.179
16	-18.005	13.480	-68.983	.848	21.017	-.168
16	-18.005	13.481	-68.984	.849	21.016	-.156
16	-18.005	13.482	-68.985	.849	21.015	-.144
16	-18.005	13.484	-68.987	.850	21.013	-.132
16	-18.005	13.485	-68.988	.850	21.012	-.120
16	-18.005	13.486	-68.989	.850	21.011	-.108
16	-18.005	13.487	-68.990	.851	21.010	-.096
16	-18.005	13.489	-68.991	.851	21.009	-.084
16	-18.005	13.490	-68.993	.852	21.007	-.072
16	-18.005	13.491	-68.994	.852	21.006	-.060
16	-18.005	13.492	-68.995	.852	21.005	-.048
16	-18.005	13.493	-68.996	.853	21.004	-.036
16	-18.005	13.495	-68.998	.853	21.002	-.024
16	-18.005	13.496	-68.999	.854	21.001	-.012
16	-18.005	13.496	-68.999	.854	21.001	-.012
16	-18.005	13.496	-68.999	.854	21.001	-.011
16	-18.005	13.496	-68.999	.854	21.001	-.010
16	-18.005	13.496	-68.999	.854	21.001	-.008
16	-18.005	13.496	-68.999	.854	21.001	-.007
16	-18.005	13.496	-68.999	.854	21.001	-.006
16	-18.005	13.497	-69.000	.854	21.000	-.005
16	-18.005	13.497	-69.000	.854	21.000	-.004
16	-18.005	13.497	-69.000	.854	21.000	-.002
16	-18.005	13.497	-69.000	.854	21.000	-.001
16	-18.005	13.497	-69.000	.854	21.000	-.002
16	-18.005	13.497	-69.000	.854	21.000	-.002
16	-18.005	13.497	-69.000	.854	21.000	-.002
16	-18.005	13.497	-69.000	.854	21.000	-.002
16	-18.005	13.497	-69.000	.854	21.000	-.002
16	-18.005	13.497	-69.000	.854	21.000	-.002
16	-18.005	13.497	-69.000	.854	21.000	-.002

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
16	-18.005	13.497	-69.000	.854	21.000	-.002
16	-18.005	13.497	-69.000	.854	21.000	-.002
16	-18.005	13.497	-69.000	.854	21.000	-.002
16	-18.005	13.497	-69.000	.854	21.000	-.001
16	-18.005	13.497	-69.000	.854	21.000	-.001
16	-18.005	13.497	-69.000	.854	21.000	-.001
16	-18.005	13.497	-69.000	.854	21.000	-.001
16	-18.005	13.497	-69.000	.854	21.000	-.001
16	-18.005	13.497	-69.000	.854	21.000	-.001
16	-18.005	13.497	-69.000	.854	21.000	-.001
16	-18.005	13.497	-69.000	.854	21.000	-.001
16	-18.005	13.497	-69.000	.854	21.000	-.000
16	-18.005	13.497	-69.000	.854	21.000	-.000
16	-18.005	13.497	-69.000	.854	21.000	-.000
16	-18.005	13.497	-69.000	.854	21.000	-.000
17	-19.823	10.369	-65.872	0.000	24.120	-19.823
17	-19.823	10.517	-66.820	.045	23.900	-19.124
17	-19.823	10.660	-66.171	.090	23.829	-18.400
17	-19.823	10.821	-66.323	.135	23.677	-17.652
17	-19.823	10.975	-66.478	.180	23.522	-16.878
17	-19.823	11.132	-66.635	.226	23.365	-16.077
17	-19.823	11.290	-66.793	.271	23.207	-15.248
17	-19.823	11.450	-66.953	.316	23.047	-14.389
17	-19.823	11.611	-67.114	.361	22.886	-13.500
17	-19.823	11.773	-67.275	.406	22.725	-12.578
17	-19.823	11.935	-67.438	.451	22.562	-11.624
17	-19.823	12.098	-67.601	.496	22.399	-10.636
17	-19.823	12.261	-67.764	.541	22.236	-9.612
17	-19.823	12.423	-67.926	.586	22.074	-8.552
17	-19.823	12.584	-68.087	.632	21.913	-7.454
17	-19.823	12.744	-68.247	.677	21.753	-6.316
17	-19.823	12.902	-68.405	.722	21.595	-5.138
17	-19.823	13.056	-68.559	.767	21.441	-3.918
17	-19.823	13.200	-68.711	.812	21.289	-2.656
17	-19.823	13.353	-68.858	.857	21.142	-1.350
17	-19.823	13.200	-68.711	.812	21.289	-2.656
17	-19.823	13.223	-68.726	.817	21.274	-2.527
17	-19.823	13.238	-68.741	.821	21.259	-2.398
17	-19.823	13.252	-68.755	.826	21.245	-2.269
17	-19.823	13.267	-68.770	.830	21.230	-2.139
17	-19.823	13.282	-68.785	.835	21.215	-2.009
17	-19.823	13.297	-68.800	.839	21.200	-1.878
17	-19.823	13.311	-68.814	.844	21.186	-1.747
17	-19.823	13.326	-68.829	.848	21.171	-1.615
17	-19.823	13.340	-68.843	.853	21.157	-1.483

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
17	-19.823	13.355	-68.858	.857	21.142	-1.358
17	-19.823	13.369	-68.872	.862	21.128	-1.217
17	-19.823	13.384	-68.887	.866	21.113	-1.084
17	-19.823	13.398	-68.901	.871	21.099	-.950
17	-19.823	13.412	-68.915	.875	21.085	-.816
17	-19.823	13.427	-68.930	.880	21.070	-.681
17	-19.823	13.441	-68.944	.884	21.056	-.545
17	-19.823	13.455	-68.958	.889	21.042	-.410
17	-19.823	13.469	-68.972	.893	21.028	-.274
17	-19.823	13.483	-68.986	.898	21.014	-.137
17	-19.823	13.497	-69.000	.902	21.000	-.000
18	-21.784	9.938	-65.441	0.888	24.559	-21.784
18	-21.784	10.101	-65.684	.848	24.396	-21.055
18	-21.784	10.267	-65.778	.895	24.238	-20.297
18	-21.784	10.436	-65.939	.143	24.061	-19.509
18	-21.784	10.608	-66.111	.198	23.889	-18.691
18	-21.784	10.782	-66.285	.238	23.715	-17.848
18	-21.784	10.960	-66.463	.285	23.537	-16.955
18	-21.784	11.140	-66.643	.333	23.357	-16.035
18	-21.784	11.322	-66.825	.388	23.175	-15.077
18	-21.784	11.506	-67.009	.428	22.991	-14.088
18	-21.784	11.692	-67.195	.475	22.805	-13.042
18	-21.784	11.878	-67.381	.523	22.619	-11.961
18	-21.784	12.066	-67.569	.570	22.431	-10.835
18	-21.784	12.253	-67.756	.618	22.244	-9.663
18	-21.784	12.439	-67.942	.665	22.058	-8.443
18	-21.784	12.625	-68.127	.713	21.873	-7.172
18	-21.784	12.807	-68.318	.760	21.690	-5.849
18	-21.784	12.987	-68.498	.808	21.510	-4.472
18	-21.784	13.163	-68.666	.855	21.334	-3.039
18	-21.784	13.333	-68.836	.903	21.164	-1.549
18	-21.784	13.333	-68.836	.903	21.164	-1.549
18	-21.784	13.350	-68.853	.908	21.147	-1.397
18	-21.784	13.367	-68.869	.912	21.131	-1.244
18	-21.784	13.383	-68.886	.917	21.114	-1.090
18	-21.784	13.400	-68.903	.922	21.097	-.936
18	-21.784	13.416	-68.919	.927	21.081	-.782
18	-21.784	13.432	-68.935	.931	21.065	-.627
18	-21.784	13.449	-68.952	.936	21.048	-.471
18	-21.784	13.465	-68.968	.941	21.032	-.314
18	-21.784	13.481	-68.984	.946	21.016	-.158
18	-21.784	13.481	-68.984	.946	21.016	-.158
18	-21.784	13.483	-68.986	.946	21.014	-.142
18	-21.784	13.484	-68.987	.947	21.013	-.126
18	-21.784	13.486	-68.989	.947	21.011	-.110

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
18	-21.784	13.487	-68.990	.947	21.010	-.095
18	-21.784	13.489	-68.992	.948	21.000	-.079
18	-21.784	13.491	-68.994	.948	21.006	-.063
18	-21.784	13.492	-68.995	.949	21.005	-.047
18	-21.784	13.494	-68.997	.949	21.003	-.032
18	-21.784	13.495	-68.998	.950	21.002	-.016
18	-21.784	13.495	-68.998	.950	21.002	-.016
18	-21.784	13.496	-68.999	.950	21.001	-.014
18	-21.784	13.496	-68.999	.950	21.001	-.013
18	-21.784	13.496	-68.999	.950	21.001	-.011
18	-21.784	13.496	-68.999	.950	21.001	-.009
18	-21.784	13.496	-68.999	.950	21.001	-.008
18	-21.784	13.496	-68.999	.950	21.001	-.006
18	-21.784	13.497	-69.000	.950	21.000	-.005
18	-21.784	13.497	-69.000	.950	21.000	-.003
18	-21.784	13.497	-69.000	.950	21.000	-.002
18	-21.784	13.497	-69.000	.950	21.000	-.002
18	-21.784	13.497	-69.000	.950	21.000	-.001
18	-21.784	13.497	-69.000	.950	21.000	-.001
18	-21.784	13.497	-69.000	.950	21.000	-.001
18	-21.784	13.497	-69.000	.950	21.000	-.001
18	-21.784	13.497	-69.000	.950	21.000	-.000
18	-21.784	13.497	-69.000	.950	21.000	-.000
18	-21.784	13.497	-69.000	.950	21.000	-.000
19	-23.903	9.450	-64.953	0.000	25.047	-23.903
19	-23.903	9.626	-65.129	.050	24.871	-23.149
19	-23.903	9.807	-65.310	.100	24.690	-22.362
19	-23.903	9.993	-65.496	.150	24.504	-21.541
19	-23.903	10.182	-65.685	.200	24.315	-20.684
19	-23.903	10.376	-65.879	.250	24.121	-19.788
19	-23.903	10.574	-66.077	.300	23.923	-18.851
19	-23.903	10.776	-66.279	.349	23.721	-17.872
19	-23.903	10.981	-66.484	.399	23.516	-16.847
19	-23.903	11.190	-66.693	.449	23.307	-15.773
19	-23.903	11.402	-66.905	.499	23.095	-14.649
19	-23.903	11.616	-67.118	.549	22.882	-13.472
19	-23.903	11.831	-67.334	.599	22.666	-12.239
19	-23.903	12.047	-67.550	.649	22.450	-10.946
19	-23.903	12.264	-67.767	.699	22.233	-9.591
19	-23.903	12.480	-67.983	.749	22.017	-8.172
19	-23.903	12.693	-68.196	.799	21.804	-6.684
19	-23.903	12.903	-68.406	.849	21.594	-5.126
19	-23.903	13.100	-68.611	.899	21.389	-3.494

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
19	-23.903	13.307	-68.810	.948	21.190	-1.786
19	-23.903	13.497	-69.000	.998	21.000	-.000
20	-26.190	8.895	-64.398	0.000	25.602	-26.190
20	-26.190	9.085	-64.588	.052	25.412	-25.421
20	-26.190	9.280	-64.783	.105	25.217	-24.615
20	-26.190	9.481	-64.984	.157	25.016	-23.769
20	-26.190	9.688	-65.191	.209	24.809	-22.880
20	-26.190	9.902	-65.405	.262	24.595	-21.946
20	-26.190	10.121	-65.624	.314	24.376	-20.964
20	-26.190	10.346	-65.849	.366	24.151	-19.931
20	-26.190	10.576	-66.079	.419	23.921	-18.842
20	-26.190	10.812	-66.315	.471	23.685	-17.695
20	-26.190	11.052	-66.555	.523	23.445	-16.486
20	-26.190	11.297	-66.800	.576	23.200	-15.210
20	-26.190	11.545	-67.048	.628	22.952	-13.863
20	-26.190	11.796	-67.299	.680	22.701	-12.441
20	-26.190	12.049	-67.552	.732	22.448	-10.948
20	-26.190	12.301	-67.804	.785	22.196	-9.354
20	-26.190	12.552	-68.055	.837	21.945	-7.679
20	-26.190	12.799	-68.302	.889	21.698	-5.910
20	-26.190	13.041	-68.544	.942	21.456	-4.043
20	-26.190	13.274	-68.777	.994	21.223	-2.075
20	-26.190	13.497	-69.000	1.046	21.000	-.000
21	-28.661	8.267	-63.770	0.000	26.230	-28.661
21	-28.661	8.467	-63.970	.055	26.030	-27.888
21	-28.661	8.674	-64.177	.109	25.823	-27.073
21	-28.661	8.890	-64.393	.164	25.607	-26.213
21	-28.661	9.113	-64.616	.219	25.384	-25.305
21	-28.661	9.345	-64.848	.274	25.152	-24.344
21	-28.661	9.585	-65.088	.328	24.912	-23.326
21	-28.661	9.833	-65.336	.383	24.664	-22.248
21	-28.661	10.090	-65.593	.438	24.407	-21.104
21	-28.661	10.355	-65.858	.493	24.142	-19.889
21	-28.661	10.627	-66.130	.547	23.870	-18.598
21	-28.661	10.906	-66.409	.602	23.591	-17.224
21	-28.661	11.192	-66.695	.657	23.305	-15.762
21	-28.661	11.484	-66.987	.711	23.013	-14.204
21	-28.661	11.779	-67.282	.766	22.718	-12.543
21	-28.661	12.076	-67.579	.821	22.421	-10.771
21	-28.661	12.373	-67.876	.876	22.124	-8.882
21	-28.661	12.667	-68.178	.930	21.830	-6.868
21	-28.661	12.956	-68.459	.985	21.541	-4.721
21	-28.661	13.234	-68.737	1.040	21.263	-2.433
21	-28.661	12.956	-68.459	.985	21.541	-4.721

TABLE A-VI (CONT)

RAY	BETA	THETA(CRAY)	NORMAL	S	ALPHA2	RHO 2
21	-28.661	12.984	-68.487	.998	21.513	-4.498
21	-28.661	13.012	-68.515	.996	21.485	-4.274
21	-28.661	13.040	-68.543	1.001	21.457	-4.049
21	-28.661	13.068	-68.571	1.007	21.429	-3.823
21	-28.661	13.096	-68.599	1.012	21.401	-3.595
21	-28.661	13.124	-68.627	1.018	21.373	-3.365
21	-28.661	13.151	-68.654	1.023	21.346	-3.134
21	-28.661	13.179	-68.682	1.029	21.318	-2.902
21	-28.661	13.206	-68.709	1.034	21.291	-2.668
21	-28.661	13.234	-68.737	1.040	21.263	-2.433
21	-28.661	13.261	-68.764	1.045	21.236	-2.197
21	-28.661	13.288	-68.791	1.051	21.209	-1.958
21	-28.661	13.314	-68.817	1.056	21.183	-1.719
21	-28.661	13.341	-68.844	1.062	21.156	-1.478
21	-28.661	13.367	-68.870	1.067	21.130	-1.235
21	-28.661	13.394	-68.897	1.073	21.103	-.991
21	-28.661	13.420	-68.923	1.078	21.077	-.746
21	-28.661	13.446	-68.949	1.084	21.051	-.499
21	-28.661	13.471	-68.974	1.089	21.026	-.250
21	-28.661	13.471	-68.974	1.089	21.026	-.250
21	-28.661	13.474	-68.977	1.090	21.023	-.225
21	-28.661	13.477	-68.980	1.090	21.020	-.200
21	-28.661	13.479	-68.982	1.091	21.018	-.175
21	-28.661	13.482	-68.985	1.091	21.015	-.150
21	-28.661	13.484	-68.987	1.092	21.013	-.125
21	-28.661	13.487	-68.990	1.092	21.010	-.100
21	-28.661	13.489	-68.992	1.093	21.008	-.075
21	-28.661	13.492	-68.995	1.093	21.005	-.050
21	-28.661	13.494	-68.997	1.094	21.003	-.025
21	-28.661	13.497	-69.000	1.094	21.000	-.000
21	-28.661	13.494	-68.997	1.094	21.003	-.025
21	-28.661	13.495	-68.998	1.094	21.002	-.023
21	-28.661	13.495	-68.998	1.094	21.002	-.020
21	-28.661	13.495	-68.998	1.094	21.002	-.018
21	-28.661	13.496	-68.998	1.094	21.002	-.015
21	-28.661	13.496	-68.999	1.094	21.001	-.013
21	-28.661	13.496	-68.999	1.094	21.001	-.010
21	-28.661	13.496	-68.999	1.094	21.001	-.008
21	-28.661	13.497	-68.999	1.094	21.001	-.005
21	-28.661	13.497	-69.000	1.094	21.000	-.003
21	-28.661	13.497	-68.999	1.094	21.001	-.005
21	-28.661	13.497	-69.000	1.094	21.000	-.005
21	-28.661	13.497	-69.000	1.094	21.000	-.004
21	-28.661	13.497	-69.000	1.094	21.000	-.004

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
21	-20.661	13.497	-69.000	1.094	21.000	-.004
21	-20.661	13.497	-69.000	1.094	21.000	-.003
21	-20.661	13.497	-69.000	1.094	21.000	-.003
21	-20.661	13.497	-69.000	1.094	21.000	-.003
21	-20.661	13.497	-69.000	1.094	21.000	-.003
21	-20.661	13.497	-69.000	1.094	21.000	-.002
21	-20.661	13.497	-69.000	1.094	21.000	-.002
21	-20.661	13.497	-69.000	1.094	21.000	-.002
21	-20.661	13.497	-69.000	1.094	21.000	-.002
21	-20.661	13.497	-69.000	1.094	21.000	-.002
21	-20.661	13.497	-69.000	1.094	21.000	-.001
21	-20.661	13.497	-69.000	1.094	21.000	-.001
21	-20.661	13.497	-69.000	1.094	21.000	-.001
21	-20.661	13.497	-69.000	1.094	21.000	-.001
21	-20.661	13.497	-69.000	1.094	21.000	-.001
21	-20.661	13.497	-69.000	1.094	21.000	-.000
22	-31.326	7.556	-63.058	0.000	26.942	-31.326
22	-31.326	7.762	-63.265	.057	26.735	-30.564
22	-31.326	7.979	-63.482	.114	26.518	-29.756
22	-31.326	8.205	-63.700	.171	26.292	-28.898
22	-31.326	8.442	-63.945	.229	26.055	-27.985
22	-31.326	8.690	-64.193	.286	25.807	-27.012
22	-31.326	8.949	-64.452	.343	25.548	-25.974
22	-31.326	9.219	-64.722	.400	25.278	-24.866
22	-31.326	9.502	-65.005	.457	24.995	-23.688
22	-31.326	9.796	-65.299	.514	24.701	-22.410
22	-31.326	10.103	-65.606	.571	24.394	-21.046
22	-31.326	10.420	-65.923	.628	24.077	-19.582
22	-31.326	10.749	-66.252	.686	23.748	-18.005
22	-31.326	11.087	-66.590	.743	23.410	-16.308
22	-31.326	11.434	-66.937	.800	23.063	-14.477
22	-31.326	11.786	-67.289	.857	22.711	-12.501
22	-31.326	12.141	-67.644	.914	22.356	-10.367
22	-31.326	12.496	-67.999	.971	22.001	-8.063
22	-31.326	12.844	-68.347	1.028	21.653	-5.575
22	-31.326	13.188	-68.683	1.085	21.317	-2.891
22	-31.326	12.844	-68.347	1.028	21.653	-5.575
22	-31.326	12.878	-68.381	1.034	21.619	-5.315
22	-31.326	12.913	-68.415	1.040	21.585	-5.054
22	-31.326	12.947	-68.450	1.045	21.550	-4.791
22	-31.326	12.980	-68.483	1.051	21.517	-4.525
22	-31.326	13.014	-68.517	1.057	21.483	-4.258
22	-31.326	13.048	-68.551	1.063	21.449	-3.989
22	-31.326	13.081	-68.584	1.068	21.416	-3.717
22	-31.326	13.114	-68.617	1.074	21.383	-3.444
22	-31.326	13.147	-68.650	1.080	21.350	-3.168
22	-31.326	13.180	-68.683	1.085	21.317	-2.891

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
22	-31.326	13.213	-68.716	1.091	21.284	-2.611
22	-31.326	13.245	-68.748	1.097	21.252	-2.330
22	-31.326	13.278	-68.781	1.103	21.219	-2.046
22	-31.326	13.310	-68.813	1.108	21.187	-1.760
22	-31.326	13.342	-68.845	1.114	21.155	-1.472
22	-31.326	13.373	-68.876	1.120	21.124	-1.182
22	-31.326	13.405	-68.908	1.125	21.092	-.890
22	-31.326	13.436	-68.939	1.131	21.061	-.595
22	-31.326	13.466	-68.969	1.137	21.031	-.299
22	-31.326	13.436	-68.939	1.131	21.061	-.595
22	-31.326	13.439	-68.942	1.132	21.058	-.566
22	-31.326	13.442	-68.945	1.132	21.055	-.536
22	-31.326	13.445	-68.948	1.133	21.052	-.506
22	-31.326	13.448	-68.951	1.133	21.049	-.477
22	-31.326	13.451	-68.954	1.134	21.046	-.447
22	-31.326	13.454	-68.957	1.135	21.043	-.418
22	-31.326	13.457	-68.960	1.135	21.040	-.388
22	-31.326	13.460	-68.963	1.136	21.037	-.358
22	-31.326	13.463	-68.966	1.136	21.034	-.328
22	-31.326	13.466	-68.969	1.137	21.031	-.299
22	-31.326	13.470	-68.973	1.137	21.027	-.269
22	-31.326	13.473	-68.976	1.138	21.024	-.239
22	-31.326	13.476	-68.979	1.139	21.021	-.209
22	-31.326	13.479	-68.982	1.139	21.018	-.179
22	-31.326	13.482	-68.985	1.140	21.015	-.150
22	-31.326	13.485	-68.988	1.140	21.012	-.120
22	-31.326	13.488	-68.991	1.141	21.009	-.090
22	-31.326	13.491	-68.994	1.141	21.006	-.060
22	-31.326	13.494	-68.997	1.142	21.003	-.030
22	-31.326	13.491	-68.994	1.141	21.006	-.060
22	-31.326	13.491	-68.994	1.141	21.006	-.057
22	-31.326	13.492	-68.995	1.141	21.005	-.054
22	-31.326	13.492	-68.995	1.142	21.005	-.051
22	-31.326	13.492	-68.995	1.142	21.005	-.048
22	-31.326	13.492	-68.995	1.142	21.005	-.045
22	-31.326	13.493	-68.996	1.142	21.004	-.042
22	-31.326	13.493	-68.996	1.142	21.004	-.039
22	-31.326	13.493	-68.996	1.142	21.004	-.036
22	-31.326	13.494	-68.997	1.142	21.003	-.033
22	-31.326	13.494	-68.997	1.142	21.003	-.030
22	-31.326	13.494	-68.997	1.142	21.003	-.027
22	-31.326	13.495	-68.998	1.142	21.002	-.024
22	-31.326	13.495	-68.998	1.142	21.002	-.021
22	-31.326	13.495	-68.998	1.142	21.002	-.018
22	-31.326	13.496	-68.998	1.142	21.002	-.015
22	-31.326	13.496	-68.999	1.142	21.001	-.012

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
22	-31.326	13.496	-69.999	1.142	21.001	-.009
22	-31.326	13.496	-69.999	1.142	21.001	-.006
22	-31.326	13.497	-69.000	1.142	21.000	-.003
22	-31.326	13.496	-69.999	1.142	21.001	-.006
22	-31.326	13.496	-69.999	1.142	21.001	-.006
22	-31.326	13.496	-69.999	1.142	21.001	-.005
22	-31.326	13.497	-69.999	1.142	21.001	-.005
22	-31.326	13.497	-69.000	1.142	21.000	-.005
22	-31.326	13.497	-69.000	1.142	21.000	-.004
22	-31.326	13.497	-69.000	1.142	21.000	-.004
22	-31.326	13.497	-69.000	1.142	21.000	-.004
22	-31.326	13.497	-69.000	1.142	21.000	-.004
22	-31.326	13.497	-69.000	1.142	21.000	-.004
22	-31.326	13.497	-69.000	1.142	21.000	-.003
22	-31.326	13.497	-69.000	1.142	21.000	-.003
22	-31.326	13.497	-69.000	1.142	21.000	-.002
22	-31.326	13.497	-69.000	1.142	21.000	-.002
22	-31.326	13.497	-69.000	1.142	21.000	-.002
22	-31.326	13.497	-69.000	1.142	21.000	-.001
22	-31.326	13.497	-69.000	1.142	21.000	-.001
22	-31.326	13.497	-69.000	1.142	21.000	-.001
22	-31.326	13.497	-69.000	1.142	21.000	-.000
23	-34.198	6.753	-62.256	0.000	27.744	-34.198
23	-34.198	6.961	-62.464	.060	27.536	-33.465
23	-34.198	7.181	-62.684	.119	27.316	-32.683
23	-34.198	7.413	-62.916	.179	27.084	-31.846
23	-34.198	7.658	-63.161	.238	26.839	-30.949
23	-34.198	7.917	-63.420	.298	26.588	-29.986
23	-34.198	8.191	-63.694	.357	26.306	-28.951
23	-34.198	8.480	-63.983	.417	26.017	-27.835
23	-34.198	8.786	-64.289	.476	25.711	-26.629
23	-34.198	9.109	-64.612	.536	25.388	-25.323
23	-34.198	9.449	-64.952	.595	25.048	-23.907
23	-34.198	9.806	-65.309	.655	24.691	-22.367
23	-34.198	10.181	-65.684	.714	24.316	-20.688
23	-34.198	10.573	-66.076	.774	23.924	-18.855
23	-34.198	10.981	-66.484	.833	23.516	-16.858
23	-34.198	11.401	-66.904	.893	23.096	-14.653
23	-34.198	11.831	-67.333	.952	22.667	-12.242
23	-34.198	12.264	-67.767	1.012	22.233	-9.594
23	-34.198	12.693	-68.196	1.071	21.804	-6.686
23	-34.198	13.108	-68.611	1.131	21.389	-3.495
23	-34.198	13.497	-69.000	1.191	21.000	-.000

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
24	-37.285	5.852	-61.355	0.000	28.645	-37.285
24	-37.285	6.055	-61.558	.062	28.442	-36.603
24	-37.285	6.270	-61.773	.124	28.227	-35.870
24	-37.285	6.500	-62.003	.186	27.997	-35.000
24	-37.285	6.745	-62.248	.248	27.752	-34.227
24	-37.285	7.007	-62.510	.310	27.490	-33.304
24	-37.285	7.287	-62.790	.372	27.210	-32.301
24	-37.285	7.587	-63.090	.434	26.910	-31.209
24	-37.285	7.909	-63.412	.495	26.588	-30.017
24	-37.285	8.254	-63.757	.557	26.243	-28.710
24	-37.285	8.623	-64.126	.619	25.874	-27.274
24	-37.285	9.019	-64.522	.681	25.478	-25.690
24	-37.285	9.441	-64.944	.743	25.056	-23.937
24	-37.285	9.892	-65.395	.805	24.605	-21.990
24	-37.285	10.369	-65.872	.867	24.128	-19.820
24	-37.285	10.872	-66.375	.929	23.625	-17.395
24	-37.285	11.397	-66.900	.991	23.100	-14.676
24	-37.285	11.935	-67.438	1.053	22.562	-11.623
24	-37.285	12.477	-67.990	1.115	22.020	-8.189
24	-37.285	13.005	-68.508	1.177	21.492	-4.329
24	-37.285	12.477	-67.980	1.115	22.020	-8.189
24	-37.285	12.531	-68.034	1.121	21.966	-7.823
24	-37.285	12.584	-68.087	1.127	21.913	-7.452
24	-37.285	12.638	-68.141	1.133	21.859	-7.077
24	-37.285	12.691	-68.194	1.140	21.806	-6.698
24	-37.285	12.744	-68.247	1.146	21.753	-6.315
24	-37.285	12.797	-68.300	1.152	21.700	-5.927
24	-37.285	12.849	-68.352	1.158	21.648	-5.534
24	-37.285	12.902	-68.405	1.164	21.595	-5.137
24	-37.285	12.954	-68.457	1.170	21.543	-4.735
24	-37.285	13.005	-68.508	1.177	21.492	-4.329
24	-37.285	13.057	-68.559	1.183	21.441	-3.918
24	-37.285	13.107	-68.610	1.189	21.390	-3.502
24	-37.285	13.158	-68.661	1.195	21.339	-3.081
24	-37.285	13.208	-68.711	1.201	21.289	-2.656
24	-37.285	13.257	-68.760	1.208	21.240	-2.225
24	-37.285	13.306	-68.809	1.214	21.191	-1.790
24	-37.285	13.355	-68.858	1.220	21.142	-1.350
24	-37.285	13.403	-68.906	1.226	21.094	-0.905
24	-37.285	13.450	-68.953	1.232	21.047	-0.455
24	-37.285	13.403	-68.906	1.226	21.094	-0.905
24	-37.285	13.408	-68.911	1.227	21.089	-0.860
24	-37.285	13.412	-68.915	1.227	21.085	-0.815
24	-37.285	13.417	-68.920	1.228	21.080	-0.770
24	-37.285	13.422	-68.925	1.229	21.075	-0.726
24	-37.285	13.427	-68.930	1.229	21.070	-0.681

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
24	-37.285	13.431	-68.934	1.230	21.066	-.636
24	-37.285	13.436	-68.939	1.231	21.061	-.590
24	-37.285	13.441	-68.944	1.231	21.056	-.545
24	-37.285	13.446	-68.949	1.232	21.051	-.500
24	-37.285	13.450	-68.953	1.232	21.047	-.455
24	-37.285	13.455	-68.958	1.233	21.042	-.410
24	-37.285	13.460	-68.963	1.234	21.037	-.364
24	-37.285	13.464	-68.967	1.234	21.033	-.319
24	-37.285	13.469	-68.972	1.235	21.028	-.274
24	-37.285	13.474	-68.977	1.236	21.023	-.228
24	-37.285	13.478	-68.981	1.236	21.019	-.183
24	-37.285	13.483	-68.986	1.237	21.014	-.137
24	-37.285	13.488	-68.991	1.237	21.009	-.091
24	-37.285	13.492	-68.995	1.238	21.005	-.046
24	-37.285	13.492	-68.995	1.238	21.005	-.046
24	-37.285	13.493	-68.996	1.238	21.004	-.041
24	-37.285	13.493	-68.996	1.238	21.004	-.037
24	-37.285	13.494	-68.997	1.238	21.003	-.032
24	-37.285	13.494	-68.997	1.238	21.003	-.027
24	-37.285	13.495	-68.998	1.238	21.002	-.023
24	-37.285	13.495	-68.998	1.238	21.002	-.018
24	-37.285	13.496	-68.999	1.238	21.001	-.014
24	-37.285	13.496	-68.999	1.238	21.001	-.009
24	-37.285	13.497	-69.000	1.239	21.000	-.005
24	-37.285	13.497	-69.000	1.239	21.000	-.005
24	-37.285	13.497	-69.000	1.239	21.000	-.004
24	-37.285	13.497	-69.000	1.239	21.000	-.004
24	-37.285	13.497	-69.000	1.239	21.000	-.003
24	-37.285	13.497	-69.000	1.239	21.000	-.003
24	-37.285	13.497	-69.000	1.239	21.000	-.002
24	-37.285	13.497	-69.000	1.239	21.000	-.002
24	-37.285	13.497	-69.000	1.239	21.000	-.001
24	-37.285	13.497	-69.000	1.239	21.000	-.001
24	-37.285	13.497	-69.000	1.239	21.000	-.000
25	-40.591	4.840	-60.351	0.000	29.649	-40.591
25	-40.591	5.035	-60.530	.064	29.462	-39.906
25	-40.591	5.235	-60.730	.129	29.262	-39.332
25	-40.591	5.451	-60.954	.193	29.046	-38.621
25	-40.591	5.685	-61.187	.257	28.813	-37.846
25	-40.591	5.937	-61.440	.322	28.560	-37.000
25	-40.591	6.211	-61.714	.386	28.286	-36.072
25	-40.591	6.500	-62.011	.450	27.989	-35.051
25	-40.591	6.832	-62.335	.515	27.665	-33.921
25	-40.591	7.186	-62.689	.579	27.311	-32.666
25	-40.591	7.572	-63.075	.643	26.925	-31.266

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
25	-40.591	7.995	-63.498	.788	26.582	-29.695
25	-40.591	8.458	-63.961	.772	26.039	-27.923
25	-40.591	8.964	-64.467	.836	25.533	-25.913
25	-40.591	9.516	-65.019	.901	24.981	-23.620
25	-40.591	10.115	-65.618	.965	24.382	-20.980
25	-40.591	10.760	-66.263	1.029	23.737	-17.952
25	-40.591	11.442	-66.945	1.094	23.055	-14.430
25	-40.591	12.147	-67.658	1.158	22.350	-10.331
25	-40.591	12.847	-68.398	1.222	21.650	-5.554
25	-40.591	13.497	-69.080	1.287	21.000	-.000
25	-40.591	12.847	-68.350	1.222	21.650	-5.554
25	-40.591	12.915	-68.418	1.229	21.582	-5.035
25	-40.591	12.983	-68.486	1.235	21.514	-4.508
25	-40.591	13.050	-68.553	1.242	21.447	-3.973
25	-40.591	13.116	-68.619	1.248	21.381	-3.430
25	-40.591	13.182	-68.685	1.254	21.315	-2.879
25	-40.591	13.247	-68.750	1.261	21.250	-2.320
25	-40.591	13.311	-68.814	1.267	21.186	-1.753
25	-40.591	13.374	-68.877	1.274	21.123	-1.177
25	-40.591	13.436	-68.939	1.280	21.061	-.593
25	-40.591	13.497	-69.000	1.287	21.000	-.000
25	-40.591	13.436	-68.939	1.280	21.061	-.593
25	-40.591	13.442	-68.945	1.281	21.055	-.534
25	-40.591	13.448	-68.951	1.282	21.049	-.475
25	-40.591	13.454	-68.957	1.282	21.043	-.416
25	-40.591	13.460	-68.963	1.283	21.037	-.357
25	-40.591	13.467	-68.970	1.283	21.030	-.297
25	-40.591	13.473	-68.976	1.284	21.024	-.238
25	-40.591	13.479	-68.982	1.285	21.018	-.179
25	-40.591	13.485	-68.988	1.285	21.012	-.119
25	-40.591	13.491	-68.994	1.286	21.006	-.060
25	-40.591	13.491	-68.994	1.286	21.006	-.060
25	-40.591	13.492	-68.995	1.286	21.005	-.054
25	-40.591	13.492	-68.995	1.286	21.005	-.048
25	-40.591	13.493	-68.996	1.286	21.004	-.042
25	-40.591	13.493	-68.996	1.286	21.004	-.036
25	-40.591	13.494	-68.997	1.286	21.003	-.030
25	-40.591	13.495	-68.998	1.286	21.002	-.024
25	-40.591	13.495	-68.998	1.286	21.002	-.018
25	-40.591	13.496	-68.999	1.287	21.001	-.012
25	-40.591	13.496	-68.999	1.287	21.001	-.006
25	-40.591	13.497	-69.000	1.287	21.000	-.000
25	-40.591	13.496	-68.999	1.287	21.001	-.006
25	-40.591	13.496	-68.999	1.287	21.001	-.005
25	-40.591	13.497	-69.000	1.287	21.000	-.005
25	-40.591	13.497	-69.000	1.287	21.000	-.004

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
25	-40.591	13.497	-69.000	1.287	21.000	-.004
25	-40.591	13.497	-69.000	1.287	21.000	-.003
25	-40.591	13.497	-69.000	1.287	21.000	-.002
25	-40.591	13.497	-69.000	1.287	21.000	-.002
25	-40.591	13.497	-69.000	1.287	21.000	-.001
25	-40.591	13.497	-69.000	1.287	21.000	-.001
25	-40.591	13.497	-69.000	1.287	21.000	-.000
26	-44.110	3.740	-59.243	0.000	30.757	-44.110
26	-44.110	3.899	-59.402	.067	30.598	-43.620
26	-44.110	4.071	-59.574	.133	30.426	-43.076
26	-44.110	4.259	-59.762	.200	30.238	-42.482
26	-44.110	4.463	-59.966	.267	30.034	-41.829
26	-44.110	4.688	-60.191	.334	29.809	-41.109
26	-44.110	4.935	-60.438	.400	29.562	-40.310
26	-44.110	5.200	-60.711	.467	29.289	-39.420
26	-44.110	5.511	-61.014	.534	28.986	-38.423
26	-44.110	5.848	-61.351	.601	28.649	-37.290
26	-44.110	6.226	-61.729	.667	28.271	-36.021
26	-44.110	6.650	-62.153	.734	27.847	-34.559
26	-44.110	7.120	-62.631	.801	27.369	-32.873
26	-44.110	7.669	-63.172	.868	26.828	-30.909
26	-44.110	8.293	-63.786	.934	26.214	-28.600
26	-44.110	8.978	-64.481	1.001	25.519	-25.856
26	-44.110	9.763	-65.266	1.068	24.734	-22.556
26	-44.110	10.630	-66.141	1.134	23.859	-18.544
26	-44.110	11.590	-67.092	1.201	22.900	-13.618
26	-44.110	12.574	-68.077	1.268	21.923	-7.527
26	-44.110	11.590	-67.092	1.201	22.900	-13.618
26	-44.110	11.680	-67.191	1.200	22.809	-13.866
26	-44.110	11.786	-67.289	1.215	22.711	-12.501
26	-44.110	11.884	-67.387	1.221	22.613	-11.925
26	-44.110	11.983	-67.486	1.228	22.514	-11.336
26	-44.110	12.082	-67.585	1.235	22.415	-10.735
26	-44.110	12.181	-67.684	1.241	22.316	-10.120
26	-44.110	12.279	-67.782	1.248	22.218	-9.492
26	-44.110	12.378	-67.881	1.255	22.119	-8.851
26	-44.110	12.476	-67.979	1.261	22.021	-8.196
26	-44.110	12.574	-68.077	1.268	21.923	-7.527
26	-44.110	12.671	-68.174	1.275	21.826	-6.843
26	-44.110	12.767	-68.270	1.281	21.730	-6.145
26	-44.110	12.863	-68.366	1.288	21.634	-5.431
26	-44.110	12.958	-68.461	1.295	21.539	-4.703
26	-44.110	13.051	-68.554	1.301	21.446	-3.959
26	-44.110	13.144	-68.647	1.308	21.353	-3.199
26	-44.110	13.235	-68.738	1.315	21.262	-2.424

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
26	-44.118	13.324	-68.827	1.321	21.173	-1.632
26	-44.118	13.411	-68.914	1.328	21.086	-.824
26	-44.118	13.324	-68.827	1.321	21.173	-1.632
26	-44.118	13.333	-68.836	1.322	21.164	-1.552
26	-44.118	13.342	-68.845	1.323	21.155	-1.472
26	-44.118	13.350	-68.853	1.323	21.147	-1.392
26	-44.118	13.359	-68.862	1.324	21.138	-1.311
26	-44.118	13.368	-68.871	1.325	21.129	-1.230
26	-44.118	13.377	-68.880	1.325	21.120	-1.149
26	-44.118	13.385	-68.888	1.326	21.112	-1.068
26	-44.118	13.394	-68.897	1.327	21.103	-.987
26	-44.118	13.403	-68.906	1.327	21.094	-.906
26	-44.118	13.411	-68.914	1.328	21.086	-.824
26	-44.118	13.420	-68.923	1.329	21.077	-.743
26	-44.118	13.429	-68.932	1.329	21.068	-.661
26	-44.118	13.437	-68.940	1.330	21.060	-.579
26	-44.118	13.446	-68.949	1.331	21.051	-.497
26	-44.118	13.455	-68.957	1.331	21.043	-.414
26	-44.118	13.463	-68.966	1.332	21.034	-.332
26	-44.118	13.472	-68.975	1.333	21.025	-.249
26	-44.118	13.480	-68.983	1.333	21.017	-.166
26	-44.118	13.489	-68.992	1.334	21.008	-.083
26	-44.118	13.488	-68.983	1.333	21.017	-.166
26	-44.118	13.481	-68.984	1.333	21.016	-.158
26	-44.118	13.482	-68.985	1.333	21.015	-.150
26	-44.118	13.483	-68.986	1.334	21.014	-.141
26	-44.118	13.483	-68.986	1.334	21.014	-.133
26	-44.118	13.484	-68.987	1.334	21.013	-.125
26	-44.118	13.485	-68.988	1.334	21.012	-.116
26	-44.118	13.486	-68.989	1.334	21.011	-.108
26	-44.118	13.487	-68.990	1.334	21.010	-.100
26	-44.118	13.488	-68.991	1.334	21.009	-.091
26	-44.118	13.489	-68.992	1.334	21.008	-.083
26	-44.118	13.489	-68.992	1.334	21.008	-.075
26	-44.118	13.490	-68.993	1.334	21.007	-.067
26	-44.118	13.491	-68.994	1.334	21.006	-.058
26	-44.118	13.492	-68.995	1.334	21.005	-.050
26	-44.118	13.493	-68.996	1.334	21.004	-.042
26	-44.118	13.494	-68.997	1.334	21.003	-.033
26	-44.118	13.495	-68.997	1.334	21.003	-.025
26	-44.118	13.495	-68.998	1.335	21.002	-.017
26	-44.118	13.496	-68.999	1.335	21.001	-.008
26	-44.118	13.496	-68.999	1.335	21.001	-.000
26	-44.118	13.496	-68.999	1.335	21.001	-.007
26	-44.118	13.496	-68.999	1.335	21.001	-.007
26	-44.118	13.496	-68.999	1.335	21.001	-.006

TABLE A-VI (CONT)

RAY	BETA	THETA(RAY)	NORMAL	S	ALPHA2	RHO 2
26	-44.118	13.497	-68.999	1.335	21.001	-.005
26	-44.118	13.497	-69.000	1.335	21.000	-.004
26	-44.118	13.497	-69.000	1.335	21.000	-.003
26	-44.118	13.497	-69.000	1.335	21.000	-.002
26	-44.118	13.497	-69.000	1.335	21.000	-.002
26	-44.118	13.497	-69.000	1.335	21.000	-.001

TABLE A-VII

COORDINATE (X,Y) VALUES, S, ALPHA2 AND RHO2
FOR THE FINAL DESIGN OF SURFACE NUMBER 1 IN
FIGURE 20

Begin RAY	Next RAY	Xsurf (next)	Ysurf (next)	S (next)	Alpha2 (next)	RHO 2 (next)
1	1	.362	.000	.133	21.000	-.000
1	2	.465	.040	.133	21.066	-.642
1	3	.568	.079	.133	21.139	-1.324
1	4	.671	.119	.133	21.220	-2.050
1	5	.774	.159	.133	21.309	-2.824
1	6	.877	.199	.132	21.408	-3.650
1	7	.980	.239	.131	21.518	-4.534
1	8	1.082	.280	.130	21.640	-5.480
1	9	1.185	.321	.129	21.778	-6.496
1	10	1.287	.361	.127	21.932	-7.589
1	11	1.389	.403	.126	22.106	-8.765
1	12	1.491	.444	.123	22.303	-10.035
1	13	1.593	.486	.121	22.526	-11.407
1	14	1.694	.528	.118	22.779	-12.892
1	15	1.796	.570	.114	23.068	-14.503
1	16	1.896	.613	.110	23.399	-16.251
1	17	1.997	.657	.105	23.778	-18.150
1	18	2.097	.701	.100	24.213	-20.215
1	19	2.197	.746	.094	24.712	-22.460
1	20	2.296	.791	.086	25.286	-24.899
1	21	2.394	.838	.078	25.943	-27.545
1	22	2.492	.885	.068	26.693	-30.408
1	23	2.589	.934	.057	27.543	-33.492
1	24	2.685	.984	.045	28.500	-36.797
1	25	2.780	1.035	.030	29.563	-40.313
1	26	2.873	1.089	.014	30.725	-44.019

TABLE A-VIII

COORDINATE VALUES (X,Y) FOR THE RAY DIAGRAM IN FIGURE 22

RAY	X0	Y0	X1	Y1	X2	Y2	Xc	Yc	X4	Y4
1	0	.110	.287	.110	.362	.000	4.000	0.0	50.00	-.00
2	0	.150	.390	.150	.465	.040	4.000	0.0	50.00	-.52
3	0	.189	.493	.189	.568	.079	4.000	0.0	50.00	-1.06
4	0	.229	.596	.229	.671	.119	4.000	0.0	50.00	-1.65
5	0	.268	.699	.268	.774	.159	4.000	0.0	50.00	-2.27
6	0	.308	.802	.308	.877	.199	4.000	0.0	50.00	-2.93
7	0	.348	.906	.348	.980	.239	4.000	0.0	50.00	-3.65
8	0	.387	1.009	.387	1.082	.280	4.000	0.0	50.00	-4.41
9	0	.427	1.112	.427	1.185	.321	4.000	0.0	50.00	-5.24
10	0	.466	1.215	.466	1.287	.361	4.000	0.0	50.00	-6.13
11	0	.506	1.318	.506	1.389	.403	4.000	0.0	50.00	-7.09
12	0	.546	1.421	.546	1.491	.444	4.000	0.0	50.00	-8.14
13	0	.585	1.524	.585	1.593	.486	4.000	0.0	50.00	-9.28
14	0	.625	1.628	.625	1.694	.528	4.000	0.0	50.00	-10.53
15	0	.664	1.731	.664	1.796	.570	4.000	0.0	50.00	-11.90
16	0	.704	1.834	.704	1.896	.613	4.000	0.0	50.00	-13.41
17	0	.744	1.937	.744	1.997	.657	4.000	0.0	50.00	-15.08
18	0	.783	2.040	.783	2.097	.701	4.000	0.0	50.00	-16.94
19	0	.823	2.143	.823	2.197	.746	4.000	0.0	50.00	-19.02
20	0	.862	2.247	.862	2.296	.791	4.000	0.0	50.00	-21.35
21	0	.902	2.350	.902	2.394	.838	4.000	0.0	50.00	-23.99
22	0	.942	2.453	.942	2.492	.885	4.000	0.0	50.00	-27.00
23	0	.981	2.556	.981	2.589	.934	4.000	0.0	50.00	-30.44
24	0	1.021	2.659	1.021	2.685	.984	4.000	0.0	50.00	-34.41
25	0	1.060	2.762	1.060	2.780	1.035	4.000	0.0	50.00	-39.03
26	0	1.100	2.866	1.100	2.873	1.089	4.000	0.0	50.00	-44.45

CHART PROGRAM LISTING

```

10 PRINT "*****"
20 PRINT "*"
30 PRINT "          CHART          "
40 PRINT "*"
50 PRINT "*****"
60   DISP "THIS IS CHART !!!"
70   WAIT 2500
80 Main:OPTION BASE 0
90   |
100  COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Rho1,Trho1,Rho2,Trho2
110  COM F,Z3,Z4,Norm,Theta,Tdelta
120  COM Dates,Plots,Familys,Charts,Mains,Mainis,Flags,Y_hards
130  |
140  COM Stuffs,Redraus,Digitizes,Ray_traces
150  COM INTEGER I,J,Y0_loop,Nray,Nray_chart,Nray_family,Nray_stuff
160  COM INTEGER Nray_trace,Nray_density,Add_ray,Nc,Ns,Nbeta,Flag
170  |
180  COM INTEGER Line_count,Line_max,N_increment,Hit_total,Pselect,Hpib
190  COM INTEGER Family,Surf_no
200  COM REAL Theta_critical,Tol,N1,N2,N3,Delta_ray,Y0,Ya,Yb,Aperture
210  |
220  COM Y_bullet,Smax_family,Percent_image
230  COM X1(251),Y1(251),Xc(251),X2(251),Y2(251),X2max(251),Y2max(251)
240  COM Y3(251),Y4(251),Beta(251),S2(251),Xsurfmax(251),Ysurfmax(251)
250  |
260  COM Qa(251),Smax(251),Alpha2(251),Rho2(251),Hit(2001)
270  |
280  Mains="Y"          ! SET CONDITION
290  DISP ""
300  PRINTER IS 16
310  NORMAL
320  FIXED 2
330  PRINT PAGE
340  OVERLAP
350  Ys="0"
360  INPUT "SERIAL OR OVERLAP FOR I/O PROCESSING (DEFAULT=OVERLAP) ? S/O",Ys
370  IF (Ys="S") OR (Ys="s") THEN SERIAL
380  CALL Dialogue
390  DEG
400  PRINT PAGE,"   When entering values for Smax in CHART please enter reaso
nable"
410  PRINT "values. This is required because the horizontal axis for CHART is
divided"
420  PRINT "into 10 intervals. The program takes your entry for Smax"
430  PRINT "and divides by 10 to determine the tick spacing. The vertical "
440  PRINT "tick marks are under program control, enter anything you wish."
450  PRINT LIN(2),"PRESS CONT"
460  PAUSE
470  PRINT PAGE
480  Gyanastics:   Y_hards="N"
490  INPUT "DO YOU WANT A HARD COPY OF THE COMPUTED DATA? Y/N",Y_ha
rds
500  GOSUB Yhard
510  CALL Header
520  GOSUB Printer
530  CALL Header_end
540  PRINT LIN(2)
550  Mains="N"      ! RESET CONDITION
560  Header:      DISP "WORKING ..."
570  Initialize_run: Flag=0      ! RESET CONDITION
580  Y0_min=Ya*(Talpha-Trho1)/Talpha
590  Y0_max=Yb*(Talpha-Trho1)/Talpha
600  Xnray=Nray      ! AVOIDS MIXED MODE ARITHMETIC
610  Dely=(Y0_max-Y0_min)/Xnray
620  Y0_min=Y0_min-Dely
630  IF Ya=0 THEN Y0_min=Y0_min+Dely
640  Nray=Nray+Add_ray

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650          Ns=0          ! COUNTER FOR THE (X,Y) ARRAY
660          Nc=0
670          X1(Ns)=0
680          Y1(Ns)=0
690          Beta(0)=0
700 Y0_loop:  FOR Y0_loop=1 TO Nray      ! COMPUTE THE INTERCEPT OF THE INCIDENT
710                                     ! AND THE FIRST SURFACE
720          Xy0_loop=Y0_loop          ! AVOIDS MIXED MODE ARITHMETIC
730          Flag=0                    ! RESET FLAG
740          X=0
750          Rho=Rho_initial
760          Trho=TAN(Rho)
770          Y=Y0_min+Dely*Xy0_loop
780          Ns=Ns+1
790          Y1(Ns)=Y
800 One:    CALL Xipos(X,Y)
810          X1(Ns)=X
820 Next_y0_loop: NEXT Y0_loop
830          INPUT "ARE YOU USING THE CRT (C) OR THE 9872A PLOTTER (P) ? C/
P",Plots
840          IF (Plots="C") OR (Plots="c") THEN Chart
850          INPUT "PLEASE ENTER THE SELECT CODE OF THE GRAPHICS DEVICE (DE
FAULT = 7 ).",Pselect
860          INPUT "PLEASE ENTER THE HP1B ADDRESS OF THE GRAPHICS DEVICE (D
EFAULT = 5 ).",Hpib
870 Chart:  CALL Chart
880          GOSUB Yhard_end
890          PRINT LIN(2),"PRESS CONT"
900          PAUSE
910          PRINT
920          PRINT PAGE," If the scale you have chosen did not allow the compute
r "
930          PRINT "to number all of the curves you may do so manually by "
940          PRINT "answering yes (Y) to the next prompt."
950          PRINT LIN(1)," If your answer is yes, the graphics display of the
"
960          PRINT "plot will come on and a cursor will be in the lower left"
970          PRINT "corner. Position the cursor by using the DISPLAY"
980          PRINT "controls. The letter or number will be drawn with its "
990          PRINT "left side over the center of the cursor. You MUST BE
CAREFUL "
1000         PRINT "because mistakes are difficult, if not impossible to erase"
1010         PRINT "(consult the graphics rom manual (page 91) to erase a letter).
"
1020         PRINT LIN(2)," When you have completed all of your lettering,"
1030         PRINT "PRESS CONT."
1040         PRINT LIN(2),"PRESS CONT"
1050         PAUSE
1060         PRINT PAGE
1070         Ys="N"
1080         INPUT "DO YOU WANT TO NUMBER ANY OF THE CURVES ? Y/N",Ys
1090         IF (Ys="Y") OR (Ys="y") THEN CSIZE 2.5
1100         IF (Ys="Y") OR (Ys="y") THEN LETTER
1110         IF (Ys="Y") OR (Ys="y") THEN CSIZE 15/4.54
1120         IF (Ys="Y") OR (Ys="y") THEN EXIT GRAPHICS
1130         Dump_crt$="N"
1140         INPUT "DO YOU WANT A HARD COPY OF THE PLOT ? Y/N",Dump_crt$
1150         IF (Dump_crt$="Y") OR (Dump_crt$="y") THEN GOSUB Printer
1160         Flag=0          ! RESET CONDITION
1170         Ys="N"
1180         INPUT "DO YOU WANT ANOTHER PLOT DRAWN TO A DIFFERENT SCALE ? Y/N",Ys
1190         IF (Ys="Y") OR (Ys="y") THEN Chart
1200 Rerun:  PRINTER IS 16
1210         PRINT PAGE
1220         Ys="N"
1230         INPUT "ARE YOU GOING TO MAKE ANY MORE RUNS? Y/N",Ys
1240         IF (Ys="N") OR (Ys="n") THEN Family

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1250 Rerun2: Changes="N"
1260 INPUT "ARE YOU GOING TO CHANGE ANY PARAMETERS (n2,n3,Alpha,Nray, OR
RHO-INITIAL)? Y/N",Changes
1270 IF (Changes="N") OR (Changes="n") THEN Gyanastics
1280 GOSUB Printer
1290 INPUT "WHAT IS THE NEW VALUE OF RHO-INITIAL ?",Rho_initial
1300 Rho_initial=-1+ABS(Rho_initial)
1310 Trho1=TAN(Rho_initial)
1320 INPUT "WHAT IS THE NEW VALUE OF ALPHA?",Alpha
1330 Talpha=TAN(Alpha)
1340 N2: INPUT "WHAT IS THE NEW VALUE OF n2?",N2
1350 INPUT "WHAT IS THE NEW VALUE OF n3?",N3
1360 IF N3>N2 THEN BEEP
1370 IF N3>N2 THEN DISP "n3 MUST BE < n2, PLEASE RE-ENTER THE VALUES
"
1380 IF N3>N2 THEN WAIT 2500
1390 IF N3>N2 THEN N2
1400 IF N3<N2 THEN Theta_critical=ASN(N3/N2)
1410 Ya: INPUT "WHAT IS THE NEW VALUE OF Ya (INCHES) ?",Ya
1420 INPUT "WHAT IS THE NEW VALUE OF Yb (INCHES) ?",Yb
1430 IF Ya=Yb THEN BEEP
1440 IF Ya>Yb THEN DISP "Ya MUST BE < Yb; PLEASE RE-ENTER THE VALUE
S"
1450 IF Ya>Yb THEN WAIT 2500
1460 IF Ya>Yb THEN Ya
1470 Aperture=Yb-Ya
1480 Y_bullet:INPUT "WHAT IS THE NEW VALUE OF Y_bullet ( MUST BE > Yb ) ?",Y_bu
llet
1490 IF Y_bullet<Yb THEN BEEP
1500 IF Y_bullet<Yb THEN DISP "Y_bullet MUST BE > Yb : PLEASE RE-ENT
ER Y_bullet."
1510 IF Y_bullet<Yb THEN WAIT 2500
1520 IF Y_bullet<Yb THEN Y_bullet
1530 INPUT "WHAT IS THE NEW VALUE OF THE No. OF RAYS ?",Nray
1540 INPUT "WHAT IS THE NEW VALUE OF FOCUS (INCHES) ?",F
1550 GOTO Gyanastics
1560 Family: Family="N"
1570 PRINTER IS 16
1580 INPUT "DO YOU WANT TO DRAW A FAMILY OF SURFACES FROM THE DESIGN CHA
RT ? Y/N",Family
1590 IF (Family="N") OR (Family="n") THEN Finished
1600 Fam1: PRINT PAGE," Xmax is the maximum length along the GLM axis which y
ou"
1610 PRINT "want to be displayed."
1620 PRINT " A rule of thumb is to add one inch to the focal length."
1630 PRINT "For example: if the focal length is 4 inches, key in 5 and"
1640 PRINT "PRESS CONT."
1650 PRINT LIN(2),"PRESS CONT"
1660 PAUSE
1670 Y_hards="N"
1680 INPUT "DO YOU WANT A HARD COPY OF THE COMPUTED DATA ? Y/N",Y_hards
1690 IF (Y_hards="Y") OR (Y_hards="y") THEN GOSUB Yhard
1700 CALL Family
1710 GOSUB Yhard_end
1720 Dump_crt="N"
1730 INPUT "DO YOU WANT A HARD COPY OF THE PLOT ? Y/N",Dump_crt
1740 IF (Dump_crt="Y") OR (Dump_crt="y") THEN GOSUB Printer
1750 Ys="N"
1760 INPUT "DO YOU WANT TO DRAW THE PLOT USING A DIFFERENT SCALE ? Y/N",
Ys
1770 IF (Ys="Y") OR (Ys="y") THEN Fam1
1780 Mainis="Y" ! SET CONDITION
1790 Y_hards="N"
1800 INPUT "DO YOU WANT A HARD COPY OF QA,Smax,Alpha2 and Rho2 ? Y/N",Y_
hards
1810 GOSUB Yhard
1820 CALL Header

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1830     FOR I=1 TO Nray
1840         IF Line_count>Line_max THEN CALL Header
1850         PRINT USING 1870;I,Qa(I),Smax(I),Alpha2(I),Rho2(I)
1860         Line_count=Line_count+1
1870         IMAGE 14X,DDD,4(5X,DDD.DDD)
1880     NEXT I
1890     CALL Header_end
1900     GOSUB Yhard_end
1910     PRINT LIN(10),"PRESS CONT"
1920     Maini#="N"           ! RESET CONDITION
1930     PAUSE
1940 Stuff: PRINTER IS 16
1950     PRINT PAGE," Please study the display and choose the surface"
1960     PRINT "which you want to use to generate a final surface."
1970     PRINT " When you have decided which surface to use, PRESS CONT"
1980     PRINT LIN(1)," Key in the number of the surface you want to use"
1990     PRINT "in response to the prompt."
2000     PRINT LIN(1)," The computer will then determine the aperture of "
2010     PRINT "the surface and trace 250 rays through the aperture."
2020     PRINT LIN(1)," When you are ready to proceed PRESS CONT."
2030     PAUSE
2040     GRAPHICS           ! IF A NOTE TO OPERATOR IS DESIRED, THEN ENTER SETGU,
2050     WAIT 2500         ! LONG 2, MOVE 2,2 ,CSIZE 2.5 ,LABEL "PRESS CONT WHEN
2060     BEEP              ! READY" ,SETGU CSIZE 15/4.54 AFTER THE SECOND BEEP
2070     WAIT 250
2080     BEEP
2090     PAUSE
2100     EXIT GRAPHICS
2110     INPUT "WHICH SURFACE (1,2,3,etc.) ?",Family
2120     Family=INT(Family)
2130     IF Family<=0 THEN Family=1
2140     IF Family>Nray_family THEN Family=Nray_family
2150     DISP "WORKING ..."
2160 Re_stuff: CALL Stuff
2170     GOSUB Yhard_end
2180     Dump_crt#="N"
2190     INPUT "DO YOU WANT A HARD COPY OF THE PLOT ? Y/N",Dump_crt#
2200     IF (Dump_crt#="Y") OR (Dump_crt#="y") THEN GOSUB Printer
2210     Flag#           ! RESET CONDITION
2220     Redraus#="N"
2230     INPUT "DO YOU WANT ANOTHER PLOT DRAWN TO A DIFFERENT SCALE ? Y/N",Re
draw#
2240     IF (Redraus#="Y") OR (Redraus#="y") THEN Re_stuff
2250 Stuff_trace: Ys="N"
2260     INPUT "DO YOU WANT TO TRACE RAYS THROUGH THE COMPUTED SURFACE ?
Y/N",Ys
2270     IF (Ys="N") OR (Ys="n") THEN Rerun3
2280     DISP "WORKIN' ON THE RAY TRACE DATA..."
2290     FOR Y0_loop=1 TO Nray_stuff
2300         Surf_no#3
2310         Rho2=Rho2(Y0_loop)
2320         X=X2(Y0_loop)
2330         Y=Y2(Y0_loop)
2340         CALL Binary_search(X,Y)
2350         Y3(Y0_loop)=Y
2360         X=X3
2370         Surf_no#4
2380         CALL Binary_search(X,Y)
2390         Y4(Y0_loop)=Y
2400     NEXT Y0_loop
2410     Nray_trace=Nray_stuff
2420     Ray_trace#="Y"
2430     BEEP
2440     Ys="N"
2450     INPUT "DO YOU WANT A HARD COPY OF THE RAY TRACE DATA ? Y/N",Y_ha
rds
2460     GOSUB Yhard

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2470          CALL Header
2480 Stuff_trace1:FOR I=1 TO Nray_stuff
2490          IF Line_count>Line_max THEN CALL Header
2500          PRINT USING 2510;I,0,Y1(I),X1(I),Y1(I),X2(I),Y2(I),Xc(I),0,Z4,
Y4(I)
2510          IMAGE DDD,2X,D,3<2X,DD.DDD,3X,DD.DDD>,2X,D,D,3X,DD.DD,3X,4D.2D
2520          Line_count=Line_count+1
2530          NEXT I
2540          CALL Header_end
2550          GOSUB Yhard_end
2560          PRINT LIN(2),"PRESS CONT"
2570          BEEP
2580          PAUSE
2590 Re_graph:  CALL Graph
2600          Redraws="N"
2610          INPUT "DO YOU WANT ANOTHER PLOT DRAWN TO A DIFFERENT SCALE ? Y/N",Re
draws
2620          IF (Redraws="Y") OR (Redraws="y") THEN Re_graph
2630 Density:  PRINTER IS 16
2640          PRINT PAGE," The point of maximum ray density is determined by yo
u visually."
2650          PRINT "by placing the cross-hairs (they will appear automatically)
"
2660          PRINT "over the position of maximum ray density."
2670          PRINT " This is accomplished by using the DISPLAY controls (up
,down,<-,>)."
2680          PRINT "When you the get cursor in the area of interest, use the S
HIFT button"
2690          PRINT "with the DISPLAY controls (both the shift button and disp
lay control"
2700          PRINT "should be depressed simultaneously) for fine positioning."
2710          PRINT LIN(2)," The position of the vertical hair is critical,"
2720          PRINT "because its location is used for the position of the "
2730          PRINT "image plane (Z3) on the GLM axis."
2740          PRINT LIN(2),"CAUTION : Do not let the image plane intercept any
rays"
2750          PRINT "in the interior of the lens. If this is done, those rays"
2760          PRINT "will be included in the histogram."
2770          PRINT LIN(2),"PRESS CONT"
2780          PAUSE
2790          PRINT PAGE," The histogram is an illustration of the density"
2800          PRINT "of the rays that intercept the image plane versus radial "
2810          PRINT "distance from the GLM axis."
2820          PRINT LIN(2)," When the position has been located, PRESS CONT."
2830          PRINT LIN(2),"PRESS CONT"
2840          PAUSE
2850          Digitize="Y"
2860          CALL Graph
2870          IF Plot="P" THEN Dense ! P FOR HP-9872 PLOTTER
2880          Dump_crt="N"
2890          INPUT "DO YOU WANT A HARD COPY OF THE PLOT ? Y/N",Dump_crt$
2900          IF (Dump_crt="Y") OR (Dump_crt="y") THEN GOSUB Printer
2910          PRINT PAGE
2920          DISP "WORKIN' ON THE HISTOGRAM..."
2930 Dense:    CALL Density ! PRODUCE A HISTOGRAM OF THE RAY DENSITY
2940          IF Plot="P" THEN Denser
2950          Digitize="N" ! RESET CONDITION
2960          INPUT "DO YOU WANT A HARD COPY OF HISTOGRAM ? Y/N",Dump_crt$
2970          IF (Dump_crt="Y") OR (Dump_crt="y") THEN GOSUB Printer
2980 Denser:  Ys="N"
2990          INPUT "DO YOU WANT TO REDRAW THE HISTOGRAM FOR A DIFFERENT IMAGE P
LANE ? Y/N",Ys
3000          IF (Ys="Y") OR (Ys="y") THEN Flag=0
3010          IF (Ys="Y") OR (Ys="y") THEN Re_graph
3020          Ray_trace="N"
3030 Rerun3:  Ys="N"
3040          INPUT "DO YOU WANT TO TRY ANOTHER SURFACE (THIS MEANS STARTING OVER

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) ? Y/N",Ys
3050 IF (Ys="Y") OR (Ys="y") THEN Main
3060 GOTO Finished
3070 Printer:PRINTER IS 16
3080 IF (Change$="Y") OR (Change$="y") THEN Y_hards="N"
3090 IF (Dump_crt$="Y") OR (Dump_crt$="y") THEN Y_hards="Y"
3100 IF (Y_hards="Y") OR (Y_hards="y") THEN PRINTER IS 0
3110 IF (Y_hards="Y") OR (Y_hards="y") THEN PRINT CHR$(27)&"&100T"
3120 IF (Dump_crt$="Y") OR (Dump_crt$="y") THEN Crt
3130 FIXED 0
3140 FIXED 2
3150 IF Date$="" THEN 3170
3160 PRINT "DATE : ";Date$
3170 PRINT LIN(1),"Alpha = ";Alpha;"degrees";TAB(48);Rho-initial = ";R
ho_initial
3180 PRINT "TAN(Alpha) = ";Talpha;"degrees";TAB(48);"TAN(RHO-INITIAL) = ";Trhoi
3190 PRINT LIN(1),"RHO1 = ";Rho1;"degrees";TAB(48);"Theta(critical) = "
;Theta_critical;"degrees"
3200 PRINT LIN(1),"GLM Radius = ";Y_bullet;"inches"
3210 PRINT "Aperture = ";Aperture;"inches";TAB(24);"Ya = ";Ya;"inch";TAB(48);"Yb
= ";Yb;"inches"
3220 FIXED 5
3230 PRINT LIN(1),"n1 = ";N1;"TAB(24);"n2 = ";N2;"TAB(48);"n3";N3
3240 FIXED 0
3250 PRINT LIN(1),"Number of Rays = ";Nray
3260 FIXED 2
3270 PRINT LIN(1),"Design Focal Point = ";F;" inches"
3280 PRINT
3290 Crt: IF (Dump_crt$="Y") OR (Dump_crt$="y") THEN DUMP GRAPHICS
3300 IF (Y_hards="Y") OR (Y_hards="y") THEN PRINT CHR$(27)&"&136T"
3310 IF (Dump_crt$="Y") OR (Dump_crt$="y") THEN PRINTER IS 16
3320 Change$="N" ! RESET CONDITION
3330 Dump_crt$="N"
3340 Y_hards="N"
3350 RETURN
3360 Yhard: IF (Y_hards="Y") OR (Y_hards="y") THEN Flag$="1"
3370 IF (Y_hards="N") OR (Y_hards="n") THEN Flag$="0"
3380 IF Flag$="1" THEN PRINTER IS 0
3390 IF Flag$="1" THEN PRINT CHR$(27)&"&100T"
3400 RETURN
3410 Yhard_end: IF Flag$="1" THEN PRINT CHR$(27)&"&136T"
3420 IF Flag$="1" THEN PRINTER IS 16
3430 RETURN
3440 Finished: DISP "FINISHED"
3450 END
3460 SUB Snell
3470 OPTION BASE 0
3480 !
3490 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trhoi,Rho1,Trho1,Rho2,Trho2
3500 COM F,Z3,Z4,Norm,Theta,Tdelta
3510 COM Date$,Plot$,Family$,Chart$,Main$,Main$,Flag$,Y_hards
3520 !
3530 COM Stuff$,Redraw$,Digitize$,Ray_trace$
3540 COM INTEGER I,J,Y0_loop,Nray,Nray_chart,Nray_family,Nray_stuff
3550 COM INTEGER Nray_trace,Nray_density,Add_ray,Nc,Ns,Nbeta,Flag
3560 !
3570 COM INTEGER Line_count,Line_max,N_increment,Mit_total,Pselect,Hpib
3580 COM INTEGER Family,Surf_no
3590 COM REAL Theta_critical,Tol,N1,N2,N3,Delta_ray,Y0,Ya,Yb,Aperture
3600 !
3610 DEG
3620 One: Theta1=90-(Alpha+ASN(Rho)) ! RHO MUST BE DECLARED ELESWHERE
3630 Alpha2=Alpha
3640 Norm=Alpha2-90
3650 Sin_prime=N1/N2*SIN(Theta1)
3660 Theta=ASN(Sin_prime)
3670 Rho1=Alpha2+Theta-90 ! USE ALPHA2 INSTEAD OF NORM BECAUSE THE

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3680                                ! SIGN OF THE ANGLE IS DESIRED
3690      Trho1=TAN(Rho1)
3700 SUBEND
3710 SUB Plot
3720   OPTION BASE 0
3730   !
3740   COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Rho1,Trho1,Rho2,Trho2
3750   COM F,Z3,Z4,Norm,Theta1,Tdelta
3760   COM Dates,Plots,Familys,Charts,Mains,Mainis,Flags,Y_hands
3770   !
3780   COM Stuffs,Redraws,Digitizes,Ray_traces
3790   COM INTEGER I,J,Y0_loop,Nray,Nray_chart,Nray_family,Nray_stuff
3800   COM INTEGER Nray_trace,Nray_density,Add_ray,Nc,Ns,Nbeta,Flag
3810   !
3820   COM INTEGER Line_count,Line_max,N_increment,Hit_total,Pselect,Hpib
3830   COM INTEGER Family,Surf_no
3840   COM REAL Theta_critical,Tol,N1,N2,N3,Delta_ray,Y0,Ya,Yb,Aperture
3850   !
3860   COM Y_bullet,Smax_family,Percent_image
3870   COM X1(*),Y1(*),XC(*),X2(*),Y2(*),X2max(*),Y2max(*)
3880   COM Y3(*),Y4(*),Beta(*),S2(*),Xsurfm(*),Ysurfm(*)
3890   !
3900   COM Qa(*),Sax(*),Alpha2(*),Rho2(*),Hit(*)
3910   !
3920   ! THE ORIGINAL OF THIS ROUTINE WAS OBTAINED FROM THE HP UTILITIES LIBRARY
3930   ! 9845B UTILITY LIBRARY
3940   ! PROGRAM CARTRIDGE 2
3950   ! 09845-10205
3960   ! PROGRAM REGPLT
3970   ! SUB LAXES WAS ALSO BORROWED FROM THE LIBRARY
3980   !
3990   ! THIS ROUTINE IS USED TO SET UP THE LIMIT,LOCATE,SCALE AND CLIP STATE
4000   ! MENT
4010   ! STATEMENTS FOR THE FOLLOWING ROUTINES:
4020   ! 1) CHART
4030   ! 2) FAMILY
4040   ! 3) STUFF
4050   ! 4) DENSITY
4060   ! 5) RAY_TRACE
4070   !
4080   Flag=Flagc=0
4090   Set_up: IF (Plots="P") OR (Plots="p") THEN P9872a
4100   Crt: PLOTTER IS 13,"GRAPHICS"
4110   GOTO 4120
4120   P9872a: PLOTTER IS Pselect,Hpib,"9872A"
4130   GCLEAR
4140   LINE TYPE 1
4150   LDIR 0
4160   LOG 5
4170   LIMIT 0,104,0,140      ! ALL UNITS IN MILLIMETERS
4180   DATA -2,-1,1,2
4190   READ Um,Da,Md,Mu
4200   DATA .39794,.69897,.87506
4210   READ Log2,Log3,Log7
4220   !
4230   IF (Digitizes="Y") OR (Digitizes="y") THEN Digit_scale
4240   IF (Ray_traces="Y") OR (Ray_traces="y") THEN Ray_trace
4250   IF (Charts="Y") OR (Charts="y") THEN Chart
4260   IF (Familys="Y") OR (Familys="y") THEN Family
4270   IF (Stuffs="Y") OR (Stuffs="y") THEN Stuff
4280   !
4290   Chart: Xmin=0
4300   INPUT "WHAT IS THE MINIMUM VALUE OF S (INCHES) (DEFAULT = 0 INCH) ?"
4310   ,Xmin
4320   Xmax=2
4330   INPUT "WHAT IS THE MAXIMUM VALUE OF S (INCHES) (DEFAULT = 2.0 INCH)
4340   ?",Xmax

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4320         IF Flagc=1 THEN 4380
4330         Ymin=Alpha-1
4340         Ymax=90
4350         INPUT "WHAT IS THE MINIMUM VALUE OF ALPHA2 (DEGREES) (DEFAULT = ALPH
A-1 DEG) ?",Ymin
4360         INPUT "WHAT IS THE MAXIMUM VALUE OF ALPHA2 (DEGREES) (DEFAULT = 90 D
EG) ?",Ymax
4370         IF Flagc=1 THEN 4430
4380         IF Xmin>Xmax THEN BEEP
4390         IF Xmin>Xmax THEN DISP "Smin IS > Smax : PLEASE RE-ENTER VALUES IN
CORRECT ORDER"
4400         IF Xmin>Xmax THEN WAIT 2500
4410         IF Xmin>Xmax THEN Flagc=1
4420         IF Xmin>Xmax THEN Chart
4430         IF Ymin>Ymax THEN BEEP
4440         IF Ymin>Ymax THEN DISP "ALPHA2min IS > ALPHA2max : PLEASE RE-ENTER
VALUES IN CORRECT ORDER"
4450         IF Ymin>Ymax THEN WAIT 2500
4460         IF Ymin>Ymax THEN Flagc=1
4470         IF Ymin>Ymax THEN 4330
4480         Xorg=Xmin
4490         Yorg=Ymin
4500         Flagc=Flagc+1
4510         GOTO Chart_scale
4520 Family: Xmin=Ymin=Xorg=Yorg=0
4530         Ymax=Y_bullet
4540         Xmax=5
4550         INPUT "WHAT IS THE MAXIMUM VALUE OF X (INCHES) (DEFAULT = 5 INCHES)
?",Xmax
4560         IF Xmax<=Xmin THEN BEEP
4570         IF Xmax<=Xmin THEN DISP "Xmax MUST BE > Xmin. PLEASE RE-ENTER T
HE VALUES IN THE CORRECT ORDER."
4580         IF Xmax<=Xmin THEN WAIT 2500
4590         IF Xmax<=Xmin THEN Family
4600 Family_scale: LOCATE 15,130,35,100
4610         GOSUB Same
4620         SCALE Xmin-.5*ABS(Ytic),Xmax+.5*ABS(Ytic),Ymin-.5*ABS(Ytic),Y
_bullet+.5*ABS(Ytic)
4630         CLIP Xmin-.5*ABS(Ytic),Xmax+.5*ABS(Ytic),Ymin-.5*ABS(Ytic),Y
_bullet+.5*ABS(Ytic)
4640         GOSUB Same_axes
4650         SUBEXIT
4660 Stuff: Xmin=Ymin=Xorg=Yorg=0
4670         Xmax=5
4680         Ymax=Y_bullet
4690         INPUT "WHAT IS THE MAXIMUM VALUE OF X (INCHES) (DEFAULT = 5 INCHES)
?",Xmax
4700         IF Xmax<=Xmin THEN BEEP
4710         IF Xmax<=Xmin THEN DISP "Xmax MUST BE > Xmin. PLEASE RE-ENTER TH
E VALUES IN THE CORRECT ORDER."
4720         IF Xmax<=Xmin THEN WAIT 2500
4730         IF Xmax<=Xmin THEN Stuff
4740 Stuff_scale: LOCATE 15,130,35,100
4750         GOSUB Same
4760         SCALE Xmin-.5*ABS(Ytic),Xmax+.5*ABS(Ytic),Ymin-.5*ABS(Ytic),Y
_bullet+.5*ABS(Ytic)
4770         CLIP Xmin-.5*ABS(Ytic),Xmax+.5*ABS(Ytic),Ymin-.5*ABS(Ytic),Y
_bullet+.5*ABS(Ytic)
4780         GOSUB Same_axes
4790         SUBEXIT
4800 Ray_trace: Xmin=Xorg=Yorg=0
4810         Xmax=5
4820         INPUT "WHAT IS THE MAXIMUM VALUE OF X (INCHES) (DEFAULT = 5 INCH
ES) ?",Xmax
4830         IF Xmax<=Xmin THEN BEEP
4840         IF Xmax<=Xmin THEN DISP "Xmax MUST BE > Xmin. PLEASE RE-ENTE
R THE VALUES IN THE CORRECT ORDER."

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4850         IF Xmax<Xmin THEN WAIT 2500
4860         IF Xmax<Xmin THEN Ray_trace
4870         Ymax=Y_bullet
4880         Ymin=-Ymax
4890 Ray_trace_scale: LOCATE 15,130,25,100
4900         GOSUB Same
4910         SCALE Xmin-.5*ABS(Ytic),Xmax+.5*ABS(Ytic),-Y_bullet-.25*AB
S(Ytic),Y_bullet+.25*ABS(Ytic)
4920         CLIP Xmin-.5*ABS(Ytic),Xmax+.5*ABS(Ytic),-Y_bullet-.25*AB
S(Ytic),Y_bullet+.25*ABS(Ytic)
4930         GOSUB Same_axes
4940         CLIP Xmin,100,Ymin,Ymax
4950         SUBEXIT
4960 Chart_scale: LOCATE 18,133,29,100      ! ALL UNITS IN GDU'S
4970         GOSUB Same                        ! DRAW THE DESIGN CHART
4980         Xtic=(Xmax-Xmin)/10
4990         SCALE Xmin,Xmax+.25*ABS(Xtic),Ymin,Ymax+.25*ABS(Ytic)
5000         CLIP Xmin,Xmax,Ymin,Ymax
5010         GOSUB Same_axes
5020         FRAME
5030         SUBEXIT
5040 Digit_scale: LOCATE 0,130,30,100      ! ALL UNITS IN GDU'S
5050         Xmax=Y_bullet                    ! DRAW THE HISTOGRAM
5060         Xmin=-Xmax
5070         Xorg=Yorg=0
5080         Ymax=1
5090         Ymin=0
5100         GOSUB Same
5110         SCALE -Y_bullet-.15*ABS(Ytic),Y_bullet+.15*ABS(Ytic),-.15*ABS(
Ytic),1+.15*ABS(Ytic)
5120         CLIP -Y_bullet-.15*ABS(Ytic),Y_bullet+.15*ABS(Ytic),-.15*ABS(
Ytic),1+.15*ABS(Ytic)
5130         GOSUB Same_axes
5140         SUBEXIT
5150 Same_axes: CALL Laxes(Xtic,Ytic,Xorg,Yorg,1,1,2,Xmin-Xfudge,Xmax,Ymin-Yfu
dge,Ymax)
5160         CLIP Xmin,Xmax,Ymin,Ymax
5170         RETURN
5180 Same: Lx=LGT(Xmax-Xmin)
5190         Ly=LGT(Ymax-Ymin)
5200         Xfudge=.20*(Xmax-Xmin)
5210         Yfudge=.20*(Ymax-Ymin)
5220 Tic_marks: Testxtic=FRACT(Lx)+<Lx<0>
5230         Xtic=10^(INT(Lx)-1)*(1+.5*(Testxtic>Log2) AND (Testxtic<Log5))
+4*(Testxtic=Log5) AND (Testxtic=Log7))+6.5*(Testxtic>Log7)
5240         Testytic=FRACT(Ly)+<Ly<0>
5250         Ytic=10^(INT(Ly)-1)*(1+.5*(Testytic>Log2) AND (Testytic<Log5))
+4*(Testytic=Log5) AND (Testytic=Log7))+6.5*(Testytic>Log7)
5260         RETURN
5270         SUBEXIT
5280 SUB Laxes(Xtic,Ytic,Xorg,Yorg,Xmaj,Ymaj,Minticsize,Xmin,Xmax,Ymin,Ymax)
5290 OPTION BASE 0
5300 |
5310 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Rho1,Trho1,Rho2,Trho2
5320 COM F,Z3,Z4,Norm,Theta,Tdelta
5330 COM Dates,Plots,Families,Charts,Mains,Mainis,Flags,Y_hards
5340 |
5350 COM Stuffs,Redraws,Digitizes,Ray_traces
5360 COM INTEGER I,J,Y0_loop,Nray,Nray_chart,Nray_family,Nray_stuff
5370 COM INTEGER Nray_trace,Nray_density,Add_ray,Nc,Ns,Nbeta,Flag
5380 |
5390 COM INTEGER Line_count,Line_max,N_increment,Hit_total,Pselect,Hpib
5400 COM INTEGER Family,Surf_no
5410 COM REAL Theta_critical,Tol,N1,N2,N3,Delta_ray,Y0,Ya,Yb,Aperture
5420 |
5430 COM Y_bullet,Smax_family,Percent_image
5440 COM XI(<*),Y1(<*),X2(<*),Y2(<*),X2max(<*),Y2max(<*)

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5450 COM Y3(*),Y4(*),Beta(*),S2(*),Xsurfmax(*),Ysurfmax(*)
5460 |
5470 COM Ga(*),Saax(*),Alpha2(*),Rho2(*),Hit(*)
5480 |
5490 |
5500 | THIS ROUTINE IS USED TO DRAW AND LABEL THE AXES FOR THE FOLLOWING
5510 | ROUTINES:
5520 | 1) CHART
5530 | 2) FAMILY
5540 | 3) STUFF
5550 | 4) DENSITY
5560 | 5) RAY_TRACE
5570 |
5580 Flag=1
5590 DEG
5600 LINE TYPE 1
5610 LDIR 0
5620 LORG 5
5630 IF (Xmin)=Xmax) OR (Ymin)=Ymax) THEN SUBEXIT
5640 GRAPHICS
5650 Xfudge=.02*(Xmax-Xmin)
5660 Yfudge=.02*(Ymax-Ymin)
5670 Xmaj=1
5680 Ymaj=1
5690 Minticize=2
5700 IF (Digitize="Y") OR (Digitize="y") THEN Digit_axis
5710 IF (Ray_traces="Y") OR (Ray_traces="y") THEN Ray_trace_axis
5720 IF (Charts="Y") OR (Charts="y") THEN Chart_axis
5730 IF (Families="Y") OR (Families="y") THEN Family_axis
5740 IF (Stuffs="Y") OR (Stuffs="y") THEN Stuff_axis
5750 Chart_axis: LINE TYPE 3
5760 GRID Xtic,Ytic,Xorg,Yorg,Xmaj,Ymaj,2*Minticize
5770 LINE TYPE 1
5780 GOTO Labelx
5790 Family_axis: AXES Xtic,Ytic,Xorg,Yorg,Xmaj,Ymaj,Minticize
5800 GOTO Labelx
5810 Stuff_axis: AXES Xtic,Ytic,Xorg,Yorg,Xmaj,Ymaj,Minticize
5820 GOTO Labelx
5830 Ray_trace_axis: AXES Xtic,Ytic,Xorg,Yorg,Xmaj,Ymaj,Minticize
5840 GOTO Labelx_ray
5850 Digit_axis: AXES .1,.1,0,0,1,1,2
5860 GOTO Labelx_d
5870 Labelx: FIXED 3
5880 LDIR 90
5890 LORG 0
5900 Parx: FOR A=Xorg TO Xmax STEP ABS(Xtic)
5910 MOVE A,Yorg-Yfudge
5920 LABEL USING 5950;A
5930 IMAGE DD.D
5940 IMAGE DD.DD
5950 IMAGE 0,K
5960 NEXT A
5970 Labely: LDIR 0
5980 LORG 0
5990 Pary: FOR A=Yorg TO Ymax STEP ABS(Ytic) | FOR CHART AND FAMILY
6000 MOVE Xorg-Xfudge,A
6010 LABEL USING 5950;A
6020 NEXT A
6030 GOTO Label
6040 Labelx_ray: LDIR 90
6050 LORG 0
6060 Parx_ray: FOR A=Xorg TO Xmax STEP ABS(Xtic)
6070 MOVE A,Yorg-Yfudge
6080 LABEL USING 5950;A
6090 NEXT A
6100 Labely_ray: LDIR 0
6110 LORG 0

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6120 Pary_ray:   FOR A=Y_bullet TO Y_bullet STEP ABS(Ytic)      | FOR RAY_TRACE
6130             MOVE Xorg-Xfudge,A
6140             IF A=0 THEN LABEL USING 5950;A
6150             IF A=0 THEN Next_a
6160             LABEL USING 6170;A
6170             IMAGE DD.D
6180 Next_a:     NEXT A
6190             GOTO Label_
6200 Labelx_d:  LDIR 90
6210             LORG 8
6220             FOR A=-Y_bullet TO Y_bullet STEP .1
6230             MOVE A,Yorg-Yfudge
6240             IF A=0 THEN LABEL USING 5950;A
6250             IF A=0 THEN GOTO Next_aa
6260             LABEL USING 6170;A
6270 Next_aa:   NEXT A
6280 Labely_d:  LDIR 0
6290             LORG 8
6300             FOR A=0 TO Y_bullet STEP .1
6310             MOVE Xorg-Xfudge,A
6320             IF A=0 THEN LABEL USING 5950;A
6330             IF A=0 THEN GOTO Nexta
6340             LABEL USING 6170;A
6350 Nexta:     NEXT A
6360 Label_:   SETGU
6370             LDIR 0
6380             LORG 5
6390             CSIZE 2.5
6400             IF (Digitize="Y") OR (Digitize="y") THEN Digit_label
6410             IF (Ray_traces="Y") OR (Ray_traces="y") THEN Ray_trace_label
6420             IF (Charts="Y") OR (Charts="y") THEN Chart_label
6430             IF (Famils="Y") OR (Famils="y") THEN Family_label
6440             IF (Stuffs="Y") OR (Stuffs="y") THEN Stuff_label
6450 Chart_label: Centerx=74.80
6460             Centery=64
6470             |
6480             MOVE .5*Centerx,9
6490             LABEL USING 6500;F
6500             IMAGE "Design Focal Point : ",DD.DD," inches"
6510             MOVE 1.5*Centerx,9
6520             LABEL USING 6530;Nray_chart
6530             IMAGE "Number of Rays : ",K
6540             MOVE .5*Centerx,5
6550             LABEL USING 6560;Alpha
6560             IMAGE "Alpha : "DD.DD" deg"
6570             MOVE 1.5*Centerx,5
6580             LABEL USING 6590;N2
6590             IMAGE "n2 : ",D.DDDDD
6600             |
6610             CSIZE 3
6620             MOVE Centerx,15
6630             LABEL "S : Distance Along Refracted Ray in the Lens ( Inches )
-
6640             LDIR 90
6650             MOVE .8,Centery
6660             LABEL "Alpha 2 : Angle of the Tangent Line at"
6670             MOVE 4.8,Centery
6680             LABEL "the Second Surface ( Degrees )"
6690             |
6700             GOTO End_label
6710 Family_label: Centerx=Centerx_family=72.5
6720             Centery=Centery_family=66.5
6730             |
6740             IF (Stuffs="Y") OR (Stuffs="y") THEN Stuff_label
6750             MOVE .5*Centerx,9
6760             LABEL USING 6500;F
6770             MOVE 1.5*Centerx,9

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6780 LABEL USING 6530;Nray_family .
6790 MOVE .5*Centerx,5
6800 LABEL USING 6560;Alpha
6810 MOVE 1.5*Centerx,5
6820 LABEL USING 6590;N2
6830 |
6840 MOVE Centerx,23
6850 LABEL "Distance Along GLM Axis (inches)"
6860 CSIZE 3
6870 MOVE Centerx,15
6880 LABEL "FAMILY OF SURFACES"
6890 LDIR 90
6900 MOVE 1.5,Centery
6910 LABEL "Radial Distance from the Axis (inches)"
6920 |
6930 GOTO End_label
6940 Stuff_label: Centerx=72.5
6950 Centery=66.5
6960 |
6970 MOVE .5*Centerx,9
6980 LABEL USING 6500;F
6990 MOVE 1.5*Centerx,9
7000 LABEL USING 6530;Nray_stuff
7010 MOVE .5*Centerx,5
7020 LABEL USING 6560;Alpha
7030 MOVE 1.5*Centerx,5
7040 LABEL USING 6590;N2
7050 MOVE Centerx,5
7060 LABEL USING 7070;Aperture
7070 IMAGE "Aperture : "DD.DDD" inch"
7080 |
7090 MOVE Centerx,23
7100 LABEL "Distance Along GLM Axis (inches)"
7110 CSIZE 3
7120 MOVE Centerx,15
7130 LABEL USING 7140;Family
7140 IMAGE "SURFACE NUMBER "K
7150 |
7160 LDIR 90
7170 MOVE 1.5,Centery
7180 LABEL "Radial Distance from the Axis (inches)"
7190 |
7200 GOTO End_label
7210 Ray_trace_label: Centerx=72.5 | CHANGE IN GRAPH AS WELL
7220 Centery=62.5
7230 |
7240 MOVE 1.5*Centerx,9
7250 LABEL USING 6530;Nray_trace
7260 MOVE .5*Centerx,10
7270 LABEL USING 7280;Rho_initial
7280 IMAGE "Incident Ray Angle : ",3D.DD," deg"
7290 MOVE .5*Centerx,6
7300 LABEL USING 7070;Aperture
7310 MOVE 1.5*Centerx,6
7320 LABEL USING 6590;N2
7330 MOVE .5*Centerx,2
7340 LABEL USING 6560;Alpha
7350 MOVE Centerx,23
7360 LABEL "Distance Along the GLM Axis ( inches )"
7370 |
7380 CSIZE 3
7390 MOVE Centerx,15
7400 LABEL USING 7410;Family
7410 IMAGE "SURFACE NUMBER ",K
7420 |
7430 LDIR 90
7440 MOVE 1.3,Centery

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7450 LABEL "Radial Distance From the Axis ( inches )"
7460 |
7470 GOTO End_label
7480 Digit_label: Centerx=61.56
7490 Centery=65
7500 |
7510 MOVE 1.5*Centerx,13
7520 LABEL USING 6530;Nray_trace
7530 MOVE Centerx/2,9
7540 LABEL USING 7550;Hit_total
7550 IMAGE "Number of Hits on the Image Plane : ",K
7560 MOVE 1.5*Centerx,9
7570 LABEL USING 7580;Percent_image
7580 IMAGE "% of Rays to Image Plane : ",3D.DD
7590 MOVE 1.5*Centerx,5
7600 LABEL USING 7610;Z3
7610 IMAGE "Image Plane : ",DD.DD," inches"
7620 MOVE .5*Centerx,5
7630 LABEL USING 7640;N_increment
7640 IMAGE "Number of Increments [0,1.1] : ",K
7650 |
7660 CSIZE 3
7670 MOVE Centerx,20
7680 LABEL "Normalized Number of Hits vs Distance from the GLM Ax
is"
7690 MOVE Centerx/2,13
7700 LABEL USING 7710;Family
7710 IMAGE "SURFACE NUMBER ",K
7720 |
7730 End_label: CSIZE 15/4.54
7740 LDIR 0
7750 LOG 5
7760 SETUU
7770 SUBEND
7780 SUB Xipos(X,Y)
7790 OPTION BASE 0
7800 |
7810 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Rho1,Trho1,Rho2,Trho2
7820 |
7830 INTEGER Z
7840 DEG
7850 DEF FNY1(Y)=Y*Talpha/(Talpha-Trho1) ! FINDS THE Y-VALUE OF THE INTERCEPT
7860 ! OF THE RAY AND THE FIRST SURFACE
7870 DEF FNX1(Y)=Y/Talpha ! FINDS THE X-VALUE OF THE INTERCEPT OF THE RAY
7880 ! AND THE FIRST SURFACE
7890 Y=FNY1(Y)
7900 X=FNX1(Y)
7910 SUBEND
7920 |
7930 One: FOR Z=0 TO 79
7940 IF Z=79 THEN 7960
7950 PRINT CHR$(220);
7960 IF Z=79 THEN PRINT CHR$(220)
7970 NEXT Z
7980 SUBEXIT
7990 SUBEND
8000 SUB Dialogue
8010 OPTION BASE 0
8020 |
8030 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Rho1,Trho1,Rho2,Trho2
8040 COM F,Z3,Z4,Norm,Thetal,Tdelta
8050 COM Dates,Plots,Families,Charts,Mains,Mainis,Flags,Y_hands
8060 |
8070 COM Stuffs,Redraws,Digitizes,Ray_traces
8080 COM INTEGER I,J,Y0_loop,Nray,Nray_chart,Nray_family,Nray_stuff
8090 COM INTEGER Nray_trace,Nray_density,Add_ray,Nc,Ns,Nbeta,Flag
8100 |

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0110 COM INTEGER Line_count,Line_max,N_increment,Hit_total,Pselect,Hpib
0120 COM INTEGER Family,Surf_no
0130 COM REAL Theta_critical,Tol,N1,N2,N3,Delta_ray,Y0,Ya,Yb,Aperture
0140
0150 COM Y_bullet,Smax_family,Percent_image
0160 COM X1(+),Y1(+),XC(+),X2(+),Y2(+),X2max(+),Y2max(+
0170 COM Y3(+),Y4(+),Beta(+),S2(+),Xsurfmax(+),Ysurfmax(+
0180
0190 COM Ga(+),Smax(+),Alpha2(+),Rho2(+),Hit(+
0200
0210
0220 THIS ROUTINE INITIALIZES MOST OF THE VARIABLES USED IN THE PROGRAM
0230
0240 DEG
0250 Initialize_top:Alpha=21
0260 Talpha=TAN(Alpha)
0270 Tol=.00001
0280 Z3=Z4=50
0290 N1=1
0300 N2=4
0310 N3=1
0320 F=4
0330 Y_bullet=1.1
0340 Ya=0 ! WHEN YA # 0 THEN THEN THE BORDERS OF THE
0350 Yb=Y_bullet ! APERTURE ARE ILLUSTRATED BY DRAWING A
0360 Aperture=Yb-Ya ! RAY AT Y=Ya AND Y=Yb. THIS IS DONE BY
0370 Add_ray=0 ! ADDING A RAY TO ALL NRAY_x DECLARATIONS
0380 Nray=10
0390 Rho_initial=Rho=0
0400 Trho=Trho=TAN(Rho_initial)
0410 Line_count=0
0420 Line_max=45
0430 N_increment=100
0440 Pselect=7
0450 Hpib=5
0460 Plots="C"
0470 Dates=""
0480 Family="N"
0490 Stuff="N"
0500 Digitize="N"
0510 Redraw="N"
0520 Ray_traces="N"
0530 PRINT PAGE,"Note to the operator: "
0540 PRINT LIN(2)," When a request for information is placed on the screen"
0550 PRINT "two options exist:"
0560 PRINT LIN(1)," 1) key in the required information and PRESS CONT."
0570 PRINT " 2) PRESS CONT if the data/parameter or other response "
0580 PRINT " has not or will not change from the previous entry. If in"
0590 PRINT " doubt, key in the correct response or data and PRESS CONT."
0600 PRINT LIN(2),"PRESS CONT"
0610 PAUSE
0620 PRINT PAGE,"The sign convention is : "
0630 PRINT LIN(1)," 1) the origin is placed at the vertex of the first su
rface"
0640 PRINT " and the GLM axis."
0650 PRINT " 2) distances: positive to the right of the origin."
0660 PRINT " positive above the origin (Radial distance)."
0670 PRINT " positive out of the meridian plane (screen)."
0680 PRINT " (ie. a right hand system.)"
0690 PRINT " 3) angles: POSITIVE IF counter-clockwise"
0700 PRINT " rotation from the GLM axis to the ray"
0710 PRINT LIN(2),"PRESS CONT"
0720 PAUSE
0730 Alpha: PRINT PAGE," Alpha is the angle of inclination (ie. the cone"
0740 PRINT "half-angle) of the FIRST surface with respect to the GLM-axis

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8750 PRINT LIN(3)," The current value of ALPHA is";Alpha;"degrees"
8760 INPUT "WHAT IS NEW VALUE OF ALPHA (DEGREES)?",Alpha
8770 Talpha=TAN(Alpha)
8780 Index: PRINT PAGE," The lens system is assumed to be operating in air."
8790 PRINT "Therefore the first index of refraction is defined as n1= 1.00000
"
8800 PRINT LIN(2)," It is assumed that n1 < n2"
8810 PRINT " and n2 > n3."
8820 N2: INPUT "WHAT IS n2 (DEFAULT VALUE = 4) ?",N2
8830 N3: INPUT "WHAT IS n3 (DEFAULT VALUE = 1) ?",N3
8840 IF N3<N2 THEN Theta_critical=ASN(N3/N2)
8850 IF N3>N2 THEN BEEP
8860 IF N3>N2 THEN DISP "n2 MUST BE > n3. PLEASE RE-ENTER n2 AND n3."
8870 IF N3>N2 THEN WAIT 4000
8880 IF N3>N2 THEN N2
8890 Rho_initial: PRINT PAGE," The rays incident on the first surface are "
8900 PRINT "assumed to be parallel to the GLM-axis. "
8910 PRINT LIN(5),"PRESS CONT"
8920 PAUSE
8930 Rho=Rho_initial
8940 Trho=TAN(Rho)
8950 CALL Snell ! COMPUTE RHO1
8960 Y_bullet: PRINT PAGE," The GLM is assumed to be symmetric around the long
itudinal"
8970 PRINT "axis. The maximum radius, called Y_bullet, is ";Y_bullet;"
inches."
8980 PRINT LIN(2)," If your design requires a different radius, plea
se"
8990 PRINT "enter the new value now."
9000 INPUT "Y_bullet (INCHES) ?",Y_bullet
9010 Aperture: PRINT PAGE," The aperture is the difference in radial distance
from the GLM axis,"
9020 PRINT "projected onto the first surface, into which light is allo
ued to enter"
9030 PRINT "the GLM optical system. The parameter values are:"
9040 PRINT LIN(2)," Ya = the lower aperture limit (default value =
";Ya;"inch)"
9050 PRINT " Yb = the upper aperture limit (default value = ";Yb;"
inch)"
9060 PRINT " and is always less than or equal to Y_bullet."
9070 INPUT "WHAT IS Ya (INCHES) ?",Ya
9080 INPUT "WHAT IS Yb (INCHES) ?",Yb
9090 IF Ya>Yb THEN BEEP
9100 IF Ya>Yb THEN DISP "Ya MUST BE < Yb. Please enter correct valu
es."
9110 IF Ya>Yb THEN WAIT 3000
9120 IF Ya>Yb THEN Aperture
9130 IF Yb>Y_bullet THEN BEEP
9140 IF Yb>Y_bullet THEN DISP "Y_bullet MUST BE ≥ Yb: PLEASE RE-
ENTER Y_bullet, Ya AND Yb."
9150 IF Yb>Y_bullet THEN WAIT 3000
9160 IF Yb>Y_bullet THEN Y_bullet
9170 Aperture=Yb-Ya
9180 IF Ya<0 THEN Add_ray=1
9190 Nray: PRINT PAGE," The program will trace";Nray;" rays through the system
unless "
9200 PRINT "you specify another value."
9210 PRINT LIN(2),"CAUTION: Entering too many lines will clutter the des
ign chart."
9220 PRINT " Try";Nray;" rays, then decide if you want more
or less rays."
9230 INPUT " HOW MANY RAYS DO YOU WANT THE PROGRAM TO TRACE ?",Nray
9240 IF Nray<2 THEN BEEP
9250 IF Nray<2 THEN DISP "YOU MUST USE AT LEAST TWO (2) RAYS. PLEASE R
E-ENTER THE CORRECT VALUE."
9260 IF Nray<2 THEN WAIT 2500
9270 IF Nray<2 THEN Nray

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9280 Focus: PRINT PAGE, " The focal point is the location on the GLM-axis at wh
ich "
9290 PRINT "you want all of the rays to pass through."
9300 PRINT LIN(2), " The minimum value of the focal point is ";Y_bullet/
Talpha;" inches."
9310 PRINT "This value has been chosen to prevent the angle of the tangen
t line"
9320 PRINT "of the second surface from exceeding 90 degrees at y = ";Y_bu
llet
9330 PRINT "(ie. at y = Y_bullet inches )."
9340 PRINT LIN(2), " The default value is ";F;" inches."
9350 INPUT "WHAT IS THE VALUE OF THE FOCAL POINT ?",F
9360 Date: PRINT PAGE
9370 INPUT "WHAT IS TODAY'S DATE ?",Date$
9380 Start: PRINTER IS 16
9390 Gymnastics: SUBEND
9400 SUB Chart
9410 OPTION BASE 0
9420 |
9430 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Rho1,Trho1,Rho2,Trho2
9440 COM F,Z3,Z4,Norm,Theta1,Tdelta
9450 COM Date$,Plot$,Family$,Chart$,Main$,Main$,Flag$,Y_hards
9460 |
9470 COM Stuff$,Redraw$,Digitize$,Ray_traces
9480 COM INTEGER I,J,Y0_loop,Nray,Nray_chart,Nray_family,Nray_stuff
9490 COM INTEGER Nray_trace,Nray_density,Add_ray,Nc,Ns,Nbeta,Flag
9500 |
9510 COM INTEGER Line_count,Line_max,N_increment,Hit_total,Pselect,Hpib
9520 COM INTEGER Family,Surf_no
9530 COM REAL Theta_critical,Tol,N1,N2,N3,Delta_ray,Y0,Ya,Yb,Aperture
9540 |
9550 COM Y_bullet,Smx_family,Percent_image
9560 COM XI(*),Y1(*),XC(*),X2(*),Y2(*),X2max(*),Y2max(*)
9570 COM Y3(*),Y4(*),Beta(*),S2(*),Xsurfmax(*),Ysurfmax(*)
9580 |
9590 COM Qa(*),Smx(*),Alpha2(*),Rho2(*),Hit(*)
9600 |
9610 | THIS ROUTINE COMPUTES AND DRAWS A FAMILY OF CURVES REPRESENTING THE
9620 | RELATIONSHIP BETWEEN THE DISTANCE ALONG THE RAY REFRACTED AT THE FIRST
9630 | SURFACE OF THE LENS AND THE SLOPE (DERIVED FROM SNELL'S LAW) REQUIRED
9640 | TO SUCCESSFULLY REFRACT THAT RAY THROUGH THE DESIRED FOCAL POINT.
9650 |
9660 | THE NOTABLE VARIABLES ARE:
9670 | 1) BETA : THE ANGLE OF A LINE DRAWN FROM THE FOCAL POINT TO THE
9680 | INTERCEPT OF THE RAY AND THE FIRST SURFACE
9690 | 2) RHO1 : THE ANGLE OF THE REFRACTED FROM THE FIRST SURFACE WITH
9700 | RESPECT TO THE GLM-AXIS (REF)
9710 | 3) RHO2 : THE REQUIRED ANGLE OF THE REFRACTED RAY FROM THE SECOND
9720 | SURFACE WRT REF
9730 | 4) HIGH : RHO1 > BETA
9740 | 5) LOW : RHO1 < BETA
9750 | 6) ALPHA2 : THE SLOPE OF THE SECOND SURFACE WRT REF REQUIRED TO
9760 | SATISFY SNELL'S LAW
9770 | 7) S : THE DISTANCE ALONG THE RAY REFRACTED FROM THE FIRST
9780 | SURFACE, MEASURED FROM THE FIRST SURFACE
9790 | 8) Q : INTERCEPT POINT OF THE INCIDENT RAY AND THE FIRST SURFACE
9800 | 9) A : X-INTERCEPT OF THE RAY REFRACTED AT Q
9810 | 10) QA : DISTANCE FROM Q TO A
9820 |
9830 DEG
9840 Nray_chart=Nray
9850 IF (Stuff$="Y") OR (Stuff$="y") THEN Nray_chart=Nray_stuff
9860 Chart$="Y"
9870 CALL Header
9880 Flag=0
9890 Draw_axes: CALL Plot

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9900 Beta: FOR I=1 TO Nray_chart      ! COMPUTE BETA FOR EACH RAY
9910     Tbeta=Y1(I)/(X1(I)-F)
9920     Beta(I)=ATN(Tbeta)
9930     A=X1(I)-Y1(I)/Trhol          ! COMPUTE THE DISTANCE ALONG THE REFRACTED
9940     Qa2=(X1(I)-A)^2+Y1(I)^2    ! RAY TO THE X-INTERCEPT
9950     Qa(I)=SQR(Qa2)              ! THIS IS THE MAX ALLOWED VALUE OF S
9960     NEXT I
9970 Chart: FOR Nbeta=1 TO Nray_chart ! COMPUTE ALPHA2 AND S FOR EACH RAY
9980     S=0
9990     Smax=Qa(Nbeta)
10000    Nstep=Smax/20
10010    J=0
10020 S:  FOR S=S0 TO Smax STEP Nstep
10030     J=J+1
10040     IF ABS(Beta(Nbeta))>ABS(Rho1) THEN High
10050     IF S<0 THEN Next_beta
10060 Low:  CALL Low_region(S,Alpha2,Nbeta)
10070     IF Tdelta<0 THEN Negative
10080     IF Rho2>0 THEN Negative
10090     IF Alpha2>90 THEN Negative
10100     IF Line_count>Line_max THEN CALL Header
10110     PRINT USING Image_data;Nbeta,Beta(Nbeta),Theta1,Norm,Rho2,S,Alpha2
10120     Line_count=Line_count+1
10130     GOSUB Graph
10140     GOTO Next_s
10150 High: CALL High_region(S,Alpha2,Nbeta)
10160     IF Tdelta<0 THEN Negative
10170     IF Rho2>0 THEN Negative
10180     IF Alpha2>90 THEN Negative
10190     IF Line_count>Line_max THEN CALL Header
10200     PRINT USING Image_data;Nbeta,Beta(Nbeta),Theta1,Norm,Rho2,S,Alpha2
10210     Line_count=Line_count+1
10220     GOSUB Graph
10230     GOTO Next_s
10240 Zero_cross_over: A=F*SIN(Alpha)/SIN(Alpha+ABS(Beta(Nbeta))) ! THIS
10250     B=S*COS(ABS(Beta(Nbeta))-ABS(Rho1)) ! CONDITION EXISTS IN
10260     D=A-B ! HIGH WHEN ALPHA2 > 90 DEGREES
10270     E=S*SIN(ABS(Beta(Nbeta))-ABS(Rho1))
10280     Tdelta=E/D
10290     Arho2=ABS(Beta(Nbeta))+ATN(Tdelta)
10300     IF Arho2<0 THEN Negative
10310     Rho2=-1*Arho2
10320 Norm_z_cross: A=COS(Rho2)-N2/N3*COS(Rho1)
10330     B=N2/N3*SIN(ABS(Rho1))-SIN(ABS(Rho2))
10340     Tnorm=B/A
10350     Norm=ATN(Tnorm)
10360     Theta1=Norm+ABS(Rho1)
10370     Theta2=Norm+ABS(Rho2)
10380     Alpha2=Norm+90
10390     IF Line_count>Line_max THEN CALL Header
10400     PRINT USING Image_data;Nbeta,Beta(Nbeta),Theta1,Norm,Rho2,S,Alpha2
10410     Line_count=Line_count+1
10420     GOSUB Graph
10430 Next_s: Smax(Nbeta)=S
10440     Alpha2(Nbeta)=Alpha2
10450     NEXT S
10460     S=S-Nstep
10470     IF S<Qa(Nbeta) THEN Negative
10480 Next_beta: IF Line_count>Line_max THEN CALL Header
10490     PRINT
10500     Line_count=Line_count+1
10510     Flag=2 ! LABEL THE PLOT WITH NBETA
10520     GOSUB Graph
10530     Flag=1 ! RESET
10540     NEXT Nbeta
10550     Flag=3 ! TELL GRAPH THIS IS THE LAST BETA
10560     CALL Graph

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10570      Charts="N"
10580      CALL Header_end
10590      SUBEXIT
10600 Negative: IF Nstep<Tol THEN Next_beta
10610          S=S-Nstep ! RHO2 < 0 FOR LOW OR ALPHA2 > 0 FOR HIGH OR LOW
10620          S0=S
10630          Nstep=Nstep/10
10640          Rho2=0
10650          GOTO S
10660 Graph: GRAPHICS
10670      SETUU
10680      LINE TYPE 1
10690      LDIR 0
10700      LORC 2
10710      CSIZE 2.5
10720          IF J=1 THEN MOVE S,Alpha2
10730          IF J=2 THEN DRAW S,Alpha2 ! DO NOT CHANGE
10740          IF (J>=3) AND (Flag<>2) THEN DRAW S,Alpha2 ! DO NOT CHANGE
10750          IF Flag=2 THEN LABEL USING 10770;Nbeta
10760      CSIZE 15/4.54
10770      IMAGE K
10780      RETURN
10790 Image_data: IMAGE DDD,4X,3(4D.3D,5X),4D.3D,5X,2D.3D,5X,4D.3D
10800 ! IMAGE STATEMENT IS FOR Nbeta,Beta(Nbeta),Theta,Norm,Rho2,S,Alpha2
10810 SUBEND
10820 SUB Low_region(S,Alpha2,INTEGER N)
10830 OPTION BASE 0
10840 !
10850 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Rho1,Trho1,Rho2,Trho2
10860 COM F,Z3,Z4,Norm,Theta,Tdelta
10870 COM Date$,Plot$,Family$,Chart$,Main$,Main$,Flag$,Y_hands
10880 !
10890 COM Stuff$,Redraw$,Digitize$,Ray_traces$
10900 COM INTEGER I,J,Y0_loop,Nray,Nray_chart,Nray_family,Nray_stuff
10910 COM INTEGER Nray_trace,Nray_density,Add_ray,Nc,Ns,Nbeta,Flag
10920 !
10930 COM INTEGER Line_count,Line_max,N_increment,Hit_total,Pselect,Hpib
10940 COM INTEGER Family,Surf_no
10950 COM REAL Theta_critical,Tol,N1,N2,N3,Delta_ray,Y0,Ya,Yb,Aperture
10960 !
10970 COM Y_bullet,Smax_family,Percent_image
10980 COM X1(*),Y1(*),Xc(*),X2(*),Y2(*),X2max(*),Y2max(*)
10990 COM Y3(*),Y4(*),Beta(*),S2(*),Xsurfmax(*),Ysurfmax(*)
11000 !
11010 COM Qa(*),Smax(*),Alpha2(*),Rho2(*),Hit(*)
11020 !
11030 DEG
11040 Tdelta:A=SIN(Alpha+ABS(Beta(N))) ! COMPUTE RHO2 = f(S)
11050      B=F+SIN(Alpha)/A
11060      C=S*COS(ABS(Rho1)-ABS(Beta(N)))
11070      D=B-C
11080      E=S*SIN(ABS(Rho1)-ABS(Beta(N)))
11090      Tdelta=E/D
11100      Delta=ATN(Tdelta)
11110      Arho2=ABS(Beta(N))-Delta
11120      Rho2=-1*Arho2
11130 Normal:A=COS(Rho2)-N2/N3*COS(Rho1) ! COMPUTE ALPHA2 = f(RHO2)
11140      B=SIN(ABS(Rho2))-N2/N3*SIN(ABS(Rho1))
11150      Tanora=B/A
11160      Anora=ATN(Tanora)
11170      Theta=Anora-ABS(Rho1)
11180      Theta=Anora-ABS(Rho2)
11190      Norm=-1*Anora
11200      Alpha2=90+Norm
11210 SUBEND
11220 SUB High_region(S,Alpha2,INTEGER N)
11230 OPTION BASE 0

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11240 !
11250 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trhoi,Rho1,Trho1,Rho2,Trho2
11260 COM F,Z3,Z4,Norm,Theta1,Tdelta
11270 COM Dates,Plots,Families,Charts,Mains,Mainis,Flags,Y_hards
11280 !
11290 COM Stuff$,Redraw$,Digitize$,Ray_traces$
11300 COM INTEGER I,J,Y0_loop,Nray,Nray_chart,Nray_family,Nray_stuff
11310 COM INTEGER Nray_trace,Nray_density,Add_ray,Nc,Ns,Nbeta,Flag
11320 !
11330 COM INTEGER Line_count,Line_max,N_increment,Hit_total,Pselect,Hpib
11340 COM INTEGER Family,Surf_no
11350 COM REAL Theta_critical,Tol,N1,N2,N3,Delta_ray,Y0,Ya,Yb,Aperture
11360 !
11370 COM Y_bullet,Smx_family,Percent_image
11380 COM X1(*),Y1(*),Xc(*),X2(*),Y2(*),X2max(*),Y2max(*)
11390 COM Y3(*),Y4(*),Beta(*),S2(*),Xsurfmax(*),Ysurfmax(*)
11400 !
11410 COM Qa(*),Smx(*),Alpha2(*),Rho2(*),Hit(*)
11420 !
11430 DEG
11440 High:A=SIN(Alpha+ABS(Beta(N))) ! COMPUTE RHO2 = f(S)
11450 B=F*SIN(Alpha)/A
11460 C=S*COS(ABS(Beta(N))-ABS(Rho1))
11470 D=B-C
11480 E=S*SIN(ABS(Beta(N))-ABS(Rho1))
11490 Tdelta=E/D
11500 Arho2=ABS(Beta(N))+ATN(Tdelta)
11510 Rho2=-1+Arho2
11520 Normal:A=N2/N3*SIN(ABS(Rho1))-SIN(ABS(Rho2)) ! COMPUTE ALPHA2 = f(RHO2)
11530 B=N2/N3*COS(Rho1)-COS(Rho2)
11540 Tanorm=A/B
11550 Anorm=ATN(Tanorm)
11560 Theta1=ABS(Rho1)-Anorm
11570 Theta2=ABS(Rho2)-Anorm
11580 Norm=-1+Anorm
11590 Alpha2=90+Norm
11600 SUBEND
11610 SUB Family
11620 OPTION BASE 0
11630 !
11640 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trhoi,Rho1,Trho1,Rho2,Trho2
11650 COM F,Z3,Z4,Norm,Theta1,Tdelta
11660 COM Dates,Plots,Families,Charts,Mains,Mainis,Flags,Y_hards
11670 !
11680 COM Stuff$,Redraw$,Digitize$,Ray_traces$
11690 COM INTEGER I,J,Y0_loop,Nray,Nray_chart,Nray_family,Nray_stuff
11700 COM INTEGER Nray_trace,Nray_density,Add_ray,Nc,Ns,Nbeta,Flag
11710 !
11720 COM INTEGER Line_count,Line_max,N_increment,Hit_total,Pselect,Hpib
11730 COM INTEGER Family,Surf_no
11740 COM REAL Theta_critical,Tol,N1,N2,N3,Delta_ray,Y0,Ya,Yb,Aperture
11750 !
11760 COM Y_bullet,Smx_family,Percent_image
11770 COM X1(*),Y1(*),Xc(*),X2(*),Y2(*),X2max(*),Y2max(*)
11780 COM Y3(*),Y4(*),Beta(*),S2(*),Xsurfmax(*),Ysurfmax(*)
11790 !
11800 COM Qa(*),Smx(*),Alpha2(*),Rho2(*),Hit(*)
11810 !
11820 ! THIS ROUTINE COMPUTES AND DRAWS A FAMILY OF SURFACES USING THE
11830 ! THE DESIGN CHART DRAWN IN SUBROUTINE CHART
11840 ! THE ROUTINE TAKES THE END POINTS OF EACH CURVE OF ALPHA2 VS S
11850 ! AND DRAWS A SURFACE USING ALPHA2 TO DRAW A LINE TO INTERCEPT THE NEXT
11860 ! RAY. THESE SURFACES ARE THEN THE MAXIMUM SURFACES FOR EACH PARAMETER
11870 ! BETA.
11880 !
11890 ! WHEN STUFFS="Y" THE ROUTINE GOES THROUGH THE I LOOP ONCE (ie FOR
11900 ! ONE SURFACE) AND THE J LOOP NRAY_STUFF TIMES.

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11910 !
11920 DEG
11930 Family$="Y"
11940 CALL Header
11950 Ymax=Y_bullet
11960 LINE TYPE 1
11970 LDIR 0
11980 LONG 5
11990 CSIZE 15/4.54
12000 Flag=0 ! RESET CONDITION
12010 Nray_family=Nray
12020 IF (Stuff$="Y") OR (Stuff$="y") THEN Nray_family=Nray_stuff
12030 Draw_axes: CALL Plot ! DRAWS AND LABELS THE AXES
12040 Step_family=INT(Nray_family/10)
12050 IF Step_family<=0 THEN Step_family=1
12060 First_surf:LINE TYPE 8 ! DRAW THE FIRST SURFACE
12070 MOVE 0,0
12080 X=Ymax/Talpha
12090 DRAW X,Ymax
12100 DRAW 100,Ymax
12110 IF (Stuff$="Y") OR (Stuff$="y") THEN Delta_b
12120 EXIT GRAPHICS
12130 BEEP
12140 Y$="N"
12150 INPUT "DO YOU WANT TO DRAW IN THE INCIDENT RAYS ? Y/N",Y$
12160 IF (Y$="N") OR (Y$="n") THEN Delta_b
12170 GRAPHICS
12180 LINE TYPE 3
12190 FOR I=Step_family TO Nray_family STEP Step_family
12200 MOVE 0,Y1(I)
12210 DRAW X1(I),Y1(I)
12220 A=X1(I)-Y1(I)/Trho1
12230 DRAW A,0
12240 NEXT I
12250 Delta_b:GRAPHICS
12260 IF (Stuff$="Y") OR (Stuff$="y") THEN Step_family=1
12270 B1=Y1(Step_family)-X1(Step_family)*Trho1
12280 B2=Y1(Step_family+1)-X1(Step_family+1)*Trho1
12290 Deltab=B2-B1
12300 Starting_points:FOR I=Step_family TO Nray_family STEP Step_family
12310 J=I ! PRINTING PURPOSES
12320 Flag_over=0 ! RESET CONDITION
12330 Flag_neg=0 ! RESET CONDITION
12340 Sfirst=Slast=Smax(I)
12350 IF (Stuff$="Y") OR (Stuff$="y") THEN Sfirst=Slast=Smax(Family)
12360 S2(I)=Slast ! FOR STUFF ONLY
12370 Delta_xsurf=S2(I)+COS(Rho1)
12380 Delta_ysurf=S2(I)+SIN(Rho1)
12390 Xsurf21=X1(I)+Delta_xsurf
12400 Ysurf21=Y1(I)+Delta_ysurf
12410 IF (Stuff$="Y") OR (Stuff$="y") THEN Xsurf21=X1(Family)+Delta_xsu
rf
12420 IF (Stuff$="Y") OR (Stuff$="y") THEN Ysurf21=Y1(Family)+Delta_ysu
rf
12430 IF Ysurf21<0 THEN GOSUB Neg_ysurf ! THE STARTING POINT
12440 X2(I)=Xsurf21 ! IS BENEATH THE X-AXIS
12450 Y2(I)=Ysurf21
12460 Xsurfmax(I)=Xsurf21 !THESE ARE THE MAXIMUM (X,Y) COORDINATES OF THE
12470 Ysurfmax(I)=Ysurf21 ! RAY IN THE LENS
12480 IF Flag_neg=1 THEN GOSUB New_s
12490 Trho2=Y2(I)/(X2(I)-F)
12500 Rho2(I)=ATN(Trho2)
12510 Alpha21=Alpha2(I)
12520 IF (Stuff$="Y") OR (Stuff$="y") THEN Alpha21=Alpha2(Family)
12530 IF Alpha21>=90 THEN Next_i
12540 Talpha21=TAN(Alpha21)
12550 Bsurf21=Ysurf21-Xsurf21*Talpha21

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12560 Xsurf1ast=Xsurf21
12570 Ysurf1ast=Ysurf21
12580 Bsurf1ast=Bsurf21
12590 IF Line_count>Line_max THEN CALL Header
12600 PRINT USING 13470;I,J,Rho2(J),Xsurf1ast,Ysurf1ast,Slast,Alpha2i
12610 Line_count=Line_count+1
12620 LINE TYPE 1
12630 CSIZE 2.5
12640 LOG 2
12650 MOVE Xsurf21,Ysurf21 ! THE STARTING POINT
12660 Surfaces:FOR J=I+1 TO Nray_family ! DRAW THE PARTICULAR SURFACE
12670 Bnext=B1+(J-1)*Deltab
12680 Numxsurf=Bnext-Bsurf1ast
12690 Xsurfnext=Numxsurf/(Talpha2i-Trho1)
12700 Ysurfnext=Xsurfnext*Trho1+Bnext
12710 X2(J)=Xsurfnext ! ONLY USED FOR STUFF. DON'T USE AN IF
12720 Y2(J)=Ysurfnext ! STATEMENT IN ORDER TO SAVE TIME
12730 X1=0
12740 CALL X1pos(X1,Ysurfnext)
12750 IF Xsurfnext<=X1 THEN GOSUB Y1
12760 DRAW Xsurfnext,Ysurfnext
12770 Xs2=(X1(J)-Xsurfnext)^2 ! COMPUTE NEXT VALUE OF S BY
12780 Ys2=(Y1(J)-Ysurfnext)^2 ! EXTENDING THE RAY FROM THE
12790 Snext=SQR(Xs2+Ys2) ! PRESENT POINT TO THE NEXT
12800 S2(J)=Snext ! ALPHA2 VS S LINE
12810 IF ABS(Beta(J))>ABS(Rho1) THEN CALL High_region(Snext,Alpha2i,J)
12820 IF ABS(Beta(J))<=ABS(Rho1) THEN CALL Low_region(Snext,Alpha2i,J)
12830 Rho2(J)=Rho2
12840 Alpha2(J)=Alpha2i
12850 IF Line_count>Line_max THEN CALL Header
12860 PRINT USING 13470;I,J,Rho2(J),X2(J),Y2(J),S2(J),Alpha2(J)
12870 Line_count=Line_count+1
12880 IF Alpha2i>=90 THEN Next_i
12890 Talpha2i=TAN(Alpha2(J))
12900 Bsurfnext=Ysurfnext-Xsurfnext*Talpha2i
12910 Bsurf1ast=Bsurfnext
12920 Xsurf1ast=Xsurfnext
12930 Ysurf1ast=Ysurfnext
12940 IF (Stuffs="Y") OR (Stuffs="y") THEN 12970
12950 X2max(I)=Xsurf1ast ! USED TO DETERMINE APERTURE FOR STUFF
12960 Y2max(I)=Ysurf1ast
12970 IF Flag_over=1 THEN Next_i
12980 Next_j: NEXT J
12990 Next_i: IF Line_count>Line_max THEN CALL Header
13000 PRINT
13010 Line_count=Line_count+1
13020 IF (Stuffs="Y") OR (Stuffs="y") THEN 13030
13030 IF Flag_over=0 THEN GOSUB Label_surf
13040 IF (Stuffs="Y") OR (Stuffs="y") THEN 13080
13050 NEXT I
13060 LOG 5 ! RESET
13070 CSIZE 15/4.54
13080 IF (Stuffs="Y") OR (Stuffs="y") THEN GOSUB Yb
13090 Flag=3
13100 CALL Graph
13110 Family="N"
13120 CALL Header_end
13130 SUBEXIT
13140 Y1: Flag_over=1
13150 Xsurfnext=Bsurf1ast/(Talpha-Talpha2i)
13160 Ysurfnext=Xsurfnext*Talpha
13170 MOVE Xsurfnext,Ysurfnext ! THE ENDPOINT
13180 CSIZE 3
13190 LOG 1
13200 IF (Stuffs="N") OR (Stuffs="n") THEN LABEL USING 13410;I
13210 IF (Stuffs="Y") OR (Stuffs="y") THEN LABEL USING 13410;Family
13220 MOVE Xsurfnext,Ysurfnext ! PLACE THE PEN BACK ON TOP OF THE POINT

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13230 RETURN
13240 New_s: Sy2=Y2(I)-Y1(I)
13250 Sx2=X2(I)-X1(I)
13260 S2(I)=SQRT(Sx2+Sy2)
13270 RETURN
13280 Neg_ysurf: Flag_neg=1 ! IF, FOR SOME NUMERICAL REASON YB1 < 0
13290 A=X1(I)-Y1(I)/Trho1
13300 IF (Stuffs="Y") OR (Stuffs="y") THEN A=X1(Family)-Y1(Family)/
Trho1
13310 Xsurf21=A ! START AT THE X-INTERCEPT
13320 Ysurf21=0
13330 RETURN
13340 Label_surf: MOVE Xsurf1ast,Ysurf1ast ! THE ENDPOINT
13350 CSIZE 3
13360 LOGIC 1
13370 IF (Stuffs="N") OR (Stuffs="n") THEN LABEL USING 13410:I
13380 IF (Stuffs="Y") OR (Stuffs="y") THEN LABEL USING 13410:Family
13390 MOVE Xsurf1ast,Ysurf1ast ! PLACE THE PEN ON TOP OF THE POINT
13400 RETURN
13410 IMAGE K
13420 Yb: Bsm=Y2max(Family)-X2max(Family)*Trho1 ! COMPUTE THE UPPER LIMIT
13430 X1=Bsm/(Talpha-Trho1) ! OF THE APERTURE. THIS IS THE FINAL VALUE OF
13440 Yb=Y1-X1*Talpha ! THE APERTURE
13450 Aperture=Yb-Ya
13460 RETURN
13470 IMAGE 2X,DDD,5X,DDD,5(5X,DDD,DDD)
13480 ! THE IMAGE STATEMENT IS FOR: I,J,Rho2(J),X2(J),Y2(J),S2(J),Alpha2(J)
13490 SUBEND
13500 SUB Ray_trace
13510 OPTION BASE 0
13520 !
13530 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Rho1,Trho1,Rho2,Trho2
13540 COM F,Z3,Z4,Norm,Theta,Tdelta
13550 COM Date$,Plot$,Family$,Chart$,Main$,Main1$,Flag$,Y_hands
13560 !
13570 COM Stuffs,Redraw$,Digitize$,Ray_traces
13580 COM INTEGER I,J,Y0_loop,Nray,Nray_chart,Nray_family,Nray_stuff
13590 COM INTEGER Nray_trace,Nray_density,Add_ray,Nc,Ns,Nbeta,Flag
13600 !
13610 COM INTEGER Line_count,Line_max,N_increment,Hit_total,Pselect,Hpib
13620 COM INTEGER Family,Surf_no
13630 COM REAL Theta_critical,Tol,N1,N2,N3,Delta_ray,Y0,Ya,Yb,Aperture
13640 !
13650 COM Y_bullet,Smax_family,Percent_image
13660 COM X1(*),Y1(*),Xc(*),X2(*),Y2(*),X2max(*),Y2max(*)
13670 COM Y3(*),Y4(*),Beta(*),S2(*),Xsurfmax(*),Ysurfmax(*)
13680 !
13690 COM Qa(*),Smax(*),Alpha2(*),Rho2(*),Hit(*)
13700 !
13710 !
13720 ! THIS ROUTINE CONTROLS THE RAY DIAGRAM FOR AN ARBITRARY NUMBER
13730 ! OF RAYS WHICH IS ENTERED BY THE OPERATOR IN RESPONSE TO A PROMPT
13740 !
13750 ! THE ROUTINE CONTROLS THE FITTING OF A POLYNOMIAL TO A SET OF POINTS
13760 ! WHEN AN ARBITRARY RAY DOES NOT COINCIDE WITH A RAY COMPUTED IN STUFF
13770 !
13780 DEG
13790 Ray_traces="Y"
13800 Select=16
13810 EXIT GRAPHICS
13820 Ys="N"
13830 INPUT "DO YOU WANT A HARD COPY OF ALL OF THE GENERATED COEFFICIENTS ? Y/N"
,Ys
13840 IF (Ys="Y") OR (Ys="y") THEN Select=0
13850 Graphics=1
13860 X=1

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13870 N=4
13880 CALL Driver(N,Select,X,Graphics)
13890 Ray_traces="N"
13900 SUBEND
13910 SUB Driver(N,Select,Input,Graphics)
13920 !
13930 OPTION BASE 1
13940 !
13950 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Rho1,Trho1,Rho2,Trho2
13960 COM F,Z3,Z4,Norm,Thetal,Tdelta
13970 COM Dates,Plots,Family$,Chart$,Main$,Main$,Flags,Y_hands
13980 !
13990 COM Stuffs,Redraws,Digitize$,Ray_traces
14000 COM INTEGER I,J,Y0_loop,Nray,Nray_chart,Nray_family,Nray_stuff
14010 COM INTEGER Nray_trace,Nray_density,Add_ray,Nc,Ns,Nbeta,Flag
14020 !
14030 COM INTEGER Line_count,Line_max,N_increment,Hit_total,Pselect,Hpib
14040 COM INTEGER Family,Surf_no
14050 !
14060 DIM Xx(N),Yy(N),A$(2),B$(2),Coeffs(0:10)
14070 PRINTER IS Select
14080 Q=4
14090 P: Degree=3
14100 CALL Polynomial(Xx(*),Yy(*),N,Degree,Coeffs(*),Regss,Resss,Totalss,Reg
gas,Resas,F,Dfreg,Dfres,Dftot,Abort)
14110 PRINT "Coefficients:"
14120 FOR I=0 TO Degree
14130 PRINT USING 14140;I,Coeffs(I)
14140 IMAGE "A("DDDD")=",K
14150 NEXT I
14160 PRINT LIN(1)
14170 GOSUB Routable
14180 IF Graphics AND (Select=16) THEN WAIT 2000
14190 IF Graphics THEN CALL Plot_cubic(Q,A,B,Coeffs(*),Xx(*),Yy(*),N,Degree
e,Select)
14200 SUBEXIT
14210 Print: PRINTER IS Select
14220 PRINT LIN(2),SPA(12);"DATA"
14230 FOR I=1 TO N
14240 PRINT USING 14250;I,Xx(I),Yy(I)
14250 IMAGE "Point #="DDDD":",5X,"X2="DDD.DDDD,5X,"Y2="DDD.DDDD
14260 NEXT I
14270 PRINT LIN(2)
14280 PRINTER IS 16
14290 RETURN
14300 Routable: PRINT USING 14310
14310 IMAGE "Source "5X"Df"11X"SS"13X"MS"12X"F",/
14320 PRINT USING 14330;Dfreg,Regss,Regas,F
14330 IMAGE "Regression"5X,MDD,4X,M7D.3D,4X,M7D.3D,5X,M4D.3D
14340 PRINT USING 14350;Dfres,Resss,Resas
14350 IMAGE "Residual "5X,MDD,4X,M7D.3D,4X,M7D.3D
14360 PRINT USING 14370;Dftot,Totalss
14370 IMAGE "Total "5X,MDD,4X,M7D.3D,/,/,/,/,/
14380 RETURN
14390 SUBEND
14400 SUB Polynomial(X(*),Y(*),N,Degree,Coeffs(*),Regss,Resss,Totalss,Regas,Res
s,F,Dfreg,Dfres,Dftot,Abort)
14410 OPTION BASE 0
14420 DIM Matrix(Degree,Degree),Inv(Degree,Degree),B(Degree)
14430 REDIM Coeffs(Degree)
14440 IF Degree>N-2 THEN SUBEXIT ! Check for higher degree than possible
14450 Dfreg=Degree
14460 Dfres=N-1-Degree
14470 Dftot=Dfreg+Dfres
14480 FOR K=0 TO Degree ! Set up system of equations
14490 FOR J=K TO Degree
14500 Matrix(K,J)=0

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14510     FOR I=1 TO N
14520     Matrix(K,J)=Matrix(K,J)+FNG(K)*FNG(J)
14530     NEXT I
14540     Matrix(J,K)=Matrix(K,J)
14550     NEXT J
14560     B(K)=0
14570     FOR I=1 TO N
14580     B(K)=B(K)+Y(I)*FNG(K)
14590     NEXT I
14600     NEXT K
14610     MAT Inv=INV(Matrix)      | Solve the system of equations
14620     MAT Coeffs=Inv*B
14630     FOR I=1 TO N
14640     X1=X1+X(I)
14650     X2=X2+X(I)*X(I)
14660     Y1=Y1+Y(I)
14670     Y2=Y2+Y(I)*Y(I)
14680     Z=Z+X(I)*Y(I)
14690     NEXT I
14700     Y1=Y1/N
14710     X1=X1/N
14720     Totalss=Y2-N*Y1*Y1      | Total Sum of Squares
14730     GOSUB Regss            | Regression Sum of Squares
14740     Resss=Totalss-Regss    | Residual Sum of Squares
14750     Regms=Regss/Dfreg
14760     Resms=Resss/Dfres
14770     F=Regms/Resms
14780     SUBEXIT
14790     Regss=0
14800     FOR I=1 TO N
14810     J=0
14820     FOR L=0 TO Degree
14830     J=J+X(I)^L*Coeffs(L)
14840     NEXT L
14850     Regss=Regss+(J-Y1)^2
14860     NEXT I
14870     RETURN
14880     SUBEXIT
14890     DEF FNG(M)=X(I)^M
14900     SUBEND
14910     SUB Plot_cubic(Q,A,B,Coeffs(*),X(*),Y(*),N,Degree,Select)
14920     IF Whichdevice=1 THEN GRAPHICS
14930     DATA -2,-1,1,2
14940     READ Ua,Da,Md,Mu
14950     DATA .39794,.69897,.87506
14960     READ Log2,Log5,Log7
14970     Xmin=FNMin(X(*),N)
14980     Xmax=FNMax(X(*),N)
14990     Lx=LGT(Xmax-Xmin)
15000     Ymin=FNMin(Y(*),N)
15010     Ymax=FNMax(Y(*),N)
15020     Ly=LGT(Ymax-Ymin)
15030     Xfudge=.20*(Xmax-Xmin)
15040     Yfudge=.20*(Ymax-Ymin)
15050     Setup: IF Plot$="P" THEN P9072
15060     Crt: PLOTTER IS "GRAPHICS"
15070     GOTO 15090
15080     P9072: PLOTTER IS Pselect,Hpib,"9072A"
15090     GCLEAR
15100     GRAPHICS
15110     LOCATE 23,123,0,100
15120     FRAME
15130     LINE TYPE 1
15140     SCALE Xmin-Xfudge,Xmax,Ymin-Yfudge,Ymax
15150     Testxtic=FRAC(TLX)*<Lx(0)
15160     Testytic=FRAC(TLY)*<Ly(0)

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15170      Xtic=10^(INT(Lx)-1)*(1+1.5*(Testxtic>Log2) AND (Testxtic<Log5))+4*
((Testxtic>Log5) AND (Testxtic<Log7))+6.5*(Testxtic>Log7))
15180      Ytic=10^(INT(Ly)-1)*(1+1.5*(Testytic>Log2) AND (Testytic<Log5))+4*
((Testytic>Log5) AND (Testytic<Log7))+6.5*(Testytic>Log7))
15190      CALL Laxes_cubic(Xtic,Ytic,Xmin,Ymin,1,1,2,Xmin-Xfudge,Xmax,Ymin-
Yfudge,Ymax)
15200      LONG 5
15210      FOR I=1 TO N
15220      MOVE X(I),Y(I)
15230      LABEL USING 15240;"*"
15240      IMAGE A
15250      NEXT I
15260      LONG 1
15270      PENUP
15280      EXIT GRAPHICS
15290      SUBEXIT
15300 Polynomial: SETUP ! CHECK THE EARLIER PROGRAM FOR THESE PARAMETER VALUES
15310      CLIP 0,123,0,100
15320      LINE TYPE 1
15330      LINE TYPE 6
15340      FOR I=Xmin TO Xmax+Xfudge STEP (Xmax+Xfudge-Xmin)/30
15350      J=0
15360      FOR L=0 TO Degree
15370      J=J+I^L*Coeffs(L)
15380      NEXT L
15390      PLOT I,J,Md ! OR DRAW ???
15400      NEXT I
15410      PENUP
15420      EXIT GRAPHICS
15430      SUBEXIT
15440 DEF FNMax(X(*),N)
15450 X=X(1)
15460 FOR I=2 TO N
15470 X=MAX(X,X(I))
15480 NEXT I
15490 RETURN X
15500 DEF FNMin(X(*),N)
15510 X=X(1)
15520 FOR I=2 TO N
15530 X=MIN(X,X(I))
15540 NEXT I
15550 RETURN X
15560 SUB Header
15570 OPTION BASE 0
15580 |
15590 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Rho1,Trho1,Rho2,Trho2
15600 COM F,Z3,Z4,Norm,Theta1,Tdelta
15610 COM Dates,Plots,Families,Charts,Mains,Mainis,Flags,Y_hards
15620 |
15630 COM Stuffs,Redraws,Digitizes,Ray_traces
15640 COM INTEGER I,J,Y0_loop,Nray,Nray_chart,Nray_family,Nray_stuff
15650 COM INTEGER Nray_trace,Nray_density,Add_ray,Nc,Ns,Nbeta,Flag
15660 |
15670 COM INTEGER Line_count,Line_max,N_increment,Hit_total,Pselect,Hpib
15680 COM INTEGER Family,Surf_no
15690 COM REAL Theta_critical,Tol,N1,N2,N3,Delta_ray,Y0,Ya,Yb,Aperture
15700 |
15710 COM Y_bullet,Smax_family,Percent_image
15720 COM XI(*),Y1(*),XC(*),X2(*),Y2(*),X2max(*),Y2max(*)
15730 COM Y3(*),Y4(*),Beta(*),S2(*),Xsurfmax(*),Ysurfmax(*)
15740 |
15750 COM Qa(*),Smax(*),Alpha2(*),Rho2(*),Hit(*)
15760 |
15770 INTEGER Z,Ztab1,Ztab2,Ztab3,Char_min,Char_max
15780 |
15790 ! THIS ROUTINE DRAWS THE HEADER FOR PRINTED OUTPUT FOR THE FOLOWING
15800 ! ROUTINES:

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15810 |          1) CHART
15820 |          2) FAMILY
15830 |          3) STUFF
15840 |          4) RAY_TRACE
15850 |
15860 |
15870 |
15880 |          THIS ROUTINE DRAWS AND PRINTS THE HEADERS FOR TABULAR DATA.
15890 |
15900 |          DEC
15910 |          Ztab1=35      ! THE ZTAB'S CAN BE USED TO POSITION TABLE HEADINGS
15920 |          Ztab2=27      ! FOR THE PRINTED OUTPUT
15930 |          Ztab3=13
15940 |          IF (Mainis="Y") OR (Mainis="y") THEN Main
15950 |          IF (Mainis="Y") OR (Mainis="y") THEN Main1
15960 |          IF (Ray_traces="Y") OR (Ray_traces="y") THEN Ray_trace
15970 |          IF (Charts="Y") OR (Charts="y") THEN Chart
15980 |          IF (Familyis="Y") OR (Familyis="y") THEN Family
15990 |          IF (Stuffs="Y") OR (Stuffs="y") THEN Family
16000 | Main:  PRINT PAGE;LIN(2)
16010 |         GOSUB Char_long
16020 |         PRINT LIN(1);TAB(Ztab2);"INITIAL PARAMETER VALUES";LIN(1)
16030 |         GOSUB Char_long
16040 |         PRINT LIN(2)
16050 |         SUBEXIT
16060 | Main1: IF Line_count>Line_max THEN GOSUB Header_end_long
16070 |        PRINT PAGE;LIN(2)
16080 |        Line_count=0
16090 |        GOSUB Char_long
16100 |        PRINT LIN(1);TAB(Ztab3),"RAY      QR      Smax      Alpha2
RHO 2",LIN(1)
16110 |        DISP TAB(Ztab3),"RAY      QR      Smax      Alpha2
RHO 2"
16120 |        GOSUB Char_long
16130 |        PRINT LIN(2)
16140 |        SUBEXIT
16150 | Chart: IF Line_count>Line_max THEN GOSUB Header_end_long
16160 |        PRINT PAGE;LIN(2)
16170 |        Line_count=0
16180 |        GOSUB Char_long
16190 |        PRINT LIN(1),"RAY      BETA      THETA(RAY)      NORMAL      RHO 2
S      ALPHA 2";LIN(1)
16200 |        DISP "RAY      BETA      THETA(RAY)      NORMAL      RHO 2
S      ALPHA 2"
16210 |        GOSUB Char_long
16220 |        PRINT LIN(2)
16230 |        SUBEXIT
16240 | Family: IF Line_count>Line_max THEN GOSUB Header_end_long
16250 |        PRINT PAGE;LIN(2)
16260 |        Line_count=0
16270 |        GOSUB Char_long
16280 |        PRINT LIN(1);"      Begin      Next      Xsurf      Ysurf      S
Alpha2      RHO 2"
16290 |        PRINT "      Ray      Ray      (next)      (next)      (next)
(next)      (next)";LIN(1)
16300 |        DISP "      Begin      Next      Xsurf      Ysurf      S
Alpha2      RHO 2"
16310 |        GOSUB Char_long
16320 |        PRINT LIN(2)
16330 |        SUBEXIT
16340 | Ray_trace: IF Line_count>Line_max THEN GOSUB Header_end_long
16350 |        PRINT PAGE;LIN(2)
16360 |        Line_count=0
16370 |        GOSUB Char_long
16380 |        PRINT LIN(1),"RAY X0 Y0      X1      Y1      X2      Y2
Xe Yc X4 Y4 ";LIN(1)
16390 |        DISP "RAY X0 Y0      X1      Y1      X2      Y2

```

```

Xc Yc X4 Y4
16400 GOSUB Char_long
16410 PRINT LIN(2)
16420 SUBEXIT
16430 Char_long: FOR Z=0 TO 79
16440 IF Z=79 THEN PRINT CHR$(228)
16450 IF Z=79 THEN 16470
16460 PRINT CHR$(228);
16470 NEXT Z
16480 RETURN
16490 Char_short: Char_min=12 ! THIS ROUTINE CAN BE USED FOR SMALL TABLES
16500 Char_max=64
16510 FOR Z=Char_min TO Char_max
16520 IF Z=Char_min THEN PRINT TAB(Char_min);
16530 IF Z=Char_max THEN PRINT CHR$(228)
16540 IF Z=Char_max THEN 16560
16550 PRINT CHR$(228);
16560 NEXT Z
16570 RETURN
16580 Header_end_long: PRINT LIN(2)
16590 GOSUB Char_long
16600 RETURN
16610 Header_end_shor: PRINT LIN(2)
16620 GOSUB Char_short
16630 RETURN
16640 SUBEND
16650 SUB Header_end
16660 !
16670 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Rho1,Trho1,Rho2,Trho2
16680 COM F,Z3,Z4,Norm,Theta,Tdelta
16690 COM Dates,Plots,Families,Charts,Mains,Mainis,Flags,Y_hards
16700 !
16710 INTEGER Z,Char_min,Char_max
16720 ! THIS ROUTINE DRAWS THE FINAL BOTTOM LINE OF A TABLE. SUB HEADER ABOVE
16730 ! DRAWS THE BOTTOM LINES ON PAGES OF TABLES WHILE OUTPUT IS STILL BEING
16740 ! CALCULATED
16750 !
16760 PRINT LIN(2)
16770 FOR Z=0 TO 79
16780 IF Z=79 THEN PRINT CHR$(228)
16790 IF Z=79 THEN 16810
16800 PRINT CHR$(228);
16810 NEXT Z
16820 SUBEXIT
16830 Short: Char_min=20 ! THIS ROUTINE CAN BE USED TO FINISH A SMALL TABLE
16840 Char_max=60 ! TO USE, INSERT AN IF STATEMENT AFTER THE PRINT LIN
(2) ABOVE
16850 FOR Z=Char_min TO Char_max
16860 IF Z=Char_min THEN PRINT TAB(Char_min);
16870 IF Z=Char_max THEN PRINT CHR$(228)
16880 IF Z=Char_max THEN 16900
16890 PRINT CHR$(228);
16900 NEXT Z
16910 SUBEXIT
16920 SUB Stuff
16930 OPTION BASE 0
16940 !
16950 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Rho1,Trho1,Rho2,Trho2
16960 COM F,Z3,Z4,Norm,Theta,Tdelta
16970 COM Dates,Plots,Families,Charts,Mains,Mainis,Flags,Y_hards
16980 !
16990 COM Stuffs,Redraws,Digitizes,Ray_traces
17000 COM INTEGER I,J,Y0_loop,Nray,Nray_chart,Nray_family,Nray_stuff
17010 COM INTEGER Nray_trace,Nray_density,Add_ray,Nc,Ns,Nbeta,Flag
17020 !
17030 COM INTEGER Line_count,Line_max,N_increment,Mit_total,Pselect,Mpib
17040 COM INTEGER Family,Surf_no

```

```

17050 COM REAL Theta_critical,Tol,N1,N2,N3,Delta_ray,Y0,Ya,Yb,Aperture
17060 !
17070 COM Y_bullet,Smax_family,Percent_image
17080 COM X1(*),Y1(*),XC(*),X2(*),Y2(*),X2max(*),Y2max(*)
17090 COM Y3(*),Y4(*),Beta(*),S2(*),Xsurfmax(*),Ysurfmax(*)
17100 !
17110 COM Qa(*),Smax(*),Alpha2(*),Rho2(*),Hit(*)
17120 !
17130 !
17140 ! THIS ROUTINE COMPUTES 250 POINTS OF THE SURFACE CHOSEN IN FAMILY
17150 ! THESE POINTS ARE THEN USED IN OTHER ROUTINES TO TRACE AN ARBITRARY
17160 ! NUMBER OF RAYS THROUGH THE DESIGN SURFACE
17170 !
17180 !
17190 DEG
17200 IF Y2max(Family)=Y1(Family) THEN Yb=Y1(Family)
17210 IF Y2max(Family)=Y1(Family) THEN Initialize
17220 !
17230 Yb: Bsm=Y2max(Family)-X2max(Family)*Trho1 ! COMPUTE THE UPPER LIMIT
17240 X1=Bsm/(Talpha-Trho1) ! OF THE APERTURE. THIS IS AN ESTIMATE FOR
17250 Yb=Y1+X1*Talpha ! THE APERTURE MAY CHANGE IN THE FINAL DESIGN
17260 Aperture=Yb-Ya ! THE ESTIMATE IS REQUIRED TO CALCULATE DELY BELOW
17270 Initialize: IF (Redraw="Y") OR (Redraw="y") THEN Redraw! INDICATES
17280 Ya=Y1(Family)
17290 Aperture=Yb-Ya
17300 Y0_min=Ya+(Talpha-Trho1)/Talpha ! REDRAW TO ANOTHER SCALE
17310 Y0_max=Yb+(Talpha-Trho1)/Talpha
17320 Nray_stuff=250
17330 INPUT "HOW MANY RAYS DO YOU WANT TO DRAW THE SURFACE WITH ( DE
FAULT = 250 MAX) ?",Nray_stuff
17340 IF Ya=0 THEN Add_ray=0
17350 IF Ya<0 THEN Add_ray=1
17360 Xnray=Nray_stuff ! AVOIDS MIXED MODE ARITHMETIC
17370 Dely=(Y0_max-Y0_min)/Xnray
17380 Y0_min=Y0_min-Dely
17390 IF Ya=0 THEN Y0_min=Y0_min+Dely
17400 Nray_stuff=Nray_stuff+Add_ray
17410 Flag=0
17420 Ns=0
17430 X2(Ns)=0
17440 Y2(Ns)=0
17450 Beta(Ns)=0
17460 Start: Stuff="Y"
17470 FOR I=1 TO Nray_stuff ! COMPUTE THE COORDINATES OF THE INTERCEPT
17480 Flag=0 ! OF THE INCIDENT RAY AND THE FIRST SURFACE
17490 X=0
17500 Rho=Rho_initial
17510 Trho=TAN(Rho)
17520 Y=Y0_min+Dely*I
17530 Ns=Ns+1
17540 YI(Ns)=Y
17550 CALL Xipos(X,Y)
17560 XI(Ns)=X
17570 Next_I: NEXT I
17580 BEEP
17590 Ys="N"
17600 INPUT "DO YOU WANT A HARD COPY OF THE COMPUTED DATA ? Y/N",Ys
17610 IF (Ys="Y") OR (Ys="y") THEN GOSUB Yhard
17620 CALL Chart
17630 BEEP
17640 Ys="N"
17650 INPUT "DO YOU WANT A HARD COPY OF THE CHART ? Y/N",Ys
17660 IF (Ys="Y") OR (Ys="y") THEN GOSUB Dump_it
17670 Ys="N"
17680 INPUT "DO YOU WANT A HARD COPY OF THE COMPUTED DATA ? Y/N",Ys
17690 IF (Ys="Y") OR (Ys="y") THEN GOSUB Yhard
17700 CALL Family

```

```

17710      Stuff$="N"
17720      SUBEXIT
17730 Redraw: Stuff$="Y"
17740          CALL Plot
17750          LINE TYPE 8
17760          MOVE 0,0
17770          DRAW Y_bullet/Talpha,Y_bullet
17780          DRAW 100,Y_bullet
17790          MOVE X2(I),Y2(I)
17800          LINE TYPE 1
17810          FOR I=2 TO Nray_stuff
17820              DRAW X2(I),Y2(I)
17830          NEXT I
17840          MOVE X2(I-1),Y2(I-1)
17850          LONG 2
17860          LABEL USING 17870;Family
17870          IMAGE K
17880      Redraw$="N"
17890      Flag=3
17900      CALL Graph
17910      SUBEXIT
17920 Dump_it: PRINTER IS 0
17930          PRINT CHR$(27)&"&100T"
17940          DUMP GRAPHICS
17950          PRINT CHR$(27)&"&136T"
17960          PRINTER IS 16
17970          RETURN
17980 Yhard: Flag$="1"
17990          PRINTER IS 0
18000          RETURN
18010      SUBEXIT
18020 SUB Binary_search(X,Y)
18030     OPTION BASE 0
18040     !
18050     COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Rho1,Trho1,Rho2,Trho2
18060     COM F,Z3,Z4,Norm,Theta1,Tdelta
18070     COM Date$,Plot$,Family$,Chart$,Main$,Main$,Flag$,Y_hards
18080     !
18090     COM Stuff$,Redraw$,Digitizes,Ray_traces
18100     COM INTEGER I,J,Y0_loop,Nray,Nray_chart,Nray_family,Nray_stuff
18110     COM INTEGER Nray_trace,Nray_density,Add_ray,Nc,Ns,Nbeta,Flag
18120     !
18130     COM INTEGER Line_count,Line_max,N_increment,Hit_total,Pselect,Hpib
18140     COM INTEGER Family,Surf_no
18150     COM REAL Theta_critical,Tol,N1,N2,N3,Delta_ray,Y0,Ya,Yb,Aperture
18160     !
18170     COM Y_bullet,Smax_family,Percent_image
18180     COM XI(*),Y1(*),XC(*),X2(*),Y2(*),X2max(*),Y2max(*)
18190     COM Y3(*),Y4(*),Beta(*),S2(*),Xsurfm(*),Ysurfm(*)
18200     !
18210     COM Ga(*),Smax(*),Alpha2(*),Rho2(*),Hit(*)
18220     !
18230     !
18240     !      THIS ROUTINE FINDS THE INTERCEPT OF THE RAY WITH THE FOLLOWING:
18250     !
18260     !          1) FIRST SURFACE
18270     !          2) SECOND SURFACE
18280     !          3) FIRST IMAGE PLANE
18290     !          4) SECOND IMAGE PLANE
18300     !
18310     !
18320     DEG
18330     DEF FNA(X,Y)=X-Y/Trho2
18340     DEF FNA1(X,Y)=X-Y/Talpha
18350     DEF FNA(A)=A-Y_bullet/Trho1      ! FINDS THE INTERCEPT OF THE RAY AND Y=Y_0
18360     !
18370     !      Rh2=TAN(Rho2)      ! RHO2 MUST BE DECLARED ELSEWHERE

```

```

10370 IF Surf_no=4 THEN Four
10380 Xc(Y0_loop)=FNA(X,Y) ! FIND THE X-INTERCEPT OF RHO2
10390 Three: Dy=(Z3-X)*Trho2
10400 Y=Y+Dy
10410 X=Z3
10420 SUBEXIT
10430 Four: Dy=(Z4-X)*Trho2
10440 Y=Y+Dy
10450 X=Z4
10460 SUBEXIT
10470 SUB Graph
10480 OPTION BASE 0
10490 !
10500 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Rho1,Trho1,Rho2,Trho2
10510 COM F,Z3,Z4,Norm,Theta,Tdelta
10520 COM Dates,Plots,Families,Charts,Mains,Mainis,Flags,Y_hards
10530 !
10540 COM Stuffs,Redraus,Digitize$,Ray_traces$
10550 COM INTEGER I,J,Y0_loop,Nray,Nray_chart,Nray_family,Nray_stuff
10560 COM INTEGER Nray_trace,Nray_density,Add_ray,Nc,Ns,Nbeta,Flag
10570 !
10580 COM INTEGER Line_count,Line_max,N_increment,Hit_total,Pselect,Hprb
10590 COM INTEGER Family,Surf_no
10600 COM REAL Theta_critical,Tol,N1,N2,N3,Delta_ray,Y0,Ya,Yb,Aperture
10610 !
10620 COM Y_bullet,Smx_family,Percent_image
10630 COM X1(*),Y1(*),XC(*),X2(*),Y2(*),X2max(*),Y2max(*)
10640 COM Y3(*),Y4(*),Beta(*),S2(*),Xsurfmax(*),Ysurfmax(*)
10650 !
10660 COM Qa(*),Smx(*),Alpha2(*),Rho2(*),Hit(*)
10670 !
10680 ! THIS ROUTINE DRAWS THE GLM FOR STUFF AND RAY_TRACE SUBROUTINES
10690 ! AND DIGITIZES THE IMAGE PLANE POSITION (Z3)
10700 !
10710 !
10720 DEG
10730 IF Flag=3 THEN Wait1
10740 IF (Digitize$="Y") OR (Digitize$="y") THEN Digit
10750 Draw_axes: CALL Plot
10760 First_surf: FIXED 2
10770 LINE TYPE 0
10780 MOVE 0,0
10790 X=Y_bullet/Talpha
10800 DRAW X,Y_bullet
10810 DRAW 100,Y_bullet
10820 MOVE 0,0
10830 DRAW X,-Y_bullet
10840 DRAW 100,-Y_bullet
10850 X2pos: MOVE X2(1),Y2(1)
10860 FOR I=2 TO Nray_stuff
10870 DRAW X2(I),Y2(I)
10880 NEXT I
10890 X2neg: MOVE X2(1),-Y2(1)
10900 FOR I=2 TO Nray_stuff
10910 DRAW X2(I),-Y2(I)
10920 NEXT I
10930 EXIT GRAPHICS
10940 Ys="N"
10950 INPUT "DO YOU WANT A HARD COPY OF THE PLOT WITHOUT RAYS ? Y/N",Ys
10960 IF (Ys="Y") OR (Ys="y") THEN GOSUB Dump_it
10970 GRAPHICS
10980 IF (Redraus="Y") OR (Redraus="y") THEN Second_image
10990 First_image: LINE TYPE 5
19000 MOVE Z3,Y_bullet
19010 DRAW Z3,-Y_bullet
19020 Second_image: LINE TYPE 6

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19030             MOVE Z4,Y_bullet
19040             DRAW Z4,-Y_bullet
19050 REM DRAW THE RAYS
19060 IF (Ray_traces="Y") OR (Ray_traces="y") THEN Nray_graph=Nray_trace
19070 IF (Stuffs="Y") OR (Stuffs="y") THEN Nray_graph=Nray_stuff
19080 First_: LINE TYPE 1
19090 CLIP 0,100,-Y_bullet,Y_bullet
19100 FOR I=1 TO Nray_graph
19110     MOVE 0,Y1(I)
19120     DRAW X1(I),Y1(I)
19130 NEXT I
19140 Second_: FOR I=1 TO Nray_graph
19150     MOVE X1(I),Y1(I)
19160     DRAW X2(I),Y2(I)
19170 NEXT I
19180 First_image_p: FOR I=1 TO Nray_graph
19190     MOVE X2(I),Y2(I)
19200     DRAW Z3,Y3(I)
19210 NEXT I
19220 Decision: WAIT 2000
19230 EXIT GRAPHICS
19240 BEEP
19250 Ys="N"
19260 INPUT "DO YOU WANT TO PLOT TO THE SECOND IMAGE PLANE ? Y/N",Ys
19270 GRAPHICS
19280 IF (Ys="N") OR (Ys="n") THEN Wait1
19290 Second_image_p: FOR I=1 TO Nray_graph
19300     MOVE Z3,Y3(I)
19310     DRAW Z4,Y4(I)
19320 NEXT I
19330 Wait1: BEEP ! THIS ROUTINE PRESENTS THE PLOT TO THE OPERATOR
19340 WAIT 250 ! IF A NOTE TO THE OPERATOR IS DESIRED, ENTER SETGU,LOG 2
19350 BEEP ! MOVE 2,2,CSIZE 2.5,LABEL "PRESS CONT",CSIZE 15/4.54,
19360 PAUSE ! SETUU AFTER THE SECOND BEEP
19370 EXIT GRAPHICS
19380 IF (Flag=0) OR (Flag=3) THEN EXIT GRAPHICS
19390 SUBEXIT
19400 Digit: GRAPHICS ! THIS ROUTINE CHANGES THE ANALOG POSITION
19410 POINTER F,0 ! OF THE IMAGE PLANE ON THE GRAPHICS DEVICE
19420 DIGITIZE Z3,Y ! TO DIGITAL DATA FOR PROCESSING
19430 LINE TYPE 5
19440 MOVE Z3,Y_bullet
19450 DRAW Z3,-Y_bullet
19460 SETGU
19470 LDIR 0
19480 LINE TYPE 1
19490 LOG 5
19500 CSIZE 2.5
19510 Centerx=72.5 ! CHANGE IN LAXES AS WELL
19520 MOVE 1.5*Centerx,2
19530 LABEL USING 19540;Z3
19540 IMAGE "Image Plane : ",DD.DD," inch"
19550 SETUU
19560 CSIZE 15/4.54
19570 WAIT 2500
19580 EXIT GRAPHICS
19590 SUBEXIT
19600 Dump_it: PRINTER IS 0
19610 PRINT CHR$(27)&"&100T"
19620 DUMP GRAPHICS
19630 PRINT CHR$(27)&"&136T"
19640 PRINTER IS 16
19650 RETURN
19660 SUBEND
19670 SUB Xineg(X,Y)
19680 OPTION BASE 0
19690 !

```

```

19700 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Rho1,Trho1,Rho2,F,Z3,Z4
19710 |
19720 DEG
19730 Alphan=-1*Alpha
19740 Talpha=TAN(Alphan)
19750 DEF FNY(Y)=Y*Talpha/(Talpha-Trho) ! FINDS THE Y-VALUE OF THE INTERCEPT
19760 | ! OF THE RAY AND THE FIRST SURFACE
19770 DEF FNX(Y)=Y/Talpha ! FINDS THE X-VALUE OF THE INTERCEPT OF THE RAY
19780 | ! AND THE FIRST SURFACE
19790 Y=FNY(Y)
19800 Whoops=X=FNX(Y)
19810 SUBEND
19820 SUB Density
19830 OPTION BASE 0
19840 |
19850 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Rho1,Trho1,Rho2,Trho2
19860 COM F,Z3,Z4,Norm,Theta1,Tdelta
19870 COM Dates,Plots,Families,Charts,Mains,Mainis,Flags,Y_hands
19880 |
19890 COM Stuffs,Redraws,Digitizes,Ray_traces
19900 COM INTEGER I,J,Y0_loop,Nray,Nray_chart,Nray_family,Nray_stuff
19910 COM INTEGER Nray_trace,Nray_density,Add_ray,Nc,Ns,Nbeta,Flag
19920 |
19930 COM INTEGER Line_count,Line_max,N_increment,Hit_total,Pselect,Hpib
19940 COM INTEGER Family,Surf_no
19950 COM REAL Theta_critical,Tol,N1,N2,N3,Delta_ray,Y0,Ya,Yb,Aperture
19960 |
19970 COM Y_bullet,Smax_family,Percent_image
19980 COM XI(*),Y1(*),XC(*),X2(*),Y2(*),X2max(*),Y2max(*)
19990 COM Y3(*),Y4(*),Beta(*),S2(*),Xsurfmax(*),Ysurfmax(*)
20000 |
20010 COM Qa(*),Smax(*),Alpha2(*),Rho2(*),Hit(*)
20020 |
20030 INTEGER Inc,K,L,M,Lines
20040 |
20050 DEG
20060 | THIS ROUTINE COMPUTES THE RAY DENSITY IN ONE DIMENSION.
20070 | ASSUMPTIONS:
20080 | 1) THE POINT OF MAXIMUM RAY DENSITY HAS BEEN FOUND VIA A
20090 | DIGITIZE STATEMENT.
20100 | 2) THE VALUES OF Y3 HAVE NOT BEEN CHANGED TO REFLECT THE
20110 | NEW VALUE OF Z3
20120 |
20130 PRINTER IS 16
20140 Nray_density=Nray_stuff
20150 Re_draw: FOR I=1 TO Nray_density ! RECOMPUTE THE VALUE OF Y3
20160 | A=Xc(I)
20170 | X=X2(I)
20180 | Y=Y2(I)
20190 | Rho2=Rho2(I)
20200 | Trho2=TAN(Rho2)
20210 Same: | Deltay=(Z3-X)*Trho2
20220 | Y3=Y+Deltay
20230 | Y3(I)=Y3
20240 | Deltay=(Z4-Z3)*Trho2
20250 | Y4(I)=Y3(I)+Deltay
20260 Next_i: NEXT I
20270 Hit_zero: MAT Hit=ZER(2001) ! ZERO THE ARRAY
20280 | Inc=0 ! FIND THE NO. OF HITS IN THE INTERVAL
20290 | Ylast=-Y_bullet ! [-Y_BULLET, -Y_BULLET+DELTA/2]
20300 | Delta=Y_bullet/N_increment
20310 | Ynext=Ylast+Delta/2
20320 | Hit(Inc)=0
20330 | FOR I=1 TO Nray_density
20340 | IF (Y3(I))>Ylast) AND (Y3(I)<Ynext) THEN Hit(Inc)=Hit(Inc)+1
20350 | NEXT I
20360 Hit_middle: ! FIND THE NO. OF HITS IN THE INTERVAL

```

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20370                                     ! [-Y_bullet+DELTA/2, Y_bullet-DELTA/2]
20380     FOR L=1 TO 2*N_increment-1
20390         Inc=Inc+1
20400         Hit(Inc)=0
20410         Ylast=Ynext
20420         Ynext=Ylast+Delta
20430         FOR I=1 TO Nray_density
20440             IF (Y3(I)>=Ylast) AND (Y3(I)<Ynext) THEN Hit(Inc)=Hit(In
c)+1
20450         NEXT I
20460     NEXT L
20470 Hit_last: Inc=2*N_increment     ! FIND THE No. OF HITS IN THE LAST INTERVAL
20480     Hit(Inc)=0                   ! [Y_bullet-DELTA/2, Y_bullet]
20490     Ylast=Y_bullet-Delta/2
20500     Ynext=Y_bullet
20510     FOR I=1 TO Nray_density
20520         IF (Y3(I)>=Ylast) AND (Y3(I)<=Ynext) THEN Hit(Inc)=Hit(Inc)+1
20530     NEXT I
20540 Normalize: Hit_total=0          ! NORMALIZE THE No. OF HITS ON THE
20550     FOR I=0 TO 2*N_increment     ! IMAGE PLANE (23) TO THE TOTAL
20560         Hit_total=Hit_total+Hit(I) ! No. OF HITS
20570     NEXT I
20580     !
20590     IF Hit_total=0 THEN None
20600     FOR I=0 TO 2*N_increment
20610         Hit(I)=Hit(I)/Hit_total
20620     NEXT I
20630 None: Pct=Hit_total/Nray_density ! % OF RAYS THAT ARRIVE AT THE
20640     Percent_image=Pct*100         ! IMAGE PLANE
20650 Graph: CALL Plot                ! PLOT AND LABEL THE AXES
20660     IF Hit_total=0 THEN Label_
20670 First_bar: Xlast=-Y_bullet      ! DRAW THE HISTOGRAM
20680     Xnext=Xlast+Delta/2 ! INTERVAL [-Y_bullet, -Y_bullet+DELTA/2]
20690     Inc=0
20700     IF Hit(Inc)=0 THEN Middle_bars
20710     CLIP Xlast,Xnext,0,Hit(Inc)
20720     FRAME
20730     GOSUB Delt
20740 Middle_bars: FOR I=1 TO 2*N_increment-1 ! INTERVAL
20750     Inc=Inc+1                     ! [-Y_bullet+DELTA/2, Y_bullet-DELTA/2]
20760     Xlast=Xnext
20770     Xnext=Xlast+Delta
20780     IF Hit(Inc)=0 THEN Next_i_0
20790     CLIP Xlast,Xnext,0,Hit(Inc)
20800     FRAME
20810     GOSUB Delt
20820 Next_i_0: NEXT I
20830 Last_bar: Inc=2*N_increment     ! INTERVAL [Y_bullet-DELTA/2, Y_bullet]
20840     Xlast=Y_bullet-Delta/2
20850     Xnext=Y_bullet
20860     IF Hit(Inc)=0 THEN Label_
20870     CLIP Xlast,Xnext,0,Hit(Inc)
20880     FRAME
20890     GOSUB Delt
20900 Label_: Digitize$="N"
20910     Flag=3
20920     CALL Graph
20930     SUBEXIT
20940 Delt: Lines=10
20950     Delt=(Xnext-Xlast)/Lines
20960     X=Xlast-Delt
20970     FOR J=1 TO Lines
20980         X=X+Delt
20990         MOVE X,0
21000         DRAW X,Hit(Inc)
21010     NEXT J
21020     RETURN

```

```

21030 SUBEND
21040 SUB Min(Xm(*),X,INTEGER M)
21050 OPTION BASE 0
21060 !
21070 DIM Xm(M)
21080 !
21090 ! THIS ROUTINE FINDS THE MINIMUM ELEMENT IN A ONE DIMENSIONAL ARRAY
21100 !
21110 X=Xm(0)
21120 FOR I=1 TO M
21130 X=Min(X,Xm(I))
21140 NEXT I
21150 SUBEND
21160 SUB Max(Xm(*),X,INTEGER M)
21170 OPTION BASE 0
21180 !
21190 DIM Xm(M)
21200 !
21210 ! THIS ROUTINE FINDS THE MAXIMUM ELEMENT IN A ONE DIMENSIONAL ARRAY
21220 !
21230 X=Xm(0)
21240 FOR I=1 TO M
21250 X=MAX(X,Xm(I))
21260 NEXT I
21270 SUBEND

```

APPENDIX B

TRACE PROGRAM DESCRIPTION AND PROGRAM LISTING

TRACE was the first program written for this thesis. TRACE was written for the purpose of automating the task of drawing the ray diagram produced when tracing rays through a conical lens with various second surfaces. The program consists of a set of subroutines called from a control program which are designed to perform a specific task(s). A detailed description of each subroutine will not be given because TRACE has extensive documentation included within the program. However, an abbreviated discussion of the geometric relationships at the first and second surfaces and the bisection routine in subroutine BINARY SEARCH follows.

TRACE occupies approximately 145 Kbytes of memory which is approximately 77% of available memory (11). A listing of TRACE is at the end of this appendix.

TRACE was designed to calculate the trajectory of up to 250 rays incident upon the first surface in the upper half-plane as illustrated in figure B-1. All of the parameters shown in figure B-1 are provided by the operator except Z4, the location of the permanent Image plane, which is set for $Z4 = 50$ inches. All of the parameter values provided by the operator have default values declared either in subroutine DIALOGUE, line number 13810 or the MAIN routine, line number 10.

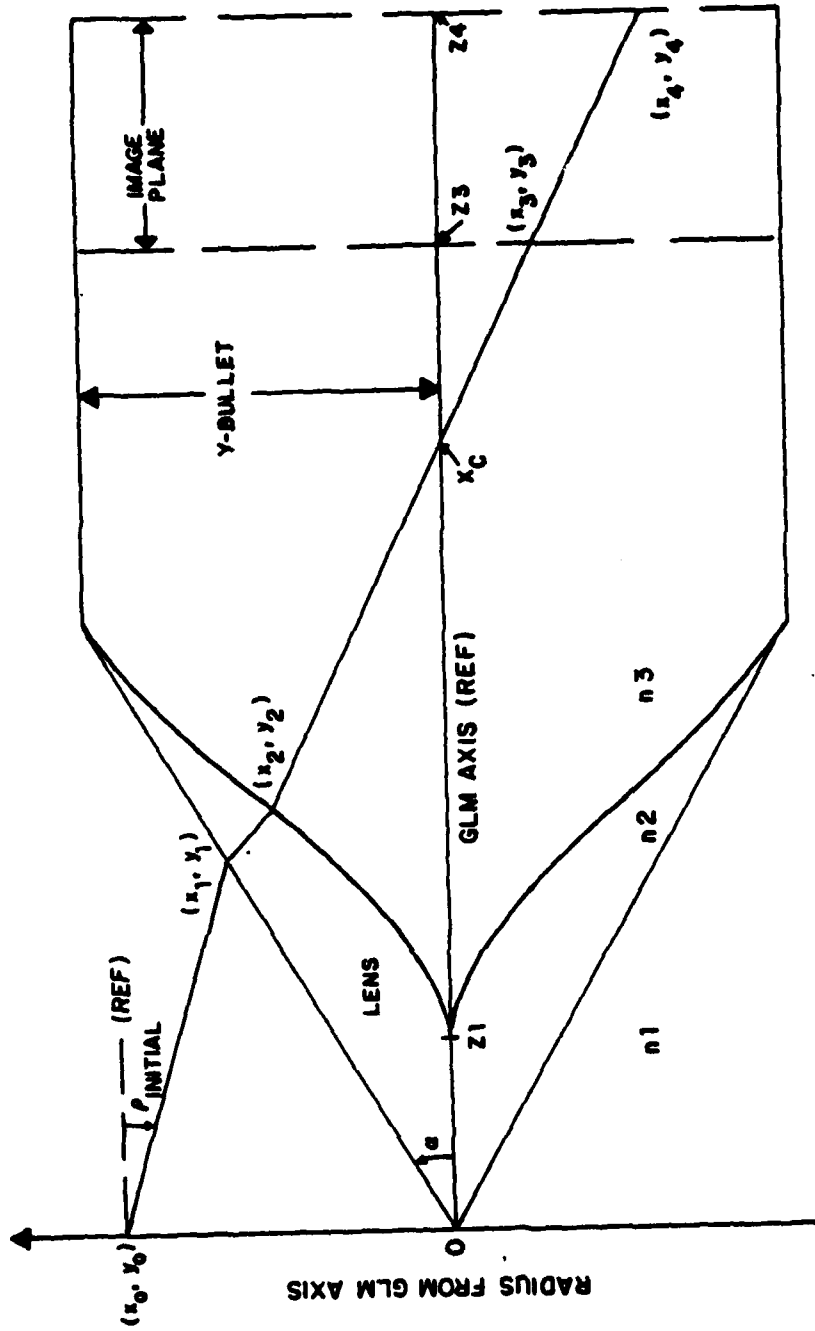


Figure B-1. Symbol Definition for the GLM.

TRACE calculates the complete trajectory of each ray before proceeding to the next ray. Each surface is assigned a number with the vertical axis, y , defined as the zeroth surface. All incident rays originate on the y -axis and are assumed to be parallel with the source at infinity. The first surface shown in figure B-2 encountered is the exterior of the conical spike which, in two dimensions, is a plane perpendicular to the meridional plane, the paper, with a cone half-angle α . The incident angle makes an angle of incidence θ_I with the first surface normal \hat{n} at point T according to

$$\theta_I = \frac{\pi}{2} (\alpha + |\rho_I|)$$

Noting that $\alpha = \alpha_2$, $\rho_R = |\text{NORM}| - \theta_R$, $\text{NORM} = \alpha_2 - \frac{\pi}{2}$ (B-1)

and applying Snell's Law $\sin\theta_R = (n_1/n_2)\sin\theta_I$ (B-2) yields

$$\rho_R = \alpha_2 + \theta_R - \frac{\pi}{2}$$

the ray angle in the lens referred to as ρ_1 in chapter III and Appendix F. As the incident ray angle ρ_I increases the angle of incidence θ_I decreases to zero when the incident causing θ_I to transition through the normal as shown in figure B-3, subroutine SNELL in TRACE detects this transition as a change in sign in θ_I . Snell's Law is defined with all arguments positive. Therefore the magnitude of θ_I is used to determine θ_R and thus ρ_R according to $\sin\theta_R = (n_2/n_1)\sin\theta_I$ yielding

$$\theta_R = \alpha_2 + \theta_R - \frac{\pi}{2} \quad (\text{B-3})$$

which is the same result for $\theta_I > 0$.

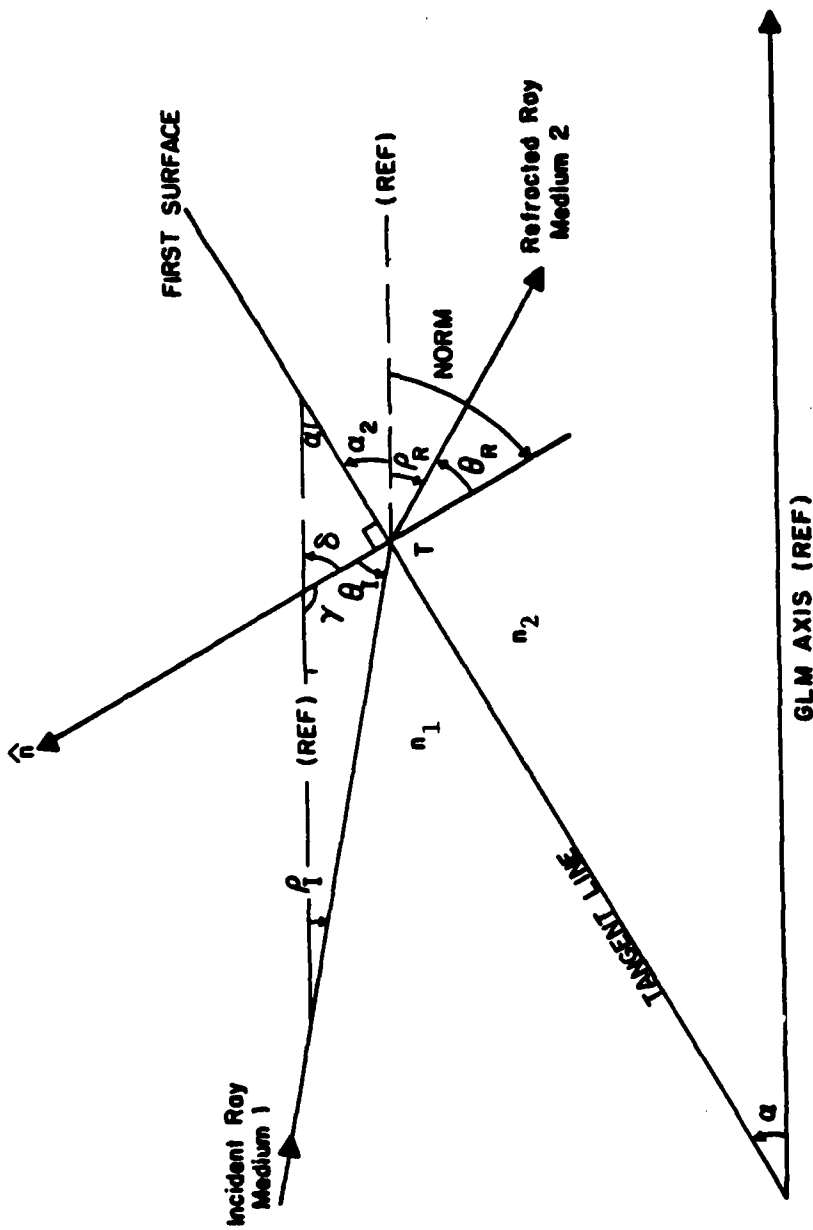


Figure B-2. Geometry and Symbol Definition for the Application of Snell's Law at the First Surface of the Conical Lens.

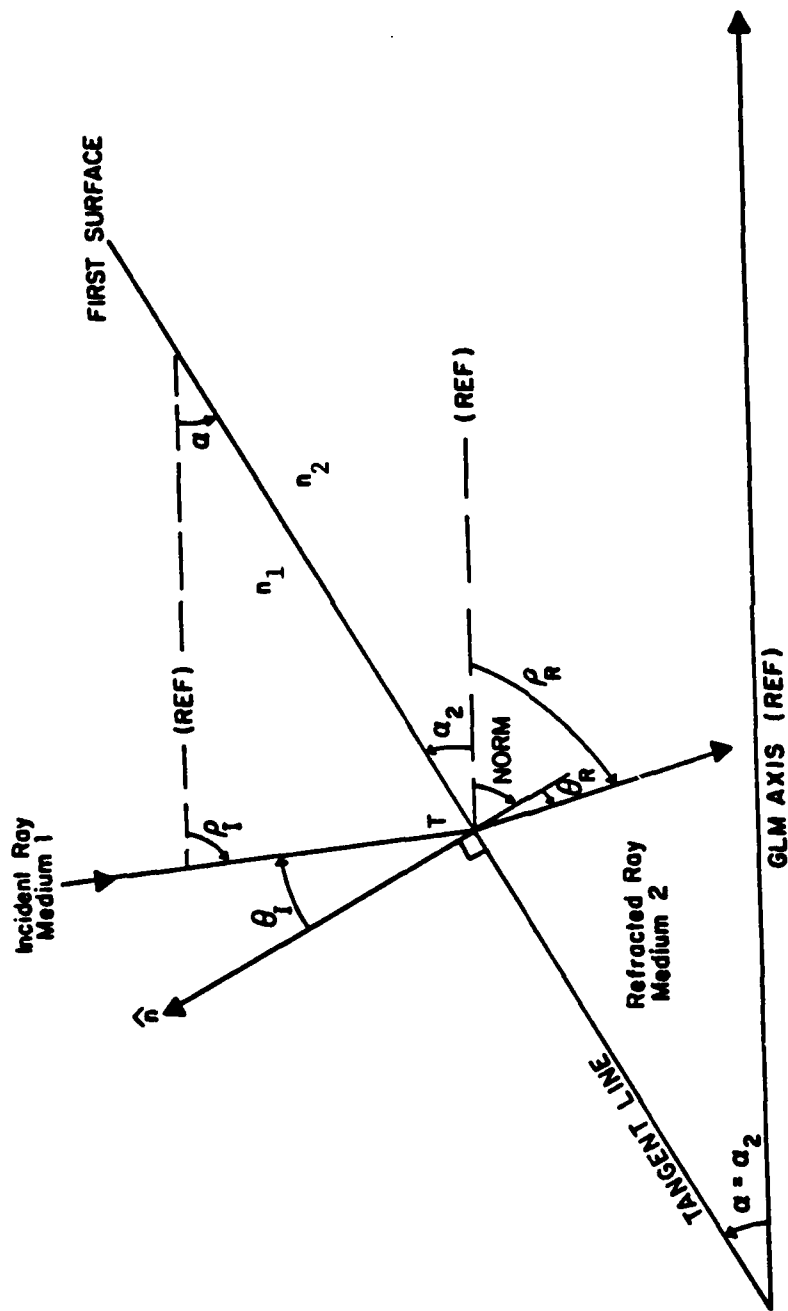


Figure B-3. Geometry and Symbol Definition for the Application of Snell's Law at the First Surface of the Conical Lens for $\theta_I < 0$.

C The application of Snell's Law at the second surface of the lens is very similar to the first surface. The geometry for $\theta_I > 0$ is shown in figure B-4 and for $\theta_I < 0$ in figure B-5. Some of the rays inside the lens may intercept the GLM axis at $x < z_1$ and therefore may intercept the branch of the second surface in the lower half-plane. The geometry for this case is shown in figure B-6. A significant difference between rays intercepting the positive and negative branches of the second surface is the definition of the normal direction \hat{n} . In figures B-4 and B-5 the direction of \hat{n} is into the lens where in figure B-6, \hat{n} is defined to be out of the lens. Practically, this contradiction in definition has no effect on TRACE because the angle of the normal used in applying Snell's Law has always been the acute angle as labeled in all of the figures. The direction of \hat{n} in figure B-6 was changed to reflect the change in sign of NORM.

The search for and calculation of the intercept of the ray refracted at the first surface and the second surface is accomplished in subroutine BINARY SEARCH. The primary method used is the bisection method illustrated in figure B-7. The bisection method can only be applied where the ray in the lens is known to intercept the second surface of the lens. Examples of rays which do not intercept the second surface are shown in figures C-2, C-5 and C-10. The method used for the rays which do not intercept the second surface is discussed later.

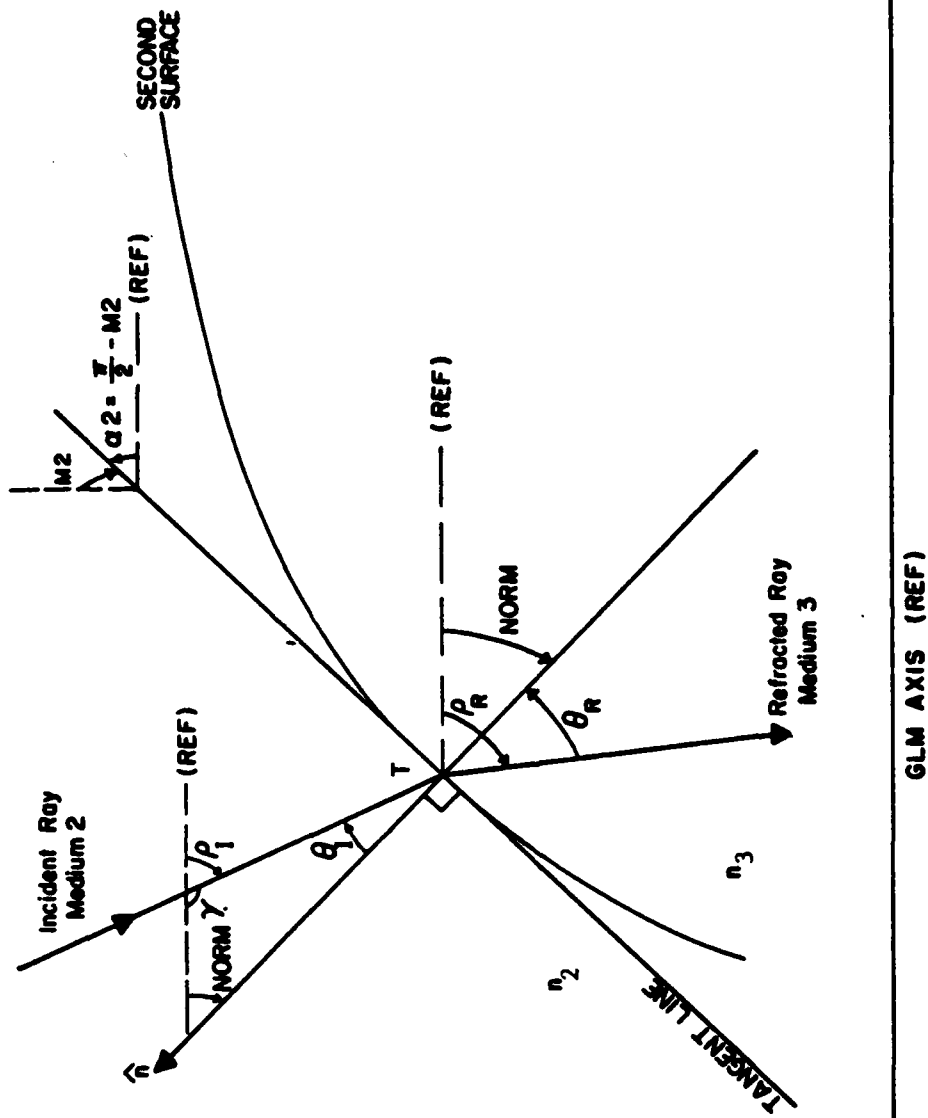


Figure B-4. Geometry and Symbol Definition for the Application of Snell's Law at the Positive Branch of the Second Surface of the Conical Lens.

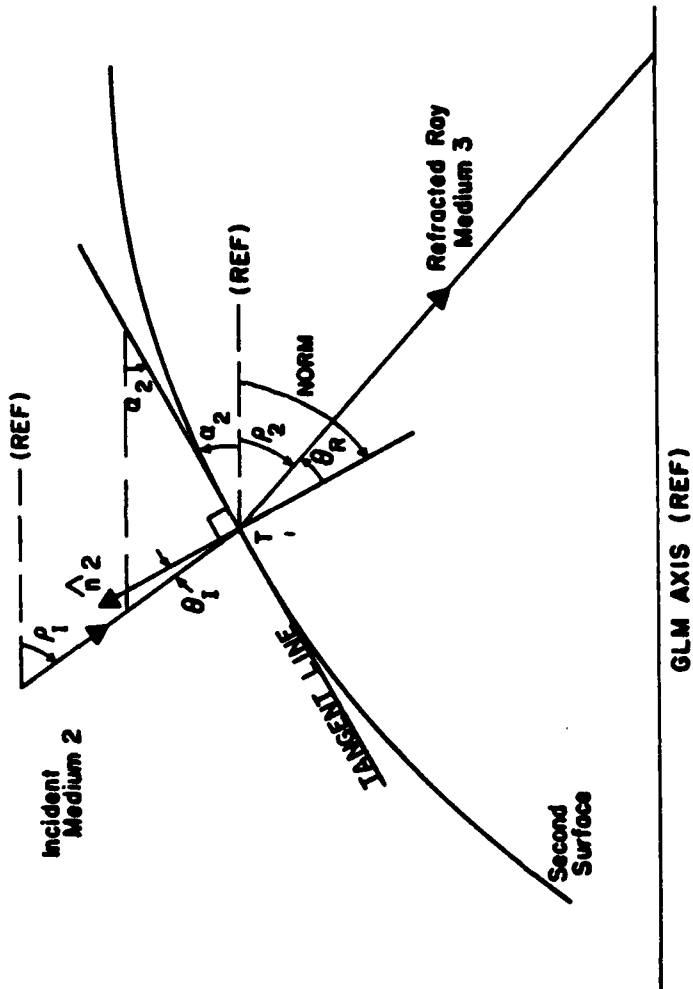


Figure B-5. Geometry and Symbol Definition for the Application of Snell's Law at the Positive Branch of the Second Surface of the Conical Lens and $\theta_I < 0$.

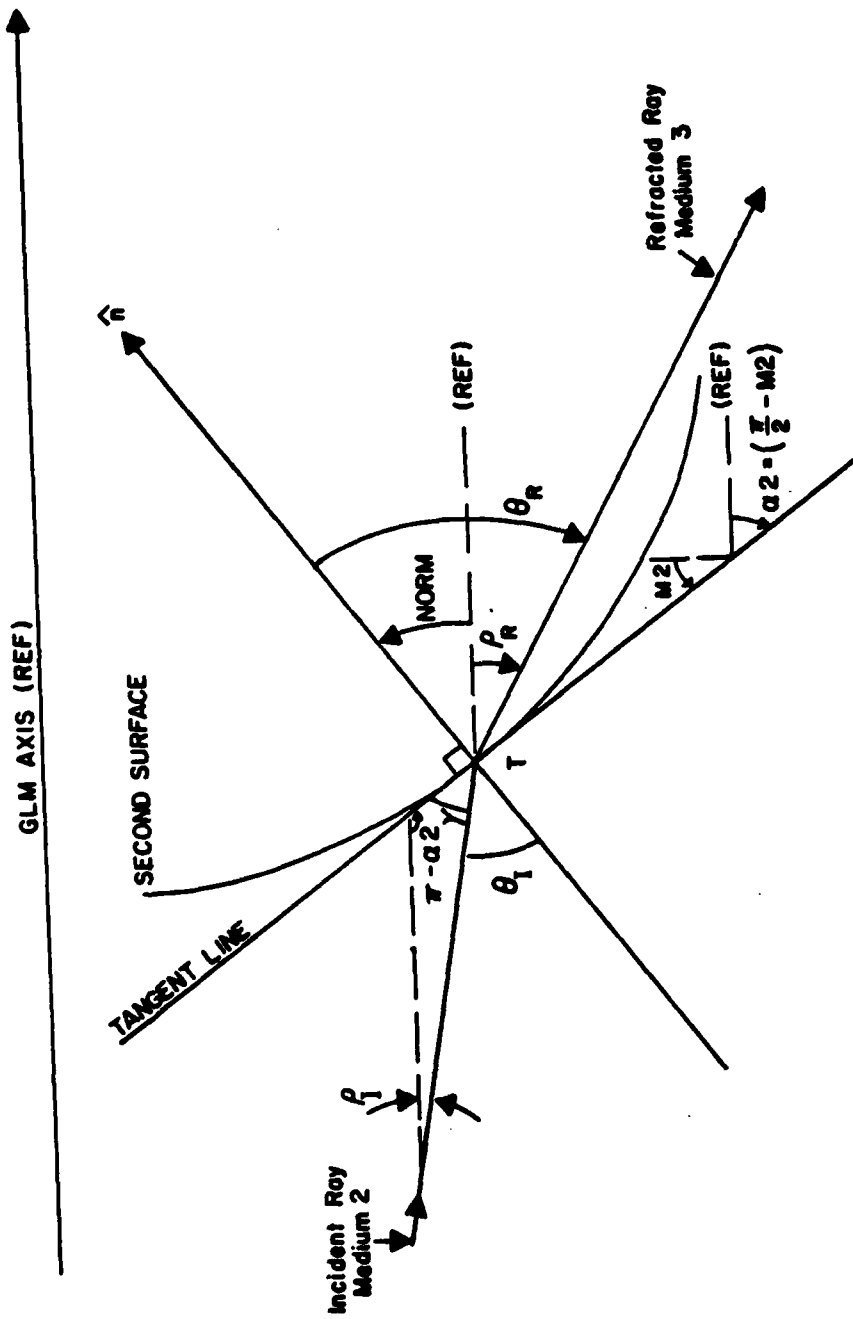


Figure B-6. Geometry and Symbol Definition for the Application of Snell's Law at Negative Branch of the Second Surface of the Conical lens.

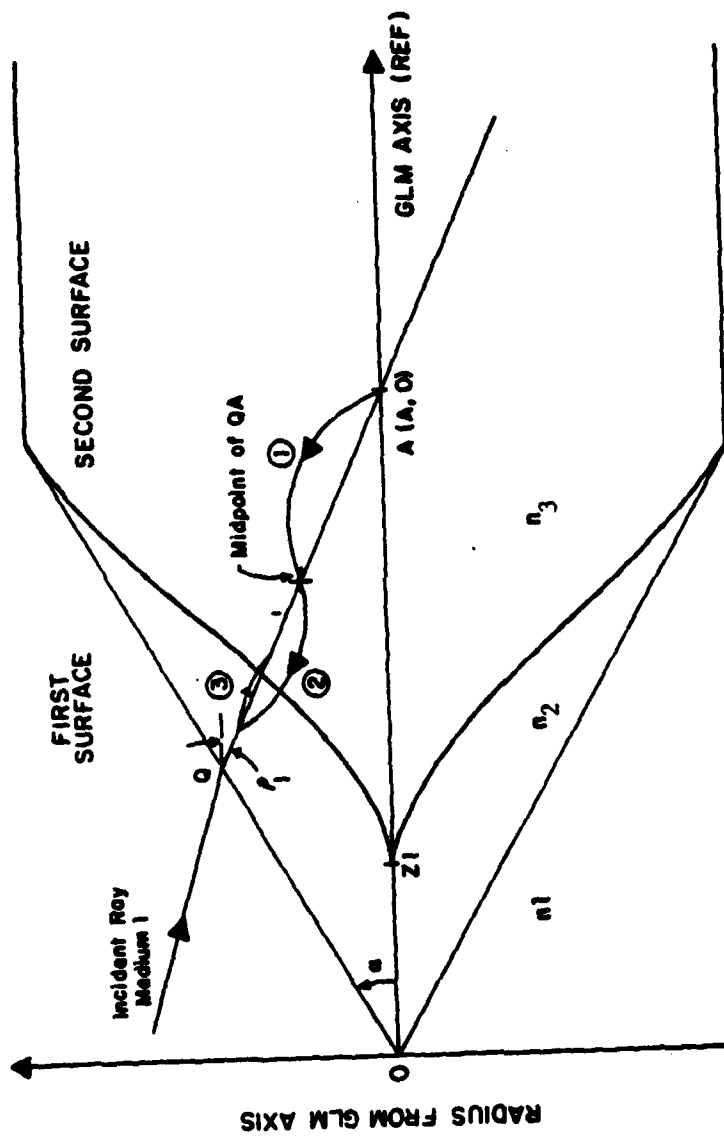


Figure B-7. Illustration of the Bisection Method Used in Subroutine BINARY SEARCH.

The bisection method converges to the intercept value quickly, especially if the ray is nearly normal to the second surface. The sequence of events is depicted in figure B-7 by the circled numbers 1, 2, etc. Assuming ρ_1 is known, the intercept of the GLM axis, A, of the ray in the lens is found. The first step in the bisection sequence, 1 is to find the midpoint of QA. The midpoint of QA, (x_{mid}, y_{mid}) is calculated under label Recurse p, line 7440 of TRACE. The midpoint is then compared to the value of the second surface at $y=y_{mid}$. The midpoint in figure B-7 is behind the second surface. Step 2 finds one midpoint of the line segment from Q to the midpoint of QA. A comparison is again made with the second surface. Now, the present location is ahead of the second surface. Step 3 is executed and the location is again compared with the second surface. The process continues until the difference between the present location on the ray (x_{mid}, y_{mid}) and the true value of the intercept (x_2, y_{mid}) , $|x_{mid}-x_2|$ is less than a specified tolerance, $tol = 10^{-5}$. Once the intercept of the ray and the second surface has been found then go to label Done, line 8140, to define the (x, y) coordinates of the intercept. The x-coordinate is defined as the average of the present location on the ray, x_{mid} , and x_2 , the value of the second surface at $y=y_{mid}$.

The ray may pass ahead, shown by $A < Z1$, of the second surface. The test for $A < Z1$ is conducted in line 6860.

If the test is true a jump to line 7720 is performed. A test is conducted in line 7870 to determine if the ray intercepts the negative branch of the second surface. If the test is true then a jump to line 8080 is made to prepare to enter the bisection method for the negative branch, which is identical to the method for the positive branch described above. The test performed in line 7870 will not detect a ray that is just tangent to the second surface. The slow march method, lines 7840 to 8000, is employed to search and find the intercept $(A, 0)$ and marches down the ray until the second surface intercept is found within the tolerance, or the wall of the GLM, $y = -Y_{\text{bullet}}$ is reached. If $y = -Y_{\text{bullet}}$ then the march is terminated and a jump to line 8250 via 8150 is made to exit the subroutine.

A special case exists when $\theta_I < 0$. The ray in the lens could intercept the positive branch. A test is conducted in line 7010 to determine if the ray intercepts the positive branch. If the test is true a jump is made to line 7330 for entry into the bisection method. If the test fails then the marching method is used. The application of the marching method for this case is made from line 7100 to 7320.

Another special case exists when the polynomial used to describe the second surface causes the second surface to intercept the first surface at $|y| < Y_{\text{bullet}}$. The test for this case is conducted in line 7370 for the positive branch and line 7770 for the negative branch. If the test

is true, then a jump is made to line 8280 and the subroutine is exited.

The "success" of a conical lens is whether light rays can be focused to a point. Success is determined two ways. The first is the ray diagram; compare figures 14, 22, C-2, C-10 and C-16 for the ability of each lens to focus light rays. The second method is by a histogram of the ray distribution on the image plane. The desired histogram is a delta function at the origin as shown in figures 15 and 23. Undesirable histograms are shown in figures C-3, C-7, C-13, C-14 and C-17. The histogram is calculated by dividing the image plane in the upper half-plane into an even number of intervals equal to $N_{\text{increment}}$. The division of the image plane is also performed in the lower half plane as shown in figure B-8. The intervals are arranged such that the GLM axis is straddled by the center interval, thus adding a half-interval to each extremity of the image plane. Hence, the total number of intervals is then $2*N_{\text{increment}} + 1$. The generation of the histogram is executed in subroutine DENSITY, line 17920. The algorithm checks each interval for an intercept of a ray with the image plane in lines 18440 to 18820, DENSITY then normalizes the distribution to the number of hits on the image plane, not the total number of rays in lines 18830 to 18930. The percentage of the rays striking the image plane is calculated in lines 18920 and 18930 and displayed to the operator by subroutine LAXES in lines 12870 and 12880. The

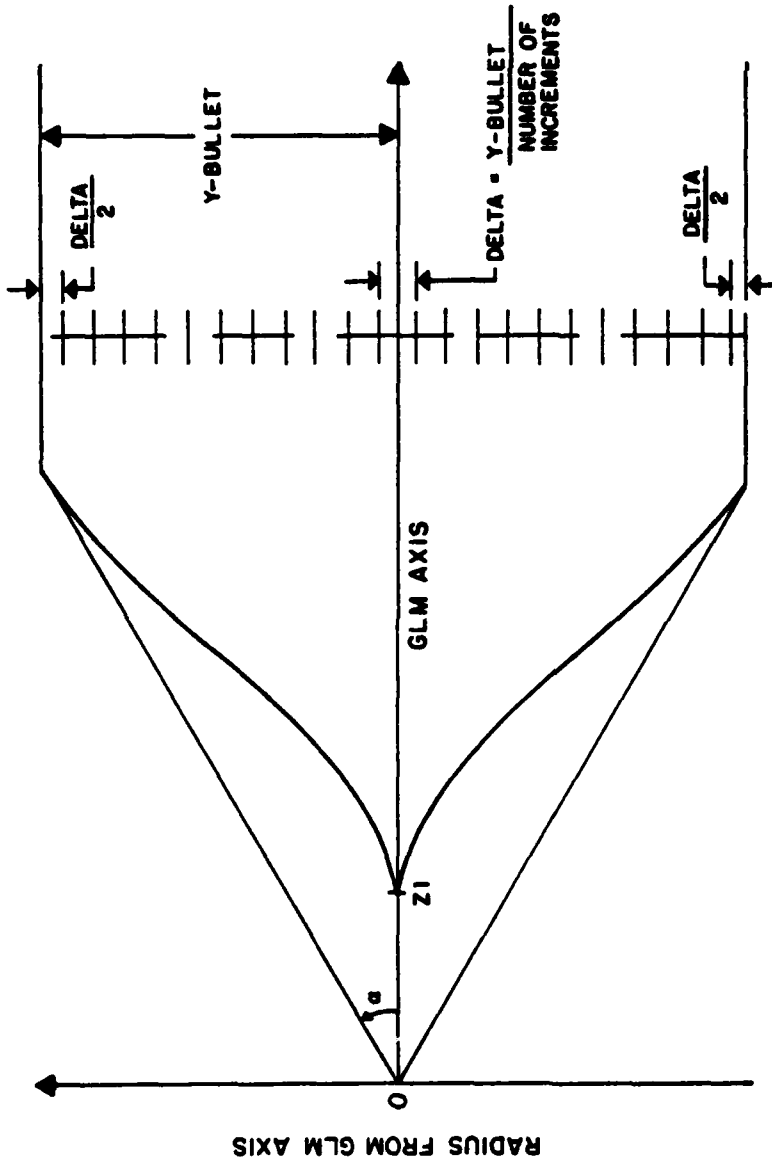


Figure B-8. Illustration of Dividing the Image Plane into a Set of N-Increment Intervals Used to Generate a Histogram of a Ray Diagram.

percentage label serves to remind the operator that the histogram represents the distribution of the rays actually striking the image plane within the boundaries of the GLM.

The subroutines in Table B-1 were copied or derived from the HP-9845B utilities library for use in TRACE.

TABLE B-I

SUBROUTINES DERIVED FROM THE HP-9845B UTILITIES LIBRARY

<u>Name</u>	<u>Line No.</u>
Main	18
Plot	10170
Laxes	11430
Dialogue	13810

TRACE PROGRAM LISTING

```

10 NORMAL
20 PRINTER IS 16
30 PRINT PAGE
40 FIXED 2
50 PRINT "*****"
60 PRINT "*"
70 PRINT "*"
80 PRINT "*"
90 PRINT "*****"
100 DISP "THIS IS TRACE"
110 WAIT 1500
120 Main:OPTION BASE 0
130 !
140 COM INTEGER I,J,Curve,Np,Nn,N,Ns,Nr,REAL Aneg(17),Apos(17),A(17),Z1,Z3,Z4
150 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Phi,Tol,Norm,Alpha2
160 COM N1,N2,N3,Percent_image,Ya,Yb,Aperture,Y_bullet
170 !
180 COM INTEGER Y0_loop,Nray,Add_ray,Surf_no,Flag,Flag2,N_increment,Hit_total
190 COM INTEGER Linecount,Line_max
200 COM INTEGER Pselect,Hpib
210 !
220 COM REAL Nmin,Nmax,R0_max
230 COM Ray_traces,Digitizes,Grins,Gs,Grincs,Plots,Dates
240 COM X(1250),Y(1250),Xc(250),N(250),R(250)
250 !
260 COM Rho(750),Phi(250),C(250),Y3(250),Hit(2001)
270 !
280 INTEGER Zz,Char_max
290 DISP ""
300 OVERLAP ! SEE THE 9845 OPERATING AND PROGRAMMING MANUAL
310 CALL Dialogue
320 DEG
330 Comments: ! FLAGS ARE USED THROUGHOUT THE PROGRAM TO INDICATE VARIOUS
340 ! CONDITIONS WHICH INFLUENCE THE BEHAVIOR AND TREATMENT OF THE
350 ! LIGHT RAY AS IT PASSES THROUGH THE LENS SYSTEM. THE EXPLANATION
360 ! OF FLAGS USED IN THE GENERATION OF THE RAY DIAGRAMS
370 ! AND THE DECLARATION LOCATION IS GIVEN BELOW:
380 !
390 ! FLAG :
400 ! 1) 0 => DECLARED IN MAIN AND BINARY SEARCH
410 ! RESET CONDITION
420 ! 2) 1 => DECLARED IN BINARY SEARCH
430 ! RAY INTERCEPTS THE NEGATIVE BRANCH
440 ! 3) 5 => DECLARED IN SNELL
450 ! Theta I < 0 DEGREES
460 ! 4) 10 => DECLARED IN SNELL
470 ! TOTAL INTERNAL REFLECTION
480 ! 5) 15 => DECLARE IN SNELL
490 ! THE RAY LEAVES THE SECOND SURFACE WITH
500 ! ABS(RHO) >= 90 DEGREES (THE RAY WILL NOT INTERCEP
510 ! THE IMAGE PLANE)
520 ! 6) 20 => DECLARED IN BINARY SEARCH
530 ! THE RAY MISSES BOTH THE POSITIVE AND NEGATIVE
540 ! BRANCHES FOR ThetaI > OR < 0 DEGREES
550 ! 7) 30 => DECLARED IN BINARY SEARCH
560 ! THE SECOND SURFACE BENDS AROUND AND CROSSES THE
570 ! FIRST SURFACE
580 !
590 !
600 ! Flag2 :
610 ! 1) 0 => DECLARED IN MAIN AND BINARY SEARCH
620 ! RESET CONDITION
630 ! 2) 1 => DECLARED IN BINARY SEARCH
640 ! THE RAY INTERCEPTS THE NEGATIVE BRANCH
650 !
660 ! NOTE: THESE ARE NOT ALL OF THE FLAGS, JUST THE ONES AFFECTING

```

```

670          1      RAYS.
680          1
690 Gyanastics:  Y_hards="N"
700              Flag2s="1"
710              INPUT "DO YOU WANT A HARD COPY OF THE COMPUTED DATA? Y/N",Y_ha
720              rd$
730              IF (Y_hards="N") OR (Y_hards="n") THEN Flag2s="0"
740              GOSUB Yhard
750              GOSUB Printer
760              BEEP
770              PAUSE
780              IF (Gs="Y") OR (Gs="y") THEN GOSUB Header_grin
790              IF (Gs="Y") OR (Gs="y") THEN Initialize_run
800              Y_hards="N"
810              INPUT "DO YOU WANT A HARD COPY OF THE COEFICIENTS PRINTED ? Y/
N",Y_hards
820              IF (Y_hards="N") OR (Y_hards="n") THEN 1000
830              GOSUB Yhard
840              GOSUB Header_coef
850              FOR I=0 TO Np
860              IF Linecount>Linemax THEN GOSUB Header_coef
870              PRINT USING Image_p;I,Apos(I)
880              Linecount=Linecount+1
890              NEXT I
900              IF Linecount>Linemax THEN GOSUB Header_coef
910              PRINT
920              Linecount=Linecount+1
930              FOR I=0 TO Nn
940              IF Linecount>Linemax THEN GOSUB Header_coef
950              PRINT USING Image_n;I,Aneg(I)
960              Linecount=Linecount+1
970              NEXT I
980 Image_p:      IMAGE 25X,"Apos("DD") = ",K
990 Image_n:      IMAGE 25X,"Aneg("DD") = ",K
1000             GOSUB Header_coef_end
1010             PRINT LIN(2),"PRESS CONT"
1020             PAUSE
1030             IF Flag2s="1" THEN Y_hards="Y"
1040             GOSUB Yhard
1050             GOSUB Header
1060 Initialize_run:Surf_no=0
1070             Z1=Apos(0)
1080             IF (Gs="Y") OR (Gs="y") THEN Z3=15
1090             Y0_min=Ya*(Talpha-Trhoi)/Talpha
1100             Y0_max=Yb*(Talpha-Trhoi)/Talpha
1110             Xnray=Nray      ! TO KEEP FROM USIN MIXED MODE ARITHMETIC
1120             Dely=(Y0_max-Y0_min)/Xnray
1130             Y0_min=Y0_min-Dely
1140             IF Ya=0 THEN Y0_min=Y0_min+Dely
1150             Nray=Nray+Add_ray
1160             Ns=-1           ! COUNTERS
1170             Nr=-1
1180             Xc(0)=0
1190             N(0)=0
1200             Phi(0)=0
1210             C(0)=0
1220 Y0_loop:     FOR Y0_loop=1 TO Nray
1230             Flag=0         ! RESET FLAG
1240             Flag_2=0
1250             X=0
1260             Rho=Rho_initial
1270             Trho=TAN(Rho)
1280             Xy0_loop=Y0_loop
1290             Y=Y0_min+Dely*Xy0_loop
1300             Ns=Ns+1
1310             Nr=Nr+1
1320             X(Ns)=X

```

```

1320         Y(Ns)=Y
1330         Rho(Nr)=Rho
1340 One: Surf_no=1
1350         Ns=Ns+1
1360         Nr=Nr+1
1370         CALL Binary_search(X,Y)
1380         X(Ns)=X
1390         Y(Ns)=Y
1400         CALL Snell(X,Y)
1410         Rho(Nr)=Rho
1420         IF (Gs="Y") OR (Gs="y") THEN Phi(Y0_loop)=Phi
1430 Two: Surf_no=2
1440         Ns=Ns+1
1450         Nr=Nr+1
1460         CALL Binary_search(X,Y)
1470         X(Ns)=X
1480         Y(Ns)=Y
1490         IF (Gs="Y") OR (Gs="y") THEN Blind
1500         IF Flag=20 THEN Blind
1510         IF Flag=30 THEN Flag_30
1520         CALL Snell(X,Y)
1530         Rho(Nr)=Rho
1540 Flag_15: IF Flag<>15 THEN Flag_10
1550         GOTO Blind
1560 Flag_10: IF Flag<>10 THEN Three      ! FLAG_30 WHEN FIXED
1570         Xc(Y0_loop)=0
1580         Rho(Nr)=0
1590         GOTO Blind
1600 Flag_30: IF Flag<>30 THEN Three
1610         Xc(Y0_loop)=0
1620         Rho(Nr)=0
1630         GOTO Blind
1640 Three: Surf_no=3      ! FIRST (MOVABLE) IMAGE PLANE
1650         Ns=Ns+1
1660         CALL Binary_search(X,Y)
1670         X(Ns)=X
1680         Y(Ns)=Y
1690 Four: Surf_no=4
1700         Ns=Ns+1
1710         CALL Binary_search(X,Y)
1720         X(Ns)=X
1730         Y(Ns)=Y
1740         GOTO Next_y0_loop
1750 Blind: Ns=Ns+1      ! THE RAY CROSSED AHEAD OF THE SECOND SURFACE
1760         X(Ns)=0      ! AND WAS NOT REFRACTED
1770         Y(Ns)=0
1780         Ns=Ns+1
1790         X(Ns)=0
1800         Y(Ns)=0
1810 Next_y0_loop: FIXED 2
1820         Nsp=Ns-1
1830         IF (Gs="Y") OR (Gs="y") THEN Print_grin
1840         IF Linecount>Linemax THEN GOSUB Header
1850         PRINT USING Image_data;X(Nsp-3);Y(Nsp-3);X(Nsp-2);Y(Nsp-2);X(
Nsp-1);Y(Nsp-1);Xc(Y0_loop);0;X(Nsp);Y(Nsp);Rho
1860         Linecount=Linecount+1
1870         GOTO Continue
1880 Print_grin: IF Linecount>Linemax THEN GOSUB Header_grin
1890         PRINT USING Image_data_g;X(Nsp-3);Y(Nsp-3);X(Nsp-2);Y(Nsp-2);X(
Nsp-1);Y(Nsp-1);Xc(Y0_loop);0;N(Y0_loop);Rho
1900         Linecount=Linecount+1
1910 Continue: NEXT Y0_loop
1920         !
1930         !
1940 Image_data: IMAGE X(2D.DD,X,DD.DD,3X),DD.DD,X,DD.DD,1X,6D.DD,X,D.DD,3X,3D.
DD,X,4D.DD,3X,4D.DD)
1950 Image_data: IMAGE D,2X,DD.DD,3X,DD.DD,2X,DD.DD,3X,DD.DD,2X,DDD.DD,3X,5D.2

```

```

D, 2X, D, 3X, DD, DD, 2X, 5D, DD, 3X, 4D, DD | USE THIS FOR Y_BULLET ≥ 10 INCHES
1960
1970 Image_data_g: IMAGE 7X(2(D, DD, XD, DD, 3X), DD, DD, X, DD, DD, 3X, 3D, DD, X, D, DD, 3X, DD
.DD, 3X, 4D, DD)
1980
1990
2000 GOSUB Header_end
2010 GOSUB Yhard_end
2020 PRINT LIN(2), "FINISHED"
2030 BEEP
2040 WAIT 250
2050 BEEP
2060 IF (Gs="Y") OR (Gs="y") THEN Graph_grin
2070 Ray_traces="N"
2080 INPUT "DO YOU WANT TO PLOT THE RESULTS OF THE TRACE ? Y/N", Ray_trace
$
2090 IF (Ray_traces="N") OR (Ray_traces="n") THEN Rerun
2100 INPUT "ON WHICH DEVICE: CRT (C) OR THE 9872 (P) ? P/C", Plots
2110 IF (Plots="C") OR (Plots="c") THEN Graph
2120 INPUT "PLEASE ENTER THE SELECT CODE OF THE GRAPHICS DEVICE (DEFAULT
= 7 )", Pselect
2130 INPUT "PLEASE ENTER THE HPID ADDRESS OF THE GRAPHICS DEVICE (DEFAULT
= 5 )", Hpid
2140 Graph: CALL Graph
2150 Ys="N"
2160 INPUT "DO YOU WANT ANOTHER PLOT DRAWN TO A DIFFERENT SCALE ? Y/N", Ys
2170 IF (Ys="Y") OR (Ys="y") THEN Graph
2180 Density: PRINTER IS 16
2190 PRINT PAGE, " The point of maximum ray density is determined by yo
u visually."
2200 PRINT "by placing the cross-hairs (they will appear automatically)
"
2210 PRINT "over the position of maximum density."
2220 PRINT " This is accomplished by using the DISPLAY controls (up
,down,←,-,→)."
2230 PRINT "When you get cursor in the area of interest, use the SHIFT
button"
2240 PRINT "with the DISPLAY controls (both shift and display control
s"
2250 PRINT "should be depressed simultaneously) for fine positioning."
2260 PRINT LIN(2), " The position of the vertical hair is critical,"
2270 PRINT "because its location is used for the position of the "
2280 PRINT "image plane (Z3) on the GLM axis."
2290 PRINT LIN(2), "CAUTION : Do not let the image plane intercept any
rays"
2300 PRINT "in the interior of the lens. If this is done, those rays"
2310 PRINT "will be included in the histogram."
2320 PRINT "PRESS CONT"
2330 PAUSE
2340 PRINT PAGE, " The histogram is an illustration of the density"
2350 PRINT "of the rays that intercept the image plane versus radial "
2360 PRINT "distance from the GLM axis."
2370 PRINT LIN(2), " When the position has been located, PRESS CONT."
2380 PAUSE
2390 Digitize="Y"
2400 CALL Graph
2410 IF Plots="P" THEN 2460 ! P FOR HP-9872 PLOTTER
2420 Dump_crt="N"
2430 INPUT "DO YOU WANT A HARD COPY OF THE PLOT ? Y/N", Dump_crt
2440 IF (Dump_crt="Y") OR (Dump_crt="y") THEN GOSUB Printer
2450 DISP "WORKIN' ON THE HISTOGRAM..."
2460 CALL Density ! PRODUCE A HISTOGRAM OF THE RAY DENSITY
2470 IF Plots="P" THEN 2520
2480 Digitize="N" ! RESET CONDITION
2490 Dump_crt="N"
2500 INPUT "DO YOU WANT A HARD COPY OF HISTOGRAM ? Y/N", Dump_crt

```

```

2510         IF (Dump_crt$="Y") OR (Dump_crt$="y") THEN GOSUB Printer
2520         Ys="N"
2530         INPUT "DO YOU WANT TO REDRAW THE HISTOGRAM FOR A DIFFERENT IMAGE P
LANE ? Y/N",Ys
2540         IF (Ys="Y") OR (Ys="y") THEN Z3=50
2550         IF (Ys="Y") OR (Ys="y") THEN Graph
2560         Digitize$="N"           ! RESET CONDITION
2570 Rerun: PRINTER IS 16
2580         Ys="N"
2590         INPUT "ARE YOU GOING TO MAKE ANY MORE RUNS? Y/N",Ys
2600         IF (Ys="N") OR (Ys="n") THEN Finished
2610         Changes="N"
2620         INPUT "ARE YOU GOING TO CHANGE ANY PARAMETERS (n2,n3,Alpha,Nray, OR
RHO-INITIAL)? Y/N",Changes$
2630         IF (Changes$="N") OR (Changes$="n") THEN Gymnastics
2640         GOSUB Printer
2650         PRINT " If you do NOT want to change a particular parameter"
2660         PRINT "PRESS CONT in Respose to the prompt."
2670         INPUT "WHAT IS THE NEW VALUE OF RHO-INITIAL ?",Rho_initial
2680         Rho_initial=-1*ABS(Rho_initial)
2690         Trho1=TAN(Rho_initial)
2700         INPUT "WHAT IS THE NEW VALUE OF ALPHA?",Alpha
2710         Talpha=TAN(Alpha)
2720         INPUT "WHAT IS THE NEW VALUE OF Y_BULLET ?",Y_bullet
2730         INPUT "WHAT IS THE NEW VALUE OF Ya ?",Ya
2740         INPUT "WHAT IS THE NEW VALUE OF Yb ?",Yb
2750         Add_ray=0           ! RESET CONDITION
2760         IF Ya=Yb THEN BEEP
2770         IF Ya>Yb THEN DISP "Ya MUST BE < Yb. PLEASE RE-ENTER Ya AND Yb.
"
2780         IF Ya=Yb THEN WAIT 2500
2790         IF Ya>Yb THEN 2730
2800         IF Yb>Y_bullet THEN BEEP
2810         IF Yb>Y_bullet THEN DISP "Yb MUST BE < Y_bullet. PLEASE RE-ENT
ER."
2820         IF Yb>Y_bullet THEN WAIT 2500
2830         IF Yb>Y_bullet THEN 2720
2840         Aperture=Yb-Ya
2850         IF Ya<0 THEN Add_ray=1
2860         INPUT "WHAT IS THE NEW VALUE OF n2?",N2
2870         INPUT "WHAT IS THE NEW VALUE OF n3?",N3
2880         INPUT "WHAT IS THE NEW VALUE OF Z3 ?",Z3
2890         INPUT "WHAT IS THE NEW VALUE OF THE No. OF RAYS?",Nray
2900         INPUT "WHAT IS THE NEW No. OF INCREMENTS (1000 MAX ) ?",N_increment
2910         Changes="Y"
2920         GOTO Gymnastics
2930 Graph_grin: J=1
2940         FOR I=1 TO Nray
2950             R(I)=SQR(X(J)^2+Y(J)^2)
2960             C(I)=M(I)*R(I)*SIN(Phi(I))
2970             J=J+5
2980         NEXT I
2990         Ys="N"
3000         INPUT "DO YOU WANT TO PRINT A TABLE OF GRIN AND THE GRIN CONSTA
NT ? Y/N",Ys
3010         IF (Ys="N") OR (Ys="n") THEN 3150
3020         Y_hards="N"
3030         INPUT "DO YOU WANT A HARD COPY OF THE TABLE ? Y/N",Y_hards
3040         GOSUB Yhard
3050         GOSUB Header_c
3060         FOR I=1 TO Nray
3070             IF Linecount>Linemax THEN GOSUB Header_c
3080             PRINT USING 3090:I,N(I),R(I),Phi(I),SIN(Phi(I)),C(I)
3090             IMAGE 3X,4D,5(3X,4D,4D)
3100             Linecount=Linecount+1
3110         NEXT I
3120         GOSUB Header_end

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3130      GOSUB Yhard_end
3140      Ys="N"
3150      INPUT "DO YOU WANT TO PLOT THE RESULTS OF THE TRACE ? Y/N",Ys
3160      IF (Ys="N") OR (Ys="n") THEN Grinc
3170      INPUT "ON WHICH DEVICE: CRT (C) OR THE 9872 (P) ? C/P ",Plots
3180      CALL Graph
3190      Ys="N"
3200      INPUT "DO YOU WANT ANOTHER PLOT DRAWN TO A DIFFERENT SCALE ? Y/N"
3210      ,Ys
3220      IF (Ys="Y") OR (Ys="y") THEN CALL Graph
3230      Dump_crt$="N"
3240      INPUT "DO YOU WANT A HARD COPY OF THE PLOT ? Y/N",Dump_crt$
3250      IF (Dump_crt$="Y") OR (Dump_crt$="y") THEN GOSUB Printer
3260      Grinc: Grinc$="N"
3270      INPUT "DO YOU WANT A GRAPH OF THE GRIN CONSTANT C(r) vs r ? Y/N",Grinc$
3280      IF (Grinc$="N") OR (Grinc$="n") THEN Rerun_grin
3290      INPUT "ON WHICH DEVICE: CRT (C) OR THE 9872 (P) ? C/P ",Plots
3300      Grinc1: Grinc$="Y"
3310      CALL Graph
3320      Grinc$="N"      ! RESET CONDITION
3330      Dump_crt$="N"
3340      INPUT "DO YOU WANT A HARD COPY OF THE PLOT ? Y/N",Dump_crt$
3350      IF (Dump_crt$="Y") OR (Dump_crt$="y") THEN GOSUB Printer
3360      Ys="N"
3370      INPUT "DO YOU WANT ANOTHER PLOT DRAWN ? Y/N",Ys
3380      IF (Ys="Y") OR (Ys="y") THEN Grinc1
3390      Rerun_grin: Ys="N"
3400      Gs="Y"      ! INSURANCE
3410      INPUT "ARE YOU GOING TO MAKE ANOTHER RUN ? Y/N",Ys
3420      IF (Ys="N") OR (Ys="n") THEN Finished
3430      Changes="N"
3440      INPUT "ARE YOU GOING TO CHANGE ANY PARAMETERS (n2,n3,Alpha,Nray
3450      , OR RHO-INITIAL)? Y/N",Changes
3460      IF (Changes="N") OR (Changes="n") THEN Gymnastics
3470      GOSUB Printer
3480      PRINT " If you do NOT want to change a particular parameter"
3490      PRINT "PRESS CONT in response to the prompt."
3500      Add_ray=0      ! RESET CONDITION
3510      INPUT "WHAT IS THE NEW VALUE OF RHO-INITIAL ?",Rho_initial
3520      Rho_initial=-1+ABS(Rho_initial)
3530      Trho=TAN(Rho_initial)
3540      INPUT "WHAT IS THE NEW VALUE OF ALPHA?",Alpha
3550      INPUT "WHAT IS THE NEW VALUE OF Nmin ?",Nmin
3560      IF (Grinc$="C") OR (Grinc$="c") THEN 3570
3570      INPUT "WHAT IS THE NEW VALUE OF Nmax ?",Nmax
3580      INPUT "WHAT IS THE NEW VALUE OF R0_max ?",R0_max
3590      INPUT "WHAT IS THE NEW VALUE OF n3?",N3
3600      INPUT "WHAT IS THE NEW VALUE OF THE No. OF RAYS?",Nray
3610      INPUT "WHAT IS THE NEW VALUE OF Ya ?",Ya
3620      INPUT "WHAT IS THE NEW VALUE OF Yb ?",Yb
3630      IF Ya=Yb THEN BEEP
3640      IF Ya>Yb THEN DISP "Ya MUST BE < Yb. PLEASE ENTER AGAIN"
3650      IF Ya=Yb THEN WAIT 2500
3660      Aperture=Yb-Ya
3670      IF Ya<0 THEN Add_ray=Add_ray+1
3680      Changes="Y"
3690      GOSUB Printer
3700      Changes="N"      ! RESET CONDITION
3710      GOTO Gymnastics
3720      Printer: IF (Changes="Y") OR (Changes="y") THEN Y_hards$="N"
3730      IF (Dump_crt$="Y") OR (Dump_crt$="y") THEN Y_hards$="Y"
3740      IF (Y_hards$="Y") OR (Y_hards$="y") THEN PRINTER IS 0
3750      IF (Y_hards$="Y") OR (Y_hards$="y") THEN PRINT CHR$(27)&"&L100T"
3760      IF (Dump_crt$="Y") OR (Dump_crt$="y") THEN Crt
      GOSUB Header_initial

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3770     IF (Gs="Y") OR (Gs="y") THEN Grin1
3780     FIXED 0
3790     IF Linecount>Linemax THEN GOSUB Header_initial
3800     IF Dates="" THEN 3830
3810     PRINT "Curve No: ";Curve,TAB(40);"Date: ";Dates
3820     GOTO 3840
3830     PRINT "Curve No: ";Curve
3840     Linecount=Linecount+1
3850 Grin1:   FIXED 2
3860     IF Linecount>Linemax THEN GOSUB Header_initial
3870     PRINT LIN(1),"RHO(INITIAL) = ";Rho_initial;"degrees";TAB(48);"Alph
a = ";Alpha;"degrees"
3880     Linecount=Linecount+1
3890     IF Linecount>Linemax THEN GOSUB Header_initial
3900     PRINT "TAN(RHO-INITIAL) = ";Trhoi;TAB(48);"Tan(Alpha) = ";Talpha
3910     Linecount=Linecount+1
3920     FIXED 5
3930     IF (Gs="N") OR (Gs="n") THEN Grin2
3940     IF Linecount>Linemax THEN GOSUB Header_initial
3950     PRINT LIN(1),"n1 = ";N1;TAB(48);"n3 = ";N3
3960     IF (Grin3="C") OR (Grin3="c") THEN 4010
3970     IF Linecount>Linemax THEN GOSUB Header_initial
3980     PRINT LIN(1),"Nmin = ";Nmin;TAB(48);"Nmax = ";Nmax
3990     Linecount=Linecount+1
4000     GOTO 4040
4010     IF Linecount>Linemax THEN GOSUB Header_initial
4020     PRINT LIN(1),"Nmin = ";Nmin
4030     Linecount=Linecount+1
4040     IF Linecount>Linemax THEN GOSUB Header_initial
4050     PRINT
4060     Linecount=Linecount+1
4070     FOR I=1 TO Nray STEP 3
4080         IF Linecount>Linemax THEN GOSUB Header_initial
4090         IF I>=250 THEN PRINT USING 4140;I,N(I)
4100         IF I>=250 THEN 4120
4110         PRINT USING 4130;I,N(I),I+1,N(I+1),I+2,N(I+2)
4120         Linecount=Linecount+1
4130         IMAGE 3(5X,"n2("3D") = ",2D.5D)
4140         IMAGE 5X,"n2("3D") = ",2D.5D
4150     NEXT I
4160     IF Linecount>Linemax THEN GOSUB Header_initial
4170     PRINT LIN(1),"R0_max = ";R0_max;" inches"
4180     Linecount=Linecount+1
4190     GOTO Grin3
4200 Grin2:   IF Linecount>Linemax THEN GOSUB Header_initial
4210     PRINT LIN(1),"n1 = ";N1;TAB(24);"n2 = ";N2;TAB(48);"n3 = ";N3
4220     Linecount=Linecount+1
4230 Grin3:   FIXED 3
4240     IF Linecount>Linemax THEN GOSUB Header_initial
4250     PRINT LIN(1),"Aperture = ";Aperture;TAB(24);"Ya = ";Ya;" inch ";TA
B(48);"Yb = ";Yb;" inch "
4260     IF (Gs="Y") OR (Gs="y") THEN Grin4
4270     Linecount=Linecount+1
4280     FIXED 2
4290     IF Linecount>Linemax THEN GOSUB Header_initial
4300     PRINT LIN(1),"Z3 = ";Z3;"inches";TAB(48);"Z4 = ";Z4;" inches"
4310     Linecount=Linecount+1
4320 Grin4:   FIXED 0
4330     IF Linecount>Linemax THEN GOSUB Header_initial
4340     PRINT LIN(1),"Number of Rays = ";Nray
4350     Linecount=Linecount+1
4360     IF (Gs="Y") OR (Gs="y") THEN Grin5
4370     IF Linecount>Linemax THEN GOSUB Header_initial
4380     PRINT LIN(1),"Number of Increments = ";N_increment
4390     Linecount=Linecount+1
4400 Grin5:   FIXED 2
4410     IF Linecount>Linemax THEN GOSUB Header_initial

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4420 PRINT
4430 Linecount=Linecount+1
4440 GOSUB Header_end
4450 Crt: IF (Dump_crt$="Y") OR (Dump_crt$="y") THEN DUMP GRAPHICS
4460 IF (Y_hard$="Y") OR (Y_hard$="y") THEN PRINT CHR$(27)&"&136T"
4470 Change$="N" ! RESET CONDITION
4480 Dump_crt$="N"
4490 Y_hard$="N"
4500 RETURN
4510 Yhard: IF (Y_hard$="Y") OR (Y_hard$="y") THEN Flags="1"
4520 IF (Y_hard$="N") OR (Y_hard$="n") THEN Flags="0"
4530 IF (Y_hard$="Y") OR (Y_hard$="y") THEN PRINTER IS 0
4540 IF Flags="1" THEN PRINT CHR$(27)&"&100T"
4550 RETURN
4560 Yhard_end: IF (Flag$="1") OR (Flag$="0") THEN PRINT CHR$(27)&"&136T"
4570 IF (Flag$="1") OR (Flag$="0") THEN PRINTER IS 16
4580 RETURN
4590 Header_coef: IF Linecount>Linemax THEN GOSUB Header_coef_end
4600 Linecount=0
4610 PRINT PAGE;LIN(5)
4620 GOSUB Char_short
4630 PRINT LIN(1);SPA(6);"COEFFICIENTS";LIN(1)
4640 GOSUB Char_short
4650 PRINT LIN(2)
4660 RETURN
4670 Header_coef_end: PRINT LIN(2)
4680 GOSUB Char_short
4690 RETURN
4700 Header_c: IF Linecount>Linemax THEN GOSUB Header_end
4710 Linecount=0
4720 PRINT PAGE;LIN(5)
4730 GOSUB Char
4740 PRINT LIN(1)," I n(I) r(I) Phi(I)
Sin(Phi) c(I);LIN(1)
4750 DISP " I n(I) r(I) Phi(I)
Sin(Phi) c(I)"
4760 GOSUB Char
4770 PRINT LIN(2)
4780 RETURN
4790 Header_c_end: GOSUB Header_end
4800 RETURN
4810 Header_initial: IF Linecount>Linemax THEN GOSUB Header_end
4820 Linecount=0
4830 PRINT PAGE;LIN(5);TAB(20);"INITIAL PARAMETER VALUES";LIN(1)
4840 GOSUB Char
4850 PRINT LIN(2)
4860 RETURN
4870 Char_short: Char_max=25
4880 FOR Z=0 TO Char_max
4890 IF Z=Char_max THEN PRINT CHR$(228)
4900 IF Z=Char_max THEN 4920
4910 PRINT CHR$(228);
4920 NEXT Z
4930 RETURN
4940 Header: IF Linecount>Linemax THEN GOSUB Header_end
4950 Linecount=0
4960 PRINT PAGE;LIN(5)
4970 GOSUB Char
4980 PRINT LIN(1)," (X0,Y0) (X1,Y1) (X2,Y2) (Xc,Yc)
(X3,Y3) RHO";LIN(1)
4990 GOSUB Char
5000 PRINT LIN(2)
5010 DISP " (X0,Y0) (X1,Y1) (X2,Y2) (Xc,Yc)
(X3,Y3) RHO"
5020 RETURN
5030 Header_grin: IF Linecount>Linemax THEN GOSUB Header_end
5040 Linecount=0

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5050          PRINT PAGE,LIN(5)
5060          GOSUB Char
5070          PRINT LIN(1), "          (X0,Y0)          (X1,Y1)          (X3,Y3)
(Xc,Yc)      N2          RHO";LIN(1)
5080          DISP "          (X0,Y0)          (X1,Y1)          (X3,Y3)
(Xc,Yc)      N2          RHO"
5090          GOSUB Char
5100          PRINT LIN(2)
5110          RETURN
5120 Header_end: PRINT LIN(2)
5130          GOSUB Char
5140          RETURN
5150 Char: FOR Zz=0 TO 79
5160          IF Zz=79 THEN PRINT CHR$(228)
5170          IF Zz=79 THEN 5190
5180          PRINT CHR$(228);
5190          NEXT Zz
5200          PRINT RPTS("=",90)          ! THIS IS A LOT FASTER, BUT NOT AS PRETTY
5210          RETURN
5220 Finished: DISP "FINISHED"
5230          END
5240 SUB Slope(Y)
5250          OPTION BASE 0
5260          !
5270          COM INTEGER I,J,Curve,Np,Nn,N,Ns,Nr,REAL Aneg(*),Apos(*),A(*),Z1,Z3,Z4
5280          COM Alpha,Talpha,Rho,Trho,Rho_initial,Trhoi,Phi,Tol,Norm,Alpha2
5290          COM N1,N2,N3,Percent_image,Ya,Yb,Aperture,Y_bullet
5300          !
5310          COM INTEGER Y0_loop,Nray,Add_ray,Surf_no,Flag,Flag2,N_increment,Hit_total
5320          !
5330          DEG
5340          IF Surf_no=2 THEN Tuo
5350          One: Alpha2=Alpha
5360          Norm=Alpha2-90
5370          SUBEXIT
5380          Two: IF Y<0 THEN Negative
5390          Positive: Tan_m2=0          ! SLOPE WRT Y-AXIS [dx/dy]
5400          FOR I=1 TO Np
5410          Tan_m2=Tan_m2+I*Apos(I)*Y^(I-1)
5420          NEXT I
5430          M2=ABS(ATN(Tan_m2))          ! THE ANGLE IS POSITIVE CW WRT Y-AXIS
5440          Alpha2=90-M2          ! THE ANGLE IS POSITIVE CCW WRT X-AXIS
5450          Norm=Alpha2-90
5460          SUBEXIT
5470          Negative: Tan_m2=0
5480          FOR I=1 TO Nn
5490          Tan_m2=Tan_m2+I*Aneg(I)*Y^(I-1)
5500          NEXT I
5510          M2=ABS(ATN(Tan_m2))
5520          Alpha2=90-M2
5530          Tnorm=-1/TAN(Alpha2)
5540          Norm=ATN(Tnorm)-180
5550          SUBEND
5560 SUB Snell(X,Y)
5570          OPTION BASE 0
5580          !
5590          COM INTEGER I,J,Curve,Np,Nn,N,Ns,Nr,REAL Aneg(*),Apos(*),A(*),Z1,Z3,Z4
5600          COM Alpha,Talpha,Rho,Trho,Rho_initial,Trhoi,Phi,Tol,Norm,Alpha2
5610          COM N1,N2,N3,Percent_image,Ya,Yb,Aperture,Y_bullet
5620          !
5630          COM INTEGER Y0_loop,Nray,Add_ray,Surf_no,Flag,Flag2,N_increment,Hit_total
5640          COM INTEGER Linecount,LineMAX
5650          COM INTEGER Pselect,Hplb
5660          !
5670          COM REAL Hmin,Hmax,R0_max
5680          COM Ray_traces,Digitizes,Grins,CS,Grincs,Plots,Dates
5690          COM X(*),Y(*),Xc(*),Nc(*),Rc(*)

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5700 I
5710 DEG
5720 IF Surf_no=2 THEN Two
5730 One: Nn1=N1
5740 Nn2=N2
5750 Thetai=90-(Alpha+ABS(Rho))
5760 CALL Slope(Y)
5770 IF Thetai<0 THEN Neg_thetai
5780 GOTO Same
5790 Neg_thetai: Flag=5
5800 Thetai=ABS(Thetai)
5810 Sip=N1/N2*SIN(Thetai)
5820 IF ABS(Sip)>1 THEN Wrong
5830 Thetar=ASN(Sip)
5840 Rho=Norm-Thetar
5850 IF (ABS(Rho)<89.99999) OR (ABS(Rho)>90.00001) THEN Trho=TAN(R
ho)
5860 IF (ABS(Rho)>89.99999) AND (ABS(Rho)<=90) THEN Trho=-9999999
5870 IF (ABS(Rho)>90) AND (ABS(Rho)<90.00001) THEN Trho=9999999
5880 SUBEXIT
5890 Two: Nn1=N2
5900 Nn2=N3
5910 IF Y<0 THEN Negative
5920 CALL Slope(Y)
5930 Thetai=90-ABS(Rho)-Alpha2
5940 IF Thetai<0 THEN Neg_thetai2
5950 Same: IF (Gs="Y") OR (Gs="y") THEN GOSUB Grin
5960 Sin_iprime=Nn1/Nn2*SIN(Thetai)
5970 IF ABS(Sin_iprime)>1 THEN Wrong
5980 Thetar=ASN(Sin_iprime)
5990 Rho=Alpha2+Thetar-90 ! USE ALPHA2 INSTEAD OF NORM BECAUSE THE
! SIGN OF THE ANGLE IS DESIRED
6000 Trho=TAN(Rho)
6010 Phi=Alpha-Rho ! USED FOR GRIN
6020 SUBEXIT
6030 Neg_thetai2: Thetai=ABS(Thetai)
6040 Sip=Nn1/Nn2*SIN(Thetai)
6050 IF Abs(Sip)>1 THEN Wrong
6060 Thetar=ASN(Sip)
6070 Rho=Norm-Thetar
6080 IF ABS(Rho)>=90 THEN Skip ! THE RAY WILL NOT INTERCEPT
! THE IMAGE PLANE
6100 IF ABS(Rho)<89.99999 THEN Trho=TAN(Rho)
6120 IF (ABS(Rho)>89.99999) AND (ABS(Rho)<90) THEN Trho=-9999999
6130 SUBEXIT
6140 Skip: Flag=15
6150 IF ABS(Rho)>=90.000001 THEN Trho=TAN(Rho)
6160 IF ABS(Rho)<90.000001 THEN Trho=9999999
6170 Rhop=100-ABS(Rho)
6180 Trhop=TAN(Rhop)
6190 Xc(Y0_loop)=X-Y/Trhop
6200 SUBEXIT
6210 Wrong: Flag=10 ! TOTAL INTERNAL REFLECTION AT THE SECOND SURFACE
6220 SUBEXIT
6230 Negative: CALL Slope(Y)
6240 Thetai=90+ABS(Rho)-Alpha2
6250 Sip=Nn1/Nn2*SIN(Thetai)
6260 IF ABS(Sip)>1 THEN Wrong
6270 Thetar=ASN(Sip)
6280 Rho=Norm-Thetar
6290 Trho=TAN(Rho)
6300 SUBEXIT
6310 Grin: N2=0
6320 IF (Grins="P") OR (Grins="p") THEN P
6330 C: CALL Index_c(X,Y)
6340 N(Y0_loop)=N2

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6350     IF Surf_no=1 THEN Nn2=N2
6360     IF Surf_no=2 THEN Nn1=N2
6370     RETURN
6380 P:   CALL Index_p(X,Y)
6390     N(Y0_loop)=N2
6400     IF Surf_no=1 THEN Nn2=N2
6410     IF Surf_no=2 THEN Nn1=N2
6420     RETURN
6430 SUBEND
6440 SUB Binary_search(X,Y)
6450     OPTION BASE 0
6460     !
6470     COM INTEGER I,J,Curve,Np,Nn,N,Ns,Nr,REAL Aneg(*),Apos(*),A(*),Z1,Z3,Z4
6480     COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Phi,Tol,Norm,Alpha2
6490     COM N1,N2,N3,Percent_image,Ya,Yb,Aperture,Y_bullet
6500     !
6510     COM INTEGER Y0_loop,Nray,Add_ray,Surf_no,Flag,Flag2,N_increment,Hit_total
6520     COM INTEGER Linecount,Linemax
6530     COM INTEGER Pselect,Hpib
6540     !
6550     COM REAL Nmin,Hmax,R0_max
6560     COM Ray_traces,Digitize$,Grins,G$,Grincs,Plots,Date$
6570     COM X(*),Y(*),Xc(*),N(*),R(*)
6580     !
6590     COM Rho(*),Phi(*),C(*),Y3(*),Hit(*)
6600     !
6610     DEC
6620     DEF FNA(X,Y)=X-Y/Trho
6630     DEF FNA1(X,Y)=X-Y/Talpha
6640     DEF FNx(A)=A-Y_bullet/Trho      ! FINDS THE INTERCEPT OF THE RAY AND Y=-Y_b
6650     R=1
6660     IF Surf_no=1 THEN One
6670     IF Surf_no=2 THEN Two
6680     IF Surf_no=3 THEN Three
6690     Four: Dy=(Z4-X)*Trho
6700         Y=Y+Dy
6710         X=Z4
6720     SUBEXIT
6730     Three: IF (Y>0) AND (Trho>0) THEN skip !THE RAY WILL NOT CROSS THE X-AXIS
6740         Xc(Y0_loop)=FNA(X,Y)
6750     Back: Dy=(Z3-X)*Trho
6760         Y=Y+Dy
6770         X=Z3
6780     SUBEXIT
6790     One:   CALL Xipos(X,Y)
6800     SUBEXIT
6810     Two:  A=FNA(X,Y)
6820         IF Flag=5 THEN Search2 ! Theta I < 0 FROM SNELL
6830         Flag=0
6840         Flag2=0
6850         IF (G$="Y") OR (G$="y") THEN Grin
6860         IF A<Z1 THEN Negative ! THIS IS A SEPARATE AND UNRELATED TEST
6870         GOTO Positive ! FROM THAT PERFORMED IN SEARCH 2
6880     Search2: ! THIS ROUTINE IS ENTERED WHEN THE ANGLE OF INCIDENCE ON THE
6890         ! FIRST SURFACE IS < 0 DEGREES.
6900         ! THIS MEANS ThetaI HAS DECREASED FROM ITS AXIAL VALUE TO 0
6910         ! (i.e. NORMAL TO THE FIRST SURFACE) THEN CONTINUED TO ROTATE PAST
6920         ! THE NORMAL. THIS CORRESPONDS TO A TARGET AT OR NEAR CLOSEST
6930         ! POINT OF APPROACH (CPA).
6940         ! WHEN THIS HAPPENS RHO(1) CAN BE LARGE ENOUGH TO CAUSE THE RAY
6950         ! TO MISS THE FIRST AND SECOND SURFACE.
6960         ! THE ROUTINE FIRST CHECKS TO SEE IF THE RAY CROSSES THE SECOND
6970         ! SURFACE. IF SO, CONTROL SWITCHES TO FASTER BISECTION ROUTINE.
6980         ! IF NOT THEN THE ROUTINE MARCHES SLOWLY DOWN THE RAY TO FIND THE
6990         ! INTERCEPT (IF ANY).
7000     !

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7010         IF A>Z1 THEN Positive
7020
7030         Delta=.01
7040         X12=X
7050         Y12=Y
7060 !     EVEN THOUGH THE X-INTERCEPT APPEARS TO BE < Z1, THE SECOND SURFACE
7070 !     COULD BE IRREGULAR ENOUGH TO CAUSE THIS SIMPLE CHECK TO BE DECEIVING.
7080 !     THE RAY IS ASSUMED TO HAVE INTERCEPTED THE SECOND SURFACE IF THE
7090 !     DIFFERENCE BETWEEN THE RAY POSITION AND THE SECOND SURFACE < TOLERANCE
7100 March:  Deltax=Delta*COS(Rho)
7110         Deltay=Delta*SIN(Rho)
7120         X12=X12+Deltax
7130         Y12=Y12+Deltay
7140         IF Y12<0 THEN Missed ! YOU HAVE REACHED THE X-AXIS
7150         X2=0
7160         CALL X2pos(X2,Y12)
7170         Xsave=X12-X2
7180         IF ABS(Xsave)<=Tol THEN Done1 ! FOUND THE SURFACE WITHIN TOL
7190         IF Xsave<0 THEN March ! KEEP LOOKING
7200         IF Xsave>0 THEN Found_it ! THE RAY CROSSED X2POS
7210 Done1:  X=(X2+X12)/2
7220         Y=Y12
7230         SUBEXIT
7240 Missed: X=A ! THE RAY HAS MISSED THE POS AND NEG SURFACES
7250         Y=0 ! DRAW THE RAY TO THE X-AXIS
7260         GOTO Blind
7270 Found_it: Xmid=X12 ! THE RAY HAS CROSSED THE SECOND SURFACE. GO TO THE
7280         Xlast=Xmid ! BISECTION ROUTINE FOR SPEED
7290         Ymid=Y12
7300         Ylast=Ymid
7310         Xsave=0
7320         GOTO Recurse_p
7330 Positive: X1=0
7340         X2=0
7350         CALL X1pos(X1,Y)
7360         CALL X2pos(X2,Y)
7370         IF X2<=X1 THEN Whoops
7380         Xmid=A ! THE RAY HAS CROSSED THE X-AXIS BEHIND THE SECOND
7390         Xmid=A ! THE RAY HAS CROSSED THE X-AXIS BEHIND THE SECOND
7400         Xlast=Xmid ! SURFACE. THEREFORE Y>0 AT THE INTERCEPT
7410         Ymid=0
7420         Ylast=Ymid
7430         Xsave=0
7440 Recurse_p: Xmid=(X+R*Xmid)/(1+R)
7450         Ymid=(Y+R*Ymid)/(1+R)
7460         X2=0
7470         CALL X2pos(X2,Ymid)
7480         Xsave=X2-Xmid
7490         IF Xsave<0 THEN First ! INTERCEPT IS BEHIND THE MIDPOINT
7500         IF Xsave>0 THEN Second ! INTERCEPT IS AHEAD OF THE MIDPOINT
7510         IF Xsave=0 THEN Done ! INTERCEPT IS THE MIDPOINT
7520 Recurse_n: Xmid=(X+R*Xmid)/(1+R)
7530         Ymid=(Y+R*Ymid)/(1+R)
7540         X2=0
7550         CALL X2neg(X2,Ymid)
7560         Xsave=X2-Xmid
7570         IF Xsave<0 THEN First ! INTERCEPT IS BEHIND THE MIDPOINT
7580         IF Xsave>0 THEN Second ! INTERCEPT IS AHEAD OF THE MIDPOINT
7590         IF Xsave=0 THEN Done ! INTERCEPT IS THE MIDPOINT
7600 First:  IF ABS(Xsave)<Tol THEN Done
7610         Xlast=Xmid
7620         Ylast=Ymid
7630         IF Flag=1 THEN Recurse_n
7640         GOTO Recurse_p
7650 Second: IF ABS(Xsave)<Tol THEN Done
7660         X=Xmid
7670         Y=Ymid

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7680      Xmid=Xlast
7690      Ymid=Ylast
7700      IF Flag=1 THEN Recurse_n
7710      GOTO Recurse_p
7720 Negative: X1=0
7730      X2=0
7740      Xc(Y0_loop)=A
7750      CALL X1neg(X1,Y)
7760      CALL X2neg(X2,Y)
7770      IF X2<=X1 THEN Hoops
7780      Flag=1      ! THE RAY CROSSES THE X-AXIS AHEAD OF THE SECOND
7790      Y11=-Y_bullet ! SURFACE AND COULD POSSIBLY INTERCEPT X2NEG.
7800      X=A      ! THE SAME TYPE OF TESTS DESCRIBED ABOVE
7810      ! IN SEARCH 2 ARE PERFORMED HERE.
7820      Y=0
7830      Delta=.01
7840 Search: X11=FNXn(A)
7850      X2=0
7860      CALL X2neg(X2,Y11)
7870      IF X11>X2 THEN Ok ! X11 > X2max
7880      X11=A
7890      Y11=0
7900      Deltax=Delta*SIN(Rho)
7910      Deltay=Delta*COS(Rho)
7920 Search_n: IF ABS(Y11)>=Y_bullet THEN Missed2 ! THE SECOND SURFACE HAS MI
SSED
7930      X11=X11+Deltax
7940      Y11=Y11+Deltay
7950      X2=0
7960      CALL X2neg(X2,Y11)
7970      Xsave=X11-X2
7980      IF ABS(Xsave)<=Tol THEN Victory ! FOUND THE SURFACE
7990      IF Xsave>=0 THEN Ok
8000      IF Xsave<0 THEN Search_n ! KEEP LOOKING
8010 Missed2: X=FNXn(A) ! DRAW THE RAY UNTIL Y= -Y_bullet
8020      Y=-Y_bullet
8030      GOTO Blind
8040 Victory: Flag2=1
8050      X=(X11+X2)/2
8060      Y=Y11
8070      SUBEXIT
8080 Ok: Flag2=1 ! THE INTERCEPT OF THE RAY AND X2NEG HAS BEEN FOUND.
8090      Xmid=X11 ! GO TO THE BISECTION ROUTINE FOR SPEED.
8100      Xlast=Xmid
8110      Ymid=Y11
8120      Ylast=Ymid
8130      GOTO Recurse_n
8140 Done: X=(X2+Xmid)/2
8150      Y=Ymid
8160      SUBEXIT
8170 Skip: Xc(Y0_loop)=0
8180      GOTO Back
8190 Blind: IF Flag=1 THEN Blind_n
8200      Flag=20
8210      X=A
8220      Y=0
8230      Xc(Y0_loop)=A
8240      SUBEXIT
8250 Blind_n: Flag=20
8260      Xc(Y0_loop)=A
8270      SUBEXIT
8280 Hoops: Flag=30 ! THE SECOND SURFACE HAS BENT AND CROSSED THE FIRST
8290      X=X2 ! STOP THE RAY TRACE
8300      Y=Y
8310      SUBEXIT
8320 G-in: A1=Z3
8330      Y=(A-A1)*(Talpha+Trho)/(Trho-Talpha) ! INTERCEPT OF TWO LINES

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0340      X=A+Y/Trho
0350      Xc(Y0_loop)=A ! REQUIRED FOR DRAWING PURPOSES
0360      SUBEND
0370 SUB Graph
0380 OPTION BASE 0
0390 !
0400 COM INTEGER I,J,Curve,Np,Mn,N,Ns,Nr,REAL Aneg(*),Apos(*),R(*),Z1,Z3,Z4
0410 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trhoi,Phi,Tol,Norm,Alpha2
0420 COM N1,N2,N3,Percent_image,Ya,Yb,Aperture,Y_bullet
0430 !
0440 COM INTEGER Y0_loop,Nray,Add_ray,Surf_no,Flag,Flag2,N_increment,Hit_total
0450 COM INTEGER Linecount,Lineax
0460 COM INTEGER Pselect,Hpib
0470 !
0480 COM REAL Hmin,Hmax,R0_max
0490 COM Ray_traces,Digitizes,Grins,Gs,Grincs,Plots,Dates
0500 COM X(*),Y(*),Xc(*),N(*),R(*)
0510 !
0520 COM Rho(*),Phi(*),C(*),Y3(*),Hit(*)
0530 !
0540 !
0550 DEG
0560 PRINTER IS 16
0570 IF (Grincs="Y") OR (Grincs="y") THEN Grinc
0580 IF (Digitizes="Y") OR (Digitizes="y") THEN Digit
0590 Draw_axes: CALL Plot
0600 First_surf: FIXED 2
0610 LINE TYPE 8
0620 Y=Y_bullet
0630 MOVE 0,0
0640 X=Y/Talpha
0650 DRAW X,Y
0660 DRAW 100,Y
0670 MOVE 0,0
0680 DRAW X,-Y
0690 DRAW 100,-Y
0700 IF (Gs="Y") OR (Gs="y") THEN Grin_image
0710 X2pos: MOVE Apos(0),0
0720 FOR Y=0 TO Y_bullet STEP .01*Y_bullet
0730 X2pos=0
0740 FOR I=0 TO Np
0750 X2pos=X2pos+Apos(I)+Y*I
0760 NEXT I
0770 DRAW X2pos,Y
0780 NEXT Y
0790 X2neg: MOVE Apos(0),0
0800 FOR Y=0 TO -Y_bullet STEP -.01*Y_bullet
0810 X2neg=0
0820 FOR I=0 TO Mn
0830 X2neg=X2neg+Aneg(I)+Y*I
0840 NEXT I
0850 DRAW X2neg,Y
0860 NEXT Y
0870 EXIT GRAPHICS
0880 Ys="N"
0890 INPUT "DO YOU WANT A HARD COPY OF THE PLOT WITHOUT RAYS ? Y/N",Ys
0900 IF (Ys="Y") OR (Ys="y") THEN GOSUB Dump_it
0910 GRAPHICS
0920 First_image: LINE TYPE 5
0930 MOVE Z3,Y_bullet
0940 DRAW Z3,-Y_bullet
0950 Second_image: LINE TYPE 6
0960 MOVE Z4,Y_bullet
0970 DRAW Z4,-Y_bullet
0980 IF (Gs="N") OR (Gs="n") THEN First_
0990 Grin_image: LINE TYPE 7
1000 Ym=-Y_bullet+.5*Y_bullet

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9810      Xn=Z3+Yn/Talpha
9820      MOVE Xn,Yn
9830      Yn=-Yn
9840      Xn=Z3+Yn/Talpha
9850      DRAW Xn,Yn
9860 REM DRAW THE RAYS
9870 First_: LINE TYPE 1
9880      CLIP 0,100,-Y_bullet,Y_bullet
9890      I=0
9900      FOR Ray_first=1 TO Nray
9910          MOVE X(I),Y(I)
9920          DRAW X(I+1),Y(I+1)
9930          I=I+5
9940      NEXT Ray_first
9950 Second_: I=1
9960      FOR Ray_second=1 TO Nray
9970          MOVE X(I),Y(I)
9980          DRAW X(I+1),Y(I+1)
9990          I=I+5
1000     NEXT Ray_second
1010 IF (Gs="Y") OR (Gs="y") THEN Wait_
1020 First_image_p: I=2
1030     Nr=-1
1040     FOR Ray_image=1 TO Nray
1050         Nr=Nr+3
1060         MOVE X(I),Y(I)
1070         IF X(I)<>0 THEN Ok
1080         I=I+5
1090         GOTO Next_ray_image
1100 Ok: IF X(I+1)=0 THEN Reflect
1110     DRAW X(I+1),Y(I+1)
1120     I=I+5
1130     GOTO Next_ray_image
1140 Reflect: ! IF THE ANSWER TO THE QUESTION IS NO, THE RAY WAS TOTALLY
1150 ! REFLECTED AND DO NOT DRAW A LINE
1160 ! IF A LINE IS DRAWN, THEN ABS(RHO) ≥ 90 DEGREES
1170 IF (Xc(Ray_image)=0) OR (Rho(Nr)=0) THEN 9400
1180 Trho=-1*(Y(I)-Xc(Ray_image)-X(I))
1190 DRAW X(I)-<Y(I)+Y_bullet>/Trho,-Y_bullet ! RHO ≥ 90 DE
1200 GREEE
1210     I=I+5
1220 Next_ray_image: NEXT Ray_image
1230 Decision: WAIT 2000
1240 EXIT GRAPHICS
1250 BEEP
1260 Ys="N"
1270 INPUT "DO YOU WANT TO PLOT TO THE SECOND IMAGE PLANE ? Y/N",Ys
1280 GRAPHICS
1290 IF (Ys="N") OR (Ys="n") THEN Wait_
1300 Second_image_p: I=3
1310     Nr=-1
1320     FOR Ray_image2=1 TO Nray
1330         Nr=Nr+3
1340         MOVE X(I),Y(I)
1350         IF X(I)<>0 THEN Ok2
1360         I=I+5
1370         GOTO Next_ray_image2
1380 Ok2: IF X(I+1)=0 THEN Reflect2
1390     DRAW X(I+1),Y(I+1)
1400     I=I+5
1410     GOTO Next_ray_image2
1420 Reflect2: IF (Xc(Ray_image2)=0) OR (Rho(Nr)=0) THEN 9640
1430 Trho=-1*(Y(I)-Xc(Ray_image2)-X(I))
1440 DRAW X(I)-<Y(I)+Y_bullet>/Trho,-Y_bullet ! RHO ≥ 90 DE
1450 GREEE
1460     I=I+5
1470 Next_ray_image2: NEXT Ray_image2

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9660                                GOTO Wait_
9670 Grinc: CALL Plot
9680 | R1=C(I)/(N(I)*SIN(Phi(I)))
9690 | MOVE R1,C(I)
9700 | MOVE R(I),C(I)
9710 | FOR I=2 TO Nray
9720 | R=C(I)/(N(I)*SIN(Phi(I)))
9730 | DRAW R,C(I)
9740 | DRAW R(I),C(I)
9750 | NEXT I
9760 Wait_: | SETGU                                | THIS ROUTINE PRESENTS THE PLOT TO THE
9770 | LINE TYPE 1                                | OPERATOR TO STUDY UNTIL READY TO CONTINUE
9780 | LDIR 0
9790 | MOVE 2,2
9800 | CSIZE 2
9810 | LABEL "PRESS CONT"
9820 | CSIZE 15/4.54
9830 | SETUU
9840 | BEEP
9850 | WAIT 250
9860 | BEEP
9870 | PAUSE
9880 | EXIT GRAPHICS
9890 | SUBEXIT
9900 Digit: GRAPHICS
9910 | POINTER Z3,0
9920 | DIGITIZE Z3,Y
9930 | LINE TYPE 5
9940 | MOVE Z3,Y_bullet
9950 | DRAW Z3,-Y_bullet
9960 | SETGU
9970 | LDIR 0
9980 | LINE TYPE 1
9990 | LORG 5
10000 | CSIZE 2.5
10010 | Centerx=72.5 | CHANGE IN Laxes also
10020 | MOVE 1.5*Centerx,5
10030 | LABEL USING 10040:Z3
10040 | IMAGE "Image Plane : ",DD.DD," inches"
10050 | SETUU
10060 | CSIZE 15/4.54
10070 | WAIT 2500
10080 | EXIT GRAPHICS
10090 | SUBEXIT
10100 Dump_it: PRINTER IS 0
10110 | PRINT CHR$(27)&"s100T"
10120 | DUMP GRAPHICS
10130 | PRINT CHR$(27)&"s136T"
10140 | PRINTER IS 16
10150 | RETURN
10160 SUBEND
10170 SUB Plot
10180 OPTION BASE 0
10190 |
10200 COM INTEGER I,J,Curve,Np,Nn,N,Ns,Nr,REAL Aneg(*),Apos(*),R(*),Z1,Z3,Z4
10210 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Phi,Tol,Mora,Alpha2
10220 COM M1,N2,N3,Percent_image,Ya,Yb,Aperture,Y_bullet
10230 |
10240 COM INTEGER Y0_loop,Nray,Add_ray,Surf_no,Flag,Flag2,N_increment,Mit_total
10250 COM INTEGER Linecount,Lineax
10260 COM INTEGER Pselect,Mpb
10270 |
10280 COM REAL Nmin,Nmax,R0_max
10290 COM Ray_traces,Digitizes,Grins,Gs,Grincs,Plots,Dates
10300 COM X(*),Y(*),Xc(*),N(*),R(*)
10310 |
10320 COM Rho(*),Phi(*),C(*),Y3(*),Mit(*)

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10330 |
10340 | THE ORIGINAL VERSION OF THIS ROUTINE IS LOCATED IN THE HP-9845
10350 | LIBRARY TAPE No. TWO SER: .09845-10205 PROGRAM "REGPLT"
10360 |
10370 |
10380 | FMAX AND FMIN HAVE BEEN MADE INTO SUBROUTINES
10390 |
10400 Set_up: IF (Plots="P") OR (Plots="p") THEN P9872a
10410 Crt: PLOTTER IS 13,"GRAPHICS"
10420 GOTO 10440
10430 P9872a: PLOTTER IS Pselect,Hpib,"9872A"
10440 GCLEAR
10450 LIMIT 0,104,0,140 ! ALL UNITS IN MILLIMETERS
10460 LINE TYPE 1
10470 LDIR 0
10480 LORG 3
10490 |
10500 DATA -2,-1,1,2
10510 READ Um,Dm,Md,Mu
10520 DATA .39794,.69897,.87506
10530 READ Log2,Log5,Log7
10540 |
10550 IF (Grinc#"Y") OR (Grinc#"y") THEN Grinc
10560 IF (Gs#"Y") OR (Gs#"y") THEN Grin
10570 IF (Digitize#"Y") OR (Digitize#"y") THEN Digit
10580 IF (Ray_traces#"Y") OR (Ray_traces#"y") THEN Ray
10590 |
10600 Ray:Xmin=Xorg=Yorg=0
10610 Xmax=10
10620 Ymax=Y_bullet
10630 Ymin=-Ymax
10640 PRINT PAGE," Xmax is the maximum length along the GLM axis which you"
10650 PRINT "want to be displayed."
10660 PRINT LIN(1)," A rule of thumb is to pick a typical value of Xc (the
X-intercept"
10670 PRINT "from the printed output for the ray trace and add one inch to"
10680 PRINT "that value. For example: if the majority of the Xc values liste
d"
10690 PRINT "have values around 5.6, then key in 6.6 and PRESS CONT."
10700 Ray1:INPUT "WHAT IS THE VALUE OF Xmax (DEFAULT VALUE IS 10.0 INCHES ) ?",X
max
10710 IF Xmax<=Xmin THEN BEEP
10720 IF Xmax<=Xmin THEN DISP "Xmax MUST BE > Xmin = 0. PLEASE RE-ENTER
Xmax."
10730 IF Xmax<=Xmin THEN WAIT 2500
10740 IF Xmax<=Xmin THEN Ray1
10750 Ray_scale: LOCATE 15,130,25,100 ! ALL UNITS IN GDU'S
10760 GOSUB Same
10770 | SCALE Xmin=.5*Xfudge,Xmax+.5*ABS(Ytic),-Y_bullet-.25*ABS(Ytic),
Y_bullet+.25*ABS(Ytic)
10780 | SCALE Xmin=.5*ABS(Ytic),Xmax+.5*ABS(Ytic),-Y_bullet-.25*ABS(Yti
c),Y_bullet+.25*ABS(Ytic)
10790 | CLIP Xmin=.5*Xfudge,Xmax+.5*ABS(Ytic),-Y_bullet-.25*ABS(Ytic),
Y_bullet+.25*ABS(Ytic)
10800 | CLIP Xmin=.5*ABS(Ytic),Xmax+.5*ABS(Ytic),-Y_bullet-.25*ABS(Yti
c),Y_bullet+.25*ABS(Ytic)
10810 GOSUB Same_axes
10820 CLIP Xmin,100,-Y_bullet,Y_bullet
10830 SUBEXIT
10840 Digit: LOCATE 0,130,30,100 ! ALL UNITS IN GDU'S
10850 Xmax=Y_bullet
10860 Xmin=-Xmax
10870 Xorg=Yorg=0
10880 Ymax=1
10890 Ymin=0
10900 GOSUB Same
10910 Digit1_scale: SCALE -Y_bullet-.15*ABS(Ytic),Y_bullet+.15*ABS(Ytic),-.15*AB

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S(Ytic),1+.15*ABS(Ytic)
10920 CLIP -Y_bullet-.15*ABS(Ytic),Y_bullet+.15*ABS(Ytic),-.15*AB
S(Ytic),1+.15*ABS(Ytic)
10930 GOSUB Same_axes
10940 SUBEXIT
10950 Grin: GOTO Ray
10960 Grinc: LOCATE 18,133,20,101 ! ALL UNITS IN GDU'S
10970 Xorg=Yorg=0
10980 GOSUB Min_c
10990 GOSUB Max_c
11000 Ymin=Cmin=Minc
11010 Ymax=Cmax=Maxc
11020 GOSUB Min_r
11030 GOSUB Max_r
11040 Xmax=Maxr
11050 Xmin=Minr
11060 Grinc_scale: GOSUB Same
11070 SCALE Xmin,Xmax+ABS(Xtic),Ymin,Ymax+ABS(Ytic)
11080 CLIP Xmin,Xmax+ABS(Xtic),Ymin,Ymax+ABS(Ytic)
11090 GOSUB Same_axes
11100 SUBEXIT
11110 Same: Lx=LGT(Xmax-Xmin)
11120 Ly=LGT(Ymax-Ymin)
11130 Xfudge=.20*(Xmax-Xmin)
11140 Yfudge=.20*(Ymax-Ymin)
11150 Ticks: Testxtic=FRACT(Lx)*(Ly<0)
11160 Testytic=FRACT(Ly)*(Ly<0)
11170 Xtic=10^(INT(Lx)-1)*(1+.5*(Testxtic>Log2) AND (Testxtic>Log5)
+4*(Testxtic>Log5) AND (Testxtic>Log7))+6.5*(Testxtic>Log7)
11180 Ytic=10^(INT(Ly)-1)*(1+.5*(Testytic>Log2) AND (Testytic>Log5)
+4*(Testytic>Log5) AND (Testytic>Log7))+6.5*(Testytic>Log7)
11190 RETURN
11200 Same_axes: CALL Laxes(Xtic,Ytic,Xorg,Yorg,Xmaj,Ymaj,Minticsize,Xmin,Xmax,
Ymin,Ymax,Minr,Maxr)
11210 RETURN
11220 Min_r: Minr=R(0)
11230 FOR I=1 TO Nray
11240 Minr=MIN(Minr,R(I))
11250 NEXT I
11260 RETURN
11270 Max_r: Maxr=R(0)
11280 FOR I=1 TO Nray
11290 Maxr=MAX(Maxr,R(I))
11300 NEXT I
11310 RETURN
11320 Min_c: Minc=C(0)
11330 FOR I=1 TO Nray
11340 Minc=MIN(Minc,C(I))
11350 NEXT I
11360 RETURN
11370 Max_c: Maxc=C(0)
11380 FOR I=1 TO Nray
11390 Maxc=MAX(Maxc,C(I))
11400 NEXT I
11410 RETURN
11420 SUBEND
11430 SUB Laxes(Xtic,Ytic,Xorg,Yorg,Xmaj,Ymaj,Minticsize,Xmin,Xmax,Ymin,Ymax,Min
r,Maxr)
11440 OPTION BASE 0
11450 !
11460 COM INTEGER I,J,Curve,Np,Nn,N,Ns,Nr,REAL Aneg(*),Apos(*),A(*),Z1,Z3,Z4
11470 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Phi,Tol,Norn,Alpha2
11480 COM N1,N2,N3,Percent_image,Ya,Yb,Aperture,Y_bullet
11490 !
11500 COM INTEGER Y0_loop,Nray,Add_ray,Surf_no,Flag,Flag2,N_increment,Hit_tot
11510 COM INTEGER Linecount,Lineax

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11520 COM INTEGER Pselect,Hpib
11530 |
11540 COM REAL Nmin,Nmax,R0_max
11550 COM Ray_traces,Digitize$,Grin$,G$,Grinc$,Plot$,Date$
11560 COM X(*),Y(*),Xc(*),N(*),R(*)
11570 |
11580 COM Rho(*),Phi(*),C(*),Y3(*),Hit(*)
11590 |
11600 DEG
11610 LINE TYPE 1
11620 LDIR 0
11630 LORG 5
11640 IF (Xmin)=Xmax) OR (Ymin)=Ymax) THEN SUBEXIT
11650 GRAPHICS
11660 Xfudge=.02*(Xmax-Xmin)
11670 Yfudge=.02*(Ymax-Ymin)
11680 Xmaj=1
11690 Ymaj=1
11700 Minticsize=2
11710 |
11720 IF (Grinc$="Y") OR (Grinc$="y") THEN Grinc
11730 IF (G$="Y") OR (G$="y") THEN Grin
11740 IF (Digitize$="Y") OR (Digitize$="y") THEN Digit
11750 IF (Ray_traces="Y") OR (Ray_traces="y") THEN Ray
11760 |
11770 Grinc: LINE TYPE 3
11780 GRID Xtic,Ytic,Xorg,Yorg,Xmaj,Ymaj,2*Minticsize
11790 LINE TYPE 1
11800 FRAME
11810 GOTO Labelx_grinc
11820 Grin: GOTO Ray
11830 ! Digit: AXES .1,.1,0,0,1,1,2
11840 Digit: AXES Xtic,.1,0,0,1,1,2
11850 GOTO Labelx_d
11860 Ray: AXES Xtic,Ytic,Xorg,Yorg,Xmaj,Ymaj,Minticsize
11870 Labelx: LDIR 90
11880 LORG 0
11890 FOR A=Xorg TO Xmax STEP ABS(Xtic)
11900 MOVE A,Yorg-Yfudge
11910 IF A=0 THEN LABEL USING 11920;A
11920 IMAGE 0,K
11930 IF A=0 THEN GOTO 11960
11940 LABEL USING 11950;A
11950 IMAGE 000.D,K
11960 NEXT A
11970 Labely: LDIR 0
11980 LORG 0
11990 FOR A=-Y_bullet TO Y_bullet STEP ABS(Ytic)
12000 MOVE Xorg-Xfudge,A
12010 IF A=0 THEN LABEL USING 11920;A
12020 IF A=0 THEN GOTO 12040
12030 LABEL USING 11950;A
12040 NEXT A
12050 GOTO Label_
12060 |
12070 Labelx_d: LDIR 90
12080 LORG 0
12090 ! FOR A=-Y_bullet TO Y_bullet STEP .1
12100 FOR A=-Y_bullet TO Y_bullet STEP ABS(Xtic)
12110 MOVE A,Yorg-Yfudge
12120 IF A=0 THEN LABEL USING 11920;A
12130 IF A=0 THEN GOTO 12150
12140 LABEL USING 11950;A
12150 NEXT A
12160 Labely_d: LDIR 0
12170 LORG 0
12180 FOR A=0 TO Ymax STEP .1

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12190      MOVE Xorg-Xfudge,A
12200      IF A=0 THEN LABEL USING 11920;A
12210      IF A=0 THEN GOTO 12230
12220      LABEL USING 11950;A
12230      NEXT A
12240      GOTO Label_
12250      !
12260 Labelx_grinc: LDIR 90
12270      LORG 8
12280      FOR A=Xorg TO Xmax+ABS(Xtic) STEP ABS(Xtic)
12290      MOVE A,Yorg-Yfudge
12300      LABEL USING 12310;A
12310      IMAGE 8,K
12320      NEXT A
12330 Labely_grinc: LDIR 0
12340      LORG 8
12350      FOR A=Yorg TO Ymax+ABS(Ytic) STEP ABS(Ytic)
12360      MOVE Xorg-Xfudge,A
12370      LABEL USING 12310;A
12380      NEXT A
12390      !
12400 Label_: LDIR 0
12410      LORG 5
12420      MOVE -10*Xmax,0
12430      LABEL "RESET CR/LF"
12440      SETGU
12450      CSIZE 2.5
12460      IF (Grinc$="Y") OR (Grinc$="y") THEN Grinc_label
12470      IF (Gs$="Y") OR (Gs$="y") THEN Grin_label
12480      IF (Digitize$="Y") OR (Digitize$="y") THEN Digit_label
12490      IF (Ray_trace$="Y") OR (Ray_trace$="y") THEN Ray_label
12500      !
12510 Ray_label: Centerx=72.5      ! CHANGE IN Graph ALSO
12520      Centery=62.5
12530      MOVE 1.5*Centerx,13
12540      LABEL USING 12550;Nray
12550      IMAGE "Number of Rays : ",K
12560      MOVE .5*Centerx,9
12570      LABEL USING 12580;Rho_initial
12580      IMAGE "Incident Ray Angle : ",3D.DD," deg"
12590      MOVE .5*Centerx,5
12600      LABEL USING 12610;N2
12610      IMAGE "n2 : ",D.DDDDD
12620      MOVE 1.5*Centerx,9
12630      LABEL USING 12640;Aperture
12640      IMAGE "Aperture : ",D.DDD," inch"
12650      MOVE Centerx,20
12660      LABEL "Distance Along the GLM Axis (inches)"
12670      !
12680      CSIZE 3
12690      MOVE .5*Centerx,13
12700      LABEL USING 12710;Curve
12710      IMAGE "Curve Number : ",K
12720      LDIR 90
12730      MOVE 1.5,Centery
12740      LABEL "Radial Distance From the Axis (inches)"
12750      LDIR 0
12760      CSIZE 19/4.54
12770      GOTO Label_end
12780      !
12790 Digit_label: Centerx=65
12800      Centery=65
12810      MOVE 1.5*Centerx,13
12820      LABEL USING 12850;Nray
12830      MOVE .5*Centerx,9
12840      LABEL USING 12850;Hit_total

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12850      IMAGE "Number of Hits on the Image Plane : ",K
12860      MOVE 1.5*Centerx,9
12870      LABEL USING 12880;Percent_image
12880      IMAGE "% of Rays to Image Plane : ",3D,DD
12890      MOVE 1.5*Centerx,5
12900      LABEL USING 12910;Z3
12910      IMAGE "Image Plane : ",DDD,DD," inches"
12920      MOVE .5*Centerx,5
12930      LABEL USING 12940;N_increment
12940      IMAGE "Number of Increments [0,1.1] : ",K
12950      |
12960      CSIZE 3
12970      MOVE Centerx,20
12980      LABEL "Normalized Number of Hits vs Distance from the Axis"
12990      MOVE .5*Centerx,13
13000      LABEL USING 12710;Curve
13010      IMAGE "Curve Number : ",K
13020      GOTO Label_end
13030      |
13040 Grin_label: Centerx=72.5
13050      Centery=62.5
13060      CSIZE 2.5
13070      MOVE .5*Centerx,13
13080      LABEL USING 13090;N1
13090      IMAGE "n1 : ",DD,DDDDD
13100      MOVE .5*Centerx,9
13110      LABEL USING 13120;N3
13120      IMAGE "n3 : ",DD,DDDDD
13130      MOVE 1.5*Centerx,13
13140      LABEL USING 13150;Alpha
13150      IMAGE "Alpha : ",DD,DD," degrees"
13160      MOVE 1.5*Centerx,9
13170      LABEL USING 13180;Nray
13180      IMAGE "Number of Rays : ",K
13190      CSIZE 3
13200      MOVE Centerx,20
13210      LABEL "GRIN TRACE"
13220      LDIR 90
13230      MOVE 1.5,Centery
13240      LABEL "Radial Distance From the Axis ( inches )"
13250      GOTO Label_end
13260      |
13270 Grinc_label: CSIZE 3
13280      LORG 5
13290      LDIR 0
13300      Centerx=74
13310      Centery=64
13320      MOVE Centerx,5
13330      LABEL "Radius From the Origin (inches)"
13340      LDIR 90
13350      MOVE 1.5,Centery
13360      LABEL "Gradient Index Constant : C(r) (inches)"
13370      |
13380 Label_end: CSIZE 15/4.54
13390      LDIR 90
13400      LORG 5
13410      SETUU
13420      SUBEND
13430 SUB Xipos(X,Y)
13440      OPTION BASE 0
13450      |
13460      COM INTEGER I,J,Curve,Np,Nn,N,Ns,Nn,REAL Aneq(*),Apos(*),A(*),Z1,Z3,Z4
13470      COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Phi,Tol,Norm,Alpha2
13480      COM N1,N2,N3,Percent_image,Ya,Yb,Aperture,Y_bullet
13490      |
13500      COM INTEGER Y0_loop,Nray,Add_ray,Surf_no,Flag,Flag2,N_increment,Hit_tota
|

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13510 !
13520 DEG
13530 DEF FNY1(Y)=Y+Talpha/(Talpha-Trho) ! FINDS THE Y-VALUE OF THE INTERCEPT
13540 ! OF THE RAY AND THE FIRST SURFACE
13550 DEF FNX1(Y)=Y/Talpha ! FINDS THE X-VALUE OF THE INTERCEPT OF THE RAY
13560 ! AND THE FIRST SURFACE
13570 IF Surf_no=2 THEN Whoops
13580 Y=FNY1(Y)
13590 Whoops:X=FNX1(Y)
13600 SUBEND
13610 SUB Xineg(X,Y)
13620 OPTION BASE 0
13630 !
13640 COM INTEGER I,J,Curve,Np,Nn,N,Ns,Nr,REAL Aneg(*),Apos(*),A(*),Z1,Z3,Z4
13650 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Phi,Tol,Norm,Alpha2
13660 COM N1,N2,N3,Percent_image,Ya,Yb,Aperture,Y_bullet
13670 !
13680 COM INTEGER Y0_loop,Nray,Add_ray,Surf_no,Flag,Flag2,N_increment,Hit_total
13690 !
13700 DEG
13710 Alphan=-1*Alpha
13720 Talphan=TAN(Alphan)
13730 DEF FNY1(Y)=Y+Talphan/(Talphan-Trho) ! FINDS THE Y-VALUE OF THE INTERCEPT
13740 ! OF THE RAY AND THE FIRST SURFACE
13750 DEF FNX1(Y)=Y/Talphan ! FINDS THE X-VALUE OF THE INTERCEPT OF THE RAY
13760 ! AND THE FIRST SURFACE
13770 IF Surf_no=2 THEN Whoops
13780 Y=FNY1(Y)
13790 Whoops:X=FNX1(Y)
13800 SUBEND
13810 SUB Dialogue
13820 OPTION BASE 0
13830 !
13840 COM INTEGER I,J,Curve,Np,Nn,N,Ns,Nr,REAL Aneg(*),Apos(*),A(*),Z1,Z3,Z4
13850 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Phi,Tol,Norm,Alpha2
13860 COM N1,N2,N3,Percent_image,Ya,Yb,Aperture,Y_bullet
13870 !
13880 COM INTEGER Y0_loop,Nray,Add_ray,Surf_no,Flag,Flag2,N_increment,Hit_total
13890 !
13890 COM INTEGER Linecount,LineMAX
13900 COM INTEGER Pselect,Hpib
13910 !
13920 COM REAL Nmin,Nmax,R0_max
13930 COM Ray_traces,Digitizes,Grins,Gs,Grincs,Plots,Dates
13940 COM X(*),Y(*),Xc(*),N(*),R(*)
13950 !
13960 COM Rho(*),Phi(*),C(*),Y3(*),Hit(*)
13970 !
13980 DEG
13990 Initialize_top:Alpha=21
14000 Talpha=TAN(Alpha)
14010 Rho_initial=0
14020 Trho_i=TAN(Rho_initial)
14030 !
14040 Tol=.00001
14050 Z3=Z4=50
14060 N1=N3=1
14070 N2=1.5
14080 !
14090 Nray=10 ! IN ORDER TO OUTLINE THE APERTURE AN EXTRA RAY
14100 Add_ray=0 ! MUST BE ADDED IF Ya # 0
14110 Ya=0
14120 Yb=Y_bullet
14130 Aperture=Ya-Yb
14140 !
14150 Y_bullet=1.1

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14160          N_increment=100
14170          |
14180          Linecount=0
14190          Linemax=46
14200          |
14210          Nmax=4
14220          Nmin=2
14230          Ym2=(1.05*Y_bullet/2)^2 ! THE 1.05 IS A FUDGE FACTOR TO
14240          Xm2=(1.05*Y_bullet/(2+Talpha))^2 !PREVENT THE RADIUS FROM
14250          R0_max=SQR(Xm2+Ym2) ! BECOMING TOO SMALL AND CAUSING A
14260          | NUMERICAL ERROR IN THE INDEX SUBROUTINES

14270          Pselect=7
14280          Mpi=5
14290          |
14300          Grin$="C"
14310          G$="N"
14320          Grinc$="N"
14330          Plot$="C"
14340          Digitize$="N"
14350          Date$=""
14360 REM *** TEMP ***
14370 GOTO Alpha
14380 REM *** TEMP ***
14390 Begin: PRINT PAGE," The following drawing illustrates the optical proble
m"
14400 PRINT "which this program attempts to solve; focousing monochroati
c "
14410 PRINT "light rays through a conical lens for a Gun-Launched-Missile
(GLM). "
14420 PRINT " The picture is also labeled showing the various quantitie
s"
14430 PRINT "Please study the picture and become familiar with it. The va
riables"
14440 PRINT "will be explained as they appear in the program."
14450 PRINT LIN(2),"PRESS CONT"
14460 PAUSE
14470 CALL Picture
14480 PRINT PAGE," Z1 is the intercept of the second surface and the"
14490 PRINT "the GLM-axis. Therefore, the value of Z1 is APOS(0). "
14500 PRINT LIN(1),"NOTE: Apos(0) is the constant term in the polynomia
l used"
14510 PRINT " to describe the second surface of the lens in the "
14520 PRINT " upper half-plane."
14530 PRINT " The (min,max) values of Z1 are [0,infinity] inches."
14540 PRINT LIN(2),"PRESS CONT"
14550 PAUSE
14560 PRINT PAGE," There are two planes used as image planes. The first
is "
14570 PRINT "located at X=Z3 (default value = ";Z3;"inches). This locatio
n"
14580 PRINT "is programmable, according to the needs of the particular pr
oblem."
14590 PRINT "You key in the new location when locating the position of "
14600 PRINT "maximum ray density, or when a new run is begun. Directions
will "
14610 PRINT "be provided at the appropriate time."
14620 PRINT LIN(1)," The second image plane is permanent, located at X=
Z4 = ";Z4;"inches."
14630 PRINT LIN(2),"PRESS CONT"
14640 PAUSE
14650 PRINT PAGE," This program will trace mochromatic light rays which
arrive"
14660 PRINT "at the first surface parallel or at an angle to the GLM axis
"
14670 PRINT "Non-axial rays approach the GLM from 'above', for all rays a
re "

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14680 PRINT "initiated in the upper half of the meridian plane."
14690 PRINT LIN(2),"PRESS CONT"
14700 PAUSE
14710 PRINT PAGE," The program uses Snell's Law without approximation."
14720 PRINT "The appropriate variables are:"
14730 PRINT LIN(1)," 1) Norm = dy/dx = slope of the normal to the s
urface"
14740 PRINT " 2) Thetal = angle of incidence with respect to the surf
ace normal."
14750 PRINT " 3) Thetar = angle of refraction with respect to the sur
face normal."
14760 PRINT " 4) Rho = angle of the ray with respect to the GLM-axis"
14770 PRINT " (subscripts indicate the region the ray is in)
"
14780 PRINT LIN(2),"PRESS CONT"
14790 PAUSE
14800 PRINT PAGE,"The sign convention is : "
14810 PRINT LIN(1)," 1) the origin is placed at the vertex of the first su
rface."
14820 PRINT " 2) distances: (a) positive to the right of the origin."
14830 PRINT " (b) positive above the origin (Y-axis)."
14840 PRINT " (c) positive out of the meridian plane (screen
)."
14850 PRINT " (ie. a right hand system.)"
14860 PRINT " 3) angles: slope = Alpha2 is POSITIVE for counter-clockwise"
14870 PRINT " rotation from the GLM-axis to the ray"
14880 PRINT " 4) symbols: unprimed = object space."
14890 PRINT " primed = image space."
14900 PRINT LIN(2),"PRESS CONT"
14910 PAUSE
14920 Alpha:PRINT PAGE," Alpha is the angle of inclination of the "
14930 PRINT "FIRST surface with respect to the GLM-AXIS"
14940 PRINT LIN(3)," The current value of ALPHA is";Alpha;"degrees"
14950 INPUT "WHAT IS THE NEW VALUE OF ALPHA (DEGREES)?",Alpha
14960 Index:PRINT PAGE," The lens system is assumed to be operating in air."
14970 PRINT "Therefore the first index of refraction = n1= 1.00000"
14980 PRINT LIN(1)," It is assumed that n1 < n2 for the homogeneous and gra
dient cases."
14990 PRINT LIN(1)," You are free to choose any values for n2 and n3 for the
homogeneous case. "
15000 PRINT LIN(2),"PRESS CONT"
15010 PAUSE
15020 PRINT PAGE," The program has the capability to use a gradient index of
refraction (GRIN)."
15030 PRINT "Two GRIN subroutines are available:"
15040 PRINT LIN(1)," 1) Parabola : the index of region 2 (the lens) v
aries "
15050 PRINT " as a parabola from a min at the vertex"
15060 PRINT " to a maximum (at a radius specified by yo
u)"
15070 PRINT " then down to a value determined by the "
15080 PRINT " top of the GLM"
15090 PRINT " The equation is [ n(r) = k * r^2 ]"
15100 PRINT LIN(1)," 2) Circle : the index varies as a circle whose c
enter is located"
15110 PRINT " at a specified radius from the origin"
15120 PRINT " The equation is [ n(r) = SQR( R0_max^2 + r^
2 ) ]"
15130 PRINT LIN(1),"The radius (for circle) has a minimum value which is half
the "
15140 PRINT "length of the first surface; approximately ";R0_max;" inches."
15150 PRINT LIN(1)," You are free to choose any value for n3 for the GRIN ca
se."
15160 PRINT LIN(2),"PRESS CONT"
15170 PAUSE
15180 Gs="N"
15190 INPUT "ARE YOU GOING TO USE GRIN ? Y/N",Gs

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15200 IF (Gs="N") OR (Gs="n") THEN N2
15210 PRINT PAGE," Required data for grin : "
15220 PRINT LIN(1)," 1) Nmin = minimum value of the index of"
15230 PRINT " of refraction ( default = ";Nmin;" )"
15240 PRINT " 2) Nmax = maximum value of the index (not required for"
15250 PRINT " ( Default = ";Nmax;" )"
15260 PRINT " 3) R0_max = radius from the origin at which the maximum"
15270 PRINT " value of the index occurs. ( MINIMUM = ";R0"
15280 PRINT " max; )"
15280 INPUT "WHICH ONE : CIRCLE (C) OR PARABOLA (P) ( DEFAULT = C ) ? C/P",Grin$
15290 INPUT "WHAT IS Nmin ?",Nmin
15300 IF (Grin$="C") OR (Grin$="c") THEN N3
15310 INPUT "WHAT IS Nmax ?",Nmax
15320 INPUT "WHAT IS R0_max ?",R0_max
15330 N2:INPUT "WHAT IS n2 ?",N2
15340 N3:INPUT "WHAT IS n3 ?",N3
15350 IF (Gs="N") OR (Gs="n") THEN Rho_initial
15360 PRINT LIN(2),"NOTE: When the parameter data is printed, the values"
15370 PRINT " of " the index at the first surface intercept will be "
15380 PRINT " printed in the following manner:"
15390 PRINT " n(8) = 2.3543 n(9) = 2.3567 n(10) = 1.9876"
15400 PRINT " The subscript indicates the number of the ray intercepti"
15410 PRINT " ng" the first surface."
15420 PRINT LIN(2),"PRESS CONT"
15430 PAUSE
15440 Rho_initial:PRINT PAGE," The rays incident on the first surface are "
15450 PRINT " initially assumed to be parallel to the X-axis. "
15460 PRINT LIN(2)," If you want to trace rays which are at an ang"
15470 PRINT " le " other than zero (0) degrees with respect to the X-axis,"
15480 PRINT " then key in the value of the angle (in degrees) with "
15490 PRINT " respect to the X-axis."
15500 INPUT "RHO ?",Rho_initial
15510 Rho_initial=-1*ABS(Rho_initial)
15520 Trho=TAN(Rho_initial)
15530 Y_bullet: PRINT PAGE," The GLM is assumed to be assumed to be symmetric"
15540 PRINT " about the" longitudinal axis. The maximum value of the GLM radius is"
15550 PRINT " called Y_bullet whose default value is ";Y_bullet;" inch"
15560 PRINT LIN(2)," If your design requires a different value, plea"
15570 PRINT " se" enter that value now."
15580 INPUT "Y_BULLET (INCHES) ?",Y_bullet
15590 Yb=Y_bullet
15600 Aperture: PRINT PAGE," The aperture is the difference in radial distance"
15610 PRINT " from the GLM axis" projected onto the first surface,into which light is allo"
15620 PRINT " used to enter" the GLM optical system. The parameters are : "
15630 PRINT LIN(1)," 1) Ya : the minimum Y-value of the aperture"
15640 PRINT " (default value =";Ya;"inch )"
15650 PRINT " 2) Yb : the maximum Y-value of the aperture"
15660 PRINT " (default value =";Yb;"inch) and is  $\leq$  Y_bulle"
15670 INPUT "WHAT IS Ya (INCHES) ?",Ya
15680 INPUT "WHAT IS Yb (INCHES) ?",Yb
15690 IF Ya>Yb THEN BEEP
15700 IF Ya>Yb THEN PRINT "Ya must be < Yb. Please enter again."
15710 IF Ya>Yb THEN GOTO 15670

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15720      Aperture=Yb-Ya
15730      IF Ya<>0 THEN Add_ray=1
15740 Nray: PRINT PAGE," The program will trace";Nray;" rays through the syste
n unless "
15750      PRINT "you specify another value"
15760      INPUT " How many rays do you want the program to trace?",Nray
15770      Nray=INT(ABS(Nray))
15780      IF Nray<1 THEN Nray=10
15790      IF (Gs="Y") OR (Gs="y") THEN Date
15800 Digitize: PRINT PAGE," The interval between (0 ≤ Y ≤ ";Y_bullet;")
and (-";Y_bullet;" ≤ Y ≤ 0) have been divided"
15810      PRINT "into";N_increment;" increments to determine ray density.
"
15820      PRINT LIN(1),"If you want to change the number of increments, p
lease do so now."
15830      PRINT LIN(2),"The maximum number of increments is 1000."
15840      INPUT "NUMBER OF INCREMENTS ?",N_increment
15850      N_increment=INT(ABS(N_increment))
15860      IF N_increment<1 THEN N_increment=100
15870 Date:PRINT PAGE
15880      INPUT "What is today's date ?",Date$
15890 Start: IF (Gs="Y") OR (Gs="y") THEN Gymnastics
15900      PRINT PAGE," The second surface must be input as polynomial of de
gree "
15910      PRINT "16 or less, defined as a function of Y [ x=f(y) for (x,y) sy
stem ]"
15920      PRINT "If you have not fit a curve to your data, then go to the uti
lities "
15930      PRINT "library,tape two and load REGD. "
15940      PRINT "NOTE : 1) Use printer code 0 for a hard copy"
15950      PRINT "                2) Invert the X and Y values for the positive branch"
15960      PRINT "                3) Key in (Y,-X) for the negative branch"
15970      PRINT LIN(1),"NOTE : The negative branch is the second surface in
"
15980      PRINT "                the lower half plane"
15990      PRINT LIN(1)," If this is the case, then PRESS STOP, then REWIND
T15 "
16000      PRINT "fit your curve using the utilities library."
16010      PRINT LIN(1)," If not, then PRESS CONT."
16020      PAUSE
16030 Coef_data:PRINT PAGE      | THE FOLLOWING DATA ARE ARRANGED AS FOLLOWS:
16040      | DATA CURVE No.
16050      | DATA NP,NN,N
16060      | DATA APOS COEFFICIENTS X=f(Y) FOR Y>0
16070      | DATA ANEG COEFFICIENTS X=f(Y) FOR Y<0
16080      | DATA Y=F(X) COEFFICIENTS
16090      |
16100      | DATA 1 | CURVE No. ONE
16110      | DATA 4,4,4
16120      | DATA .5003067966,1.15219319,3.0130759,-3.4182912,1.39217781
16130      | DATA .5003067966,-1.15219319,3.0130759,3.4182912,1.39217781
16140      | DATA -.45216106,1.18544007,-.66358797,.25054923,-.034174038
16150      |
16160      |
16170      | DATA 2 | CURVE No. 10
16180      | DATA 3,3,3
16190      | DATA 1.5193756399,2.27918152,-2.5230983,1.63047031
16200      | DATA 1.5193756399,-2.27918152,-2.5230983,-1.63047031
16210      | DATA 3.3554752,-5.6049365,2.959523,-.4412078
16220      |
16230      |
16240      | DATA 3 | CURVE No. 11
16250      | DATA 6,6,3
16260      | DATA 2.006223634,.30397,12.96206,-62.1500,125.7966,-114.0765,30
.06104
16270      | DATA 2.006223634,-.30397,12.96206,62.1500,125.7966,114.0765,30.
06104

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16280      DATA -11.285773,13.18159,-5.328168,.767881
16290      |
16300      |
16310      DATA 4      | SURFACE NR 1 FOR n2=4, F=4 INCHES
16320      DATA 2,2,2
16330      DATA .3184681721,2.7548136449,-.3648728143
16340      DATA .3184681721,-2.7548136449,-.3648728143
16350      DATA -.1871362125,.3341667828,.82751837881
16360      |
16370      |
16380 Explain: PRINT " Since this program is intended to be used to evaluate"
16390 PRINT "various second surfaces a method of labeling the current"
16400 PRINT "design surface has been incorporated into the algorithm."
16410 PRINT " The program will ask you for a curve number. At that"
16420 PRINT "time, key in any number (integer or real) you wish to use"
16430 PRINT "identify the surface."
16440 PRINT LIN(2),"PRESS CONT"
16450 PAUSE
16460 Coef_pos: PRINT PAGE,"The current values of Curve and Np (the degree"
16470 PRINT "of the positive branch  $x = f(y)$  ) are:"
16480 READ Curve,Np,Nn,N
16490 PRINT LIN(1)," Curve = ";Curve
16500 PRINT " Np = ";Np
16510 INPUT "WHICH CURVE ARE YOU USING (CURVE No.) ?",Curve
16520 INPUT "WHAT IS THE DEGREE OF THE POLYNOMIAL FOR THE POSITIVE BR"
16530 ANCH (Np) ?",Np PRINT LIN(2)
16540 Quick_loop_p: PRINT "NOTE: These are the current values of the positive"
16550 branch coefficients:"
16560 PRINT
16570 FOR I=0 TO Np
16580 READ Apos(I)
16590 PRINT USING 16590;I,Apos(I)
16600 IMAGE "Apos("4D") = ",K
16610 NEXT I
16620 PRINT
16630 Z1=Apos(0)
16640 Anys="NONE"
16650 INPUT "ARE YOU GOING TO CHANGE ANY OF ALL OF THE COEFFICIENTS ? SOME/ALL/"
16660 NONE ",Anys
16670 IF (Anys="NONE") OR (Anys="none") THEN None_p
16680 IF (Anys="SOME") OR (Anys="some") THEN Some_p
16690 All_p:PRINT
16700 PRINT "Please key in the coefficients, beginning with the constant:"
16710 FOR I=0 TO Np
16720 INPUT "",Apos(I)
16730 PRINT USING 16590;I,Apos(I)
16740 NEXT I
16750 None_p: PRINT
16760 Ys="N"
16770 INPUT "DO YOU NEED TO MAKE ANY CORRECTIONS ? Y/N",Ys
16780 IF (Ys="N") OR (Ys="n") THEN Coef_neg
16790 Some_p: INPUT "WHAT IS THE NUMBER OF THE COEFFICIENT ? (0,1,2, etc)",Npp
16800 INPUT "KEY IN THE CORRECT VALUE, THEN CONT",Apos(Npp)
16810 PRINT USING 16590;Npp,Apos(Npp)
16820 Ys="Y"
16830 INPUT "IS THAT ALL",Ys
16840 IF (Ys="Y") OR (Ys="y") THEN Coef_neg
16850 IF (Anys="SOME") OR (Anys="some") THEN Some_p
16860 GOTO Some_p
16870 Coef_neg: PRINT PAGE,"The current values of Curve and Nn (the degree"
16880 PRINT "of the negative branch  $x = f(-y)$  ) are:"
16890 PRINT LIN(1)," Curve = ";Curve
16900 PRINT " Nn = ";Nn
16910 INPUT "WHAT IS THE DEGREE OF THE NEGATIVE BRANCH POLYNOMIAL (Nn)"
16920 "?",Nn
16930 Quick_loop_n:PRINT LIN(2),"NOTE: These are the current values of the neg

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ative branch coefficients:"
16910 PRINT
16920 FOR I=0 TO Nn
16930 READ Aneg(I)
16940 PRINT USING 16950;I,Aneg(I)
16950 IMAGE "Aneg("4D") = ",K
16960 NEXT I
16970 PRINT
16980 Anys="NONE"
16990 INPUT "ARE YOU GOING TO CHANGE ANY OF ALL OF THE COEFFICIENTS ? SOME/ALL/
NONE ",Anys
17000 IF (Anys="NONE") OR (Anys="none") THEN None_n
17010 IF (Anys="SOME") OR (Anys="some") THEN Some_n
17020 All_n:PRINT
17030 PRINT "Please key in the coefficients, beginning with the constant:"
17040 FOR I=0 TO Nn
17050 INPUT "",Aneg(I)
17060 PRINT USING 16950;I,Aneg(I)
17070 NEXT I
17080 None_n: PRINT
17090 Ys="N"
17100 INPUT "DO YOU NEED TO MAKE ANY CORRECTIONS ? Y/N",Ys
17110 IF (Ys="N") OR (Ys="n") THEN Gymnastics
17120 Some_n: INPUT "WHAT IS THE NUMBER OF THE COEFFICIENT ? (0,1,2, etc)",Nnn
17130 INPUT "KEY IN THE CORRECT VALUE, THEN CONT",Aneg(Nnn)
17140 PRINT USING 16950;Nnn,Aneg(Nnn)
17150 Ys="y"
17160 INPUT "IS THAT ALL",Ys
17170 IF (Ys="y") OR (Ys="Y") THEN Gymnastics
17180 IF (Anys="SOME") OR (Anys="some") THEN Some_n
17190 GOTO Some_n
17200 Gymnastics:SUBEND
17210 !
17220 !
17230 SUB Char
17240 FOR I=0 TO 79
17250 IF I=79 THEN PRINT CHR$(228)
17260 IF I=79 THEN 17280
17270 PRINT CHR$(228);
17280 NEXT I
17290 SUBEND
17300 SUB X2pos(X2,Y)
17310 OPTION BASE 0
17320 COM INTEGER I,J,Curve,Np,Nn,N,Ns,Nr,REAL Aneg(*),Apos(*),A(*),Z1,Z3,Z4
17330 !
17340 FOR I=0 TO Np
17350 X2=X2+Apos(I)*Y^I
17360 NEXT I
17370 SUBEND
17380 SUB X2neg(X2,Y)
17390 OPTION BASE 0
17400 COM INTEGER I,J,Curve,Np,Nn,N,Ns,Nr,REAL Aneg(*),Apos(*),A(*),Z1,Z3,Z4
17410 !
17420 FOR I=0 TO Nn
17430 X2=X2+Aneg(I)*Y^I
17440 NEXT I
17450 SUBEND
17460 SUB Index_p(X,Y)
17470 OPTION BASE 0
17480 !
17490 COM INTEGER I,J,Curve,Np,Nn,N,Ns,Nr,REAL Aneg(*),Apos(*),A(*),Z1,Z3,Z4
17500 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Phi,Tol,Norm,Alpha2
17510 COM N1,N2,N3,Percent_image,Ya,Yb,Aperture,Y_bullet
17520 !
17530 COM INTEGER Y0_loop,Nray,Add_ray,surf_no,Flag,Flag2,N_increment,Hit_tota
17540 COM INTEGER Linecount,Linesax

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17550 COM INTEGER Pselect,Hpib
17560 |
17570 COM REAL Nmin,Nmax,R0_max
17580 |
17590 DEG
17600 Xa2=.60/Talpha      ! FROM y=max + b AND Ymax = 1.2
17610 Yb2=Xa2*Talpha
17620 IF R0_max<SQR(Xa2^2+Yb2^2) THEN R0_max=SQR(Xa2^2+Yb2^2)
17630 Radius=SQR(X^2+Y^2)
17640 R2=R0_max^2
17650 K=(Nmax-Nmin)/R2
17660 B=(Radius-R0_max)^2
17670 N2=Nmax+K*B
17680 SUBEND
17690 SUB Index_c(X,Y)
17700 OPTION BASE 0
17710 |
17720 COM INTEGER I,J,Curve,Np,Nn,N,Na,Nr,REAL Aneq(*),Apos(*),A(*),Z1,Z3,Z4
17730 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Phi,Tol,Norm,Alpha2
17740 COM N1,N2,N3,Percent_image,Ya,Yb,Aperture,Y_bullet
17750 |
17760 COM INTEGER Y0_loop,Nray,Add_ray,Surf_no,Flag,Flag2,N_increment,Hit_total
17770 |
17770 COM INTEGER Linecount,LineMAX
17780 COM INTEGER Pselect,Hpib
17790 |
17800 COM REAL Nmin,Nmax,R0_max
17810 |
17820 DEG
17830 Xa2=.60/Talpha      ! FROM y=max + b AND Ymax = 1.2
17840 Yb2=Xa2*Talpha
17850 IF R0_max<SQR(Xa2^2+Yb2^2) THEN R0_max=SQR(Xa2^2+Yb2^2)
17860 Radius=SQR(X^2+Y^2)
17870 A=R0_max^2
17880 B=(Radius-R0_max)^2
17890 C2=A-B
17900 N2=Nmin+SQR(C2)
17910 SUBEND
17920 SUB Density
17930 OPTION BASE 0
17940 |
17950 COM INTEGER I,J,Curve,Np,Nn,N,Na,Nr,REAL Aneq(*),Apos(*),A(*),Z1,Z3,Z4
17960 COM Alpha,Talpha,Rho,Trho,Rho_initial,Trho1,Phi,Tol,Norm,Alpha2
17970 COM N1,N2,N3,Percent_image,Ya,Yb,Aperture,Y_bullet
17980 |
17990 COM INTEGER Y0_loop,Nray,Add_ray,Surf_no,Flag,Flag2,N_increment,Hit_total
18000 |
18000 COM INTEGER Linecount,LineMAX
18010 COM INTEGER Pselect,Hpib
18020 |
18030 COM REAL Nmin,Nmax,R0_max
18040 COM Ray_traces,Digitizes,Grins,Gs,Grincs,Plots,Dates
18050 COM X(*),Y(*),Xc(*),N(*),R(*)
18060 |
18070 COM Rho(*),Phi(*),C(*),Y3(*),Hit(*)
18080 |
18090 INTEGER Inc,K,L,M,Lines
18100 DEG
18110 ! THIS ROUTINE COMPUTES THE RAY DENSITY IN ONE DIMENSION.
18120 ! ASSUMPTIONS:
18130 ! 1) THE POINT OF MAXIMUM RAY DENSITY HAS BEEN FOUND VIA A
18140 ! DIGITIZE STATEMENT.
18150 ! 2) THE VALUES OF Y3 HAVE NOT BEEN CHANGED TO REFLECT THE
18160 ! NEW VALUE OF Z3
18170 |
18180 PRINTER IS 16
18190 Initialize_: Nr=-1

```

```

10200      Ns=-3
10210 Re_draw: FOR I=1 TO Nray
10220      Nr=Nr+3
10230      Ns=Ns+5
10240      A=Xc(I)
10250      X=X(Ns)
10260      Y=Y(Ns)
10270      Rho=Rho(Nr)
10280      Trho=TAN(Rho)
10290      IF A<Z1 THEN Negative
10300 Positive: IF Rho=0 THEN Next_1 ! TOTAL INTERNAL REFLECTION AT X2POS
10310      GOTO Same
10320 Negative: IF Y<=-Y_bullet THEN Next_1 ! Y2=-Y_bullet =>THE RAY MISSED
X2 POS/NEG
10330      IF Rho=0 THEN Next_1 ! TOTAL INTERNAL REFLECTION AT X2NEG
10340 Same:      Delay=(Z3-X)*Trho
10350      Y3=Y+Delay
10360      X(Ns+1)=Z3
10370      Y(Ns+1)=Y3
10380 Next_1: NEXT I
10390 Y3_array: J=0
10400      FOR I=1 TO Nray
10410      Y3(J)=Y(S+I-2)
10420      J=J+1
10430      NEXT I
10440 Hit_zero: MAT Hit=ZER(2001) ! ZERO THE ARRAY
10450      Inc=0 ! FIND THE No. OF HITS IN THE
10460      Ylast=-Y_bullet ! INTERVAL [-Y_BULLET,-Y_BULLET+DELTA/2]
10470      Delta=Y_bullet/N_increment
10480      Ynext=Ylast+Delta/2
10490      Hit(Inc)=0
10500      J=0
10510      FOR I=1 TO Nray
10520      IF (Xc(I)<Z1) AND (Y3(J)=0) THEN Next_J ! IGNORES NEGATIVE
10530      ! BRANCH RAYS
10540      IF (Y3(J)>=Ylast) AND (Y3(J)<Ynext) THEN Hit(Inc)=Hit(Inc)+1
10550 Next_j:      J=J+1
10560      NEXT I
10570 Hit_middle: ! FIND THE No. OF HITS IN THE INTERVAL
10580      ! [-Y_BULLET+DELTA/2, Y_BULLET-DELTA/2]
10590      FOR L=1 TO 2*N_increment-1
10600      Inc=Inc+1
10610      Hit(Inc)=0
10620      Ylast=Ynext
10630      Ynext=Ylast+Delta
10640      K=0
10650      FOR I=1 TO Nray
10660      IF (Xc(I)<Z1) AND (Y3(K)=0) THEN Next_k ! IGNORES
10670      ! NEGATIVE BRANCH RAYS
10680      IF (Y3(K)>=Ylast) AND (Y3(K)<Ynext) THEN Hit(Inc)=Hit(
Inc)+1
10690 Next_k:      K=K+1
10700      NEXT I
10710      NEXT L
10720 Hit_last: Inc=2*N_increment ! FIND THE No. OF HITS IN THE LAST INTERVAL
10730      Hit(Inc)=0 ! [Y_BULLET-DELTA/2, Y_BULLET]
10740      M=0
10750      Ylast=Y_bullet-Delta/2
10760      Ynext=Y_bullet
10770      FOR I=1 TO Nray
10780      IF (Xc(I)<Z1) AND (Y3(M)=0) THEN Next_m ! IGNORES
10790      ! NEGATIVE BRANCH RAYS
10800      IF (Y3(M)>=Ylast) AND (Y3(M)<=Ynext) THEN Hit(Inc)=Hit(Inc)+
1
10810 Next_m:      M=M+1
10820      NEXT I
10830 Normalize: Hit_total=0 ! NORMALIZE THE No. OF HITS ON THE

```

```

18840      FOR I=0 TO 2*N_increment      ! IMAGE PLANE (Z3) TO THE TOTAL
18850      Hit_total=Hit_total+Hit(I) ! No. OF HITS
18860      NEXT I
18870      !
18880      IF Hit_total=0 THEN None
18890      FOR I=0 TO 2*N_increment
18900      Hit(I)=Hit(I)/Hit_total
18910      NEXT I
18920 None: Pct=Hit_total/Nray          ! % OF RAYS THAT ARRIVE AT THE
18930      Percent_image=Pct*100        ! IMAGE PLANE
18940 Graph: CALL Plot                 ! PLOT AND LABEL THE AXES
18950      IF Hit_total=0 THEN Label_
18960 First_bar: Xlast=Y_bullet        ! DRAW THE HISTOGRAM
18970      Xnext=Xlast+Delta/2 ! INTERVAL [-Y_BULLET, -Y_BULLET+DELTA/2)
18980      Inc=0
18990      IF Hit(Inc)=0 THEN Middle_bars
19000      CLIP Xlast,Xnext,0,Hit(Inc)
19010      FRAME
19020      GOSUB Delt
19030 Middle_bars: FOR I=1 TO 2*N_increment-1 ! INTERVAL
19040      Inc=Inc+1 ! [-Y_BULLET+DELTA/2, Y_BULLET-DELTA/2)
19050      Xlast=Xnext
19060      Xnext=Xlast+Delta
19070      IF Hit(Inc)=0 THEN Next_i_m
19080      CLIP Xlast,Xnext,0,Hit(Inc)
19090      FRAME
19100      GOSUB Delt
19110 Next_i_m: NEXT I
19120 Last_bar: Inc=2*N_increment ! INTERVAL (Y_BULLET-DELTA/2, Y_BULLET]
19130      Xlast=Y_bullet-Delta/2
19140      Xnext=Y_bullet
19150      IF Hit(Inc)=0 THEN Label_
19160      CLIP Xlast,Xnext,0,Hit(Inc)
19170      FRAME
19180      GOSUB Delt
19190 Label_: LDIR 0
19200      LOG 2
19210      SETGU
19220      MOVE 2,2
19230      CSIZE 2.5
19240      LABEL "PRESS CONT"
19250      SETUU
19260      CSIZE 15/4.54
19270      BEEP
19280      WAIT 250
19290      BEEP
19300      PAUSE
19310      EXIT GRAPHICS
19320      SUBEXIT
19330 Delt: Lines=10
19340      Delt=(Xnext-Xlast)/Lines
19350      X=Xlast-Delt
19360      FOR J=1 TO Lines
19370      X=X+Delt
19380      MOVE X,0
19390      DRAW X,Hit(Inc)
19400      NEXT J
19410      RETURN
19420      SUBEND
19430 SUB Picture
19440 Scale_: GCLEAR
19450      PLOTTER IS 13,"GRAPHICS"
19460      GRAPHICS
19470      LIMIT 0,104,0,140
19480      SCALE -20,152.4,-55,55
19490      AXES 5,5,0,0,10,10
19500 Label_: MOVE 20,45

```

```

19510 LABEL "THE PROBLEM"
19520 MOVE 20,44
19530 DRAW 50,44
19540 Draw_body: MOVE 0,0
19550 DRAW 74,30
19560 DRAW 184,30
19570 MOVE 0,0
19580 DRAW 74,-30
19590 DRAW 184,-30
19600 Draw_inlet: MOVE 70,35
19610 DRAW 80,30
19620 DRAW 184,30
19630 MOVE 70,-35
19640 DRAW 80,-30
19650 DRAW 184,-30
19660 Second_surf: MOVE 30,0
19670 DRAW 35,5
19680 DRAW 40,9
19690 DRAW 45,13
19700 DRAW 50,15
19710 DRAW 74,30
19720 MOVE 30,0
19730 DRAW 35,-5
19740 DRAW 40,-9
19750 DRAW 45,-13
19760 DRAW 50,-15
19770 DRAW 74,-30
19780 Ray: MOVE 0,15
19790 DRAW 40,15
19800 DRAW 45,13
19810 DRAW 184,-14
19820 Image_plane: MOVE 80,30
19830 LINE TYPE 4
19840 DRAW 80,-30
19850 Label_picture: MOVE 65,-50
19860 LINE TYPE 1
19870 LABEL "S/S4 GLM"
19880 MOVE 85,15
19890 LABEL "IMAGE PLANE"
19900 MOVE 15,2
19910 LABEL "ALPHA"
19920 MOVE 10,0
19930 DRAW 0,2.5
19940 MOVE 5,10
19950 LABEL "INCIDENT RAY"
19960 MOVE 35,2
19970 LABEL "Z1"
19980 MOVE 35,2
19990 DRAW 30,0
20000 MOVE 113,2
20010 LABEL "Xc"
20020 MOVE 113,2
20030 DRAW 110,0
20040 MOVE 02,2
20050 LABEL "Z3"
20060 MOVE 02,2
20070 DRAW 00,0
20080 MOVE 130,3
20090 LABEL "C"
20100 MOVE 131.5,1.5
20110 LABEL "L"
20120 MOVE 5,-10
20130 LABEL "n1"
20140 MOVE 30,-10
20150 LABEL "n2"
20160 MOVE 50,-10

```

```

20170 LABEL "n3"
20180 Finished: MOVE 15,-55
20190 ! LABEL "PRESS CONT"
20200 BEEP
20210 WAIT 250
20220 BEEP
20230 PAUSE
20240 EXIT GRAPHICS
20250 SUBEND
20260 SUB X2p(X,Y)
20270 OPTION BASE 0
20280 !
20290 COM INTEGER I, J, Curve, Np, Nn, N, Ns, Nr, REAL Aneq(*), Apos(*), A(*), Z1, Z3, Z4
20300 !
20310 DEG
20320 FOR I=0 TO N
20330 Y=Y+A(I)+Y^I
20340 NEXT I
20350 SUBEND
20360 SUB X2n(X,Y)
20370 OPTION BASE 0
20380 !
20390 COM INTEGER I, J, Curve, Np, Nn, N, Ns, Nr, REAL Aneq(*), Apos(*), A(*), Z1, Z3, Z4
20400 !
20410 DEG
20420 CALL X2p(X,Y)
20430 Y=-1*Y
20440 SUBEXIT
20450 SUB Min(Xm(*), X, INTEGER M)
20460 OPTION BASE 0
20470 !
20480 ! DIM Xm(M)
20490 !
20500 X=Xm(0)
20510 FOR I=1 TO M
20520 X=MIN(X, Xm(I))
20530 NEXT I
20540 SUBEND
20550 SUB Max(Xm(*), X, INTEGER M)
20560 OPTION BASE 0
20570 !
20580 ! DIM Xm(M)
20590 !
20600 X=Xm(0)
20610 FOR I=1 TO M
20620 X=MIN(X, Xm(I))
20630 NEXT I
20640 SUBEND

```

APPENDIX C

POLYNOMIALS USED FOR THE SECOND SURFACE

A. INTRODUCTION

The following discussion compares the attributes of three analytic expressions, in polynomial form, used as second surfaces for a conical lens. The lenses are compared in terms of the individual lens ability to cause some or all of the incident light rays to converge to a point. The points of ray convergence are referred to as "focal" points although they are not focal points in the standard usage of the term. Lens designers have developed a system of standards used as figures of merit to compare one lens to another. These standards include spherical aberration, coma, tilt, astigmatism and others. The figures of merit have not been calculated because the three curves discussed in this appendix are known to be completely unsatisfactory to use as refracting surfaces. The purpose of the thesis is to discover which properties of a curve to investigate in order to lead to usable design. Therefore an intuitive comparison of ray diagrams, histograms of ray distributions and the set of basic design criteria described in chapter III are the basis for the discussion of curves A, B and C in this appendix.

B. CURVE A

Curve A, shown in figure C-1 was the first analytic expression used as a second surface to produce a ray diagram.

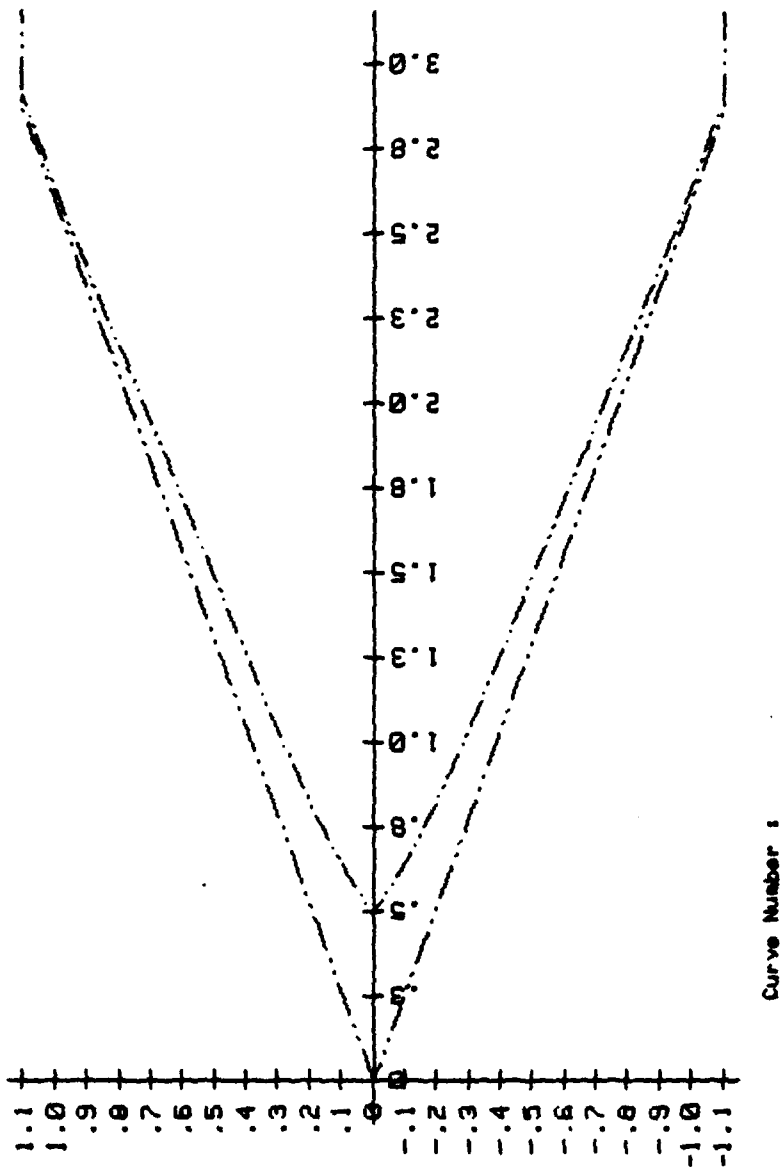


Figure C-1. Conical Lens with the Second Surface Defined by Curve A.

The curve was calculated by obtaining the data listed in Table C-1 from an arbitrary hand drawn curve. These data were used as the input to a regression analysis routine in the HP-9845B utilities library. Since TRACE requires the second surface to be expressed as a polynomial function of y , three curves were fit to the data. Table C-II contains the coefficients for each of the polynomials. The first polynomial relates the radial distance from the GLM axis to the distance along the GLM axis, i.e. $\text{radius} = f(\text{distance along the GLM axis})$. The remaining two are required by TRACE for ray tracing and graphics purposes. The second expression relates the distance along the GLM axis to the radius from the axis in the upper half-plane; i.e. $\text{distance along the GLM axis} = f(\text{radius})$. The third expression relates the distance along the GLM axis to the radius in the lower half-plane; i.e. $\text{distance along the GLM axis} = f(-\text{radius})$. All linear dimensions are in inches.

TABLE C-I
DATA POINTS FOR CURVE A

$y = f(x)^*$	$x = f(y)^*$	$x = f(-y)^*$
(Ordinate, Abscissa)	(Ordinate, Abscissa)	(Ordinate, Abscissa)
0.500, 0.00	0.000, 0.500	0.000, 0.500
0.600, 0.069	0.069, 0.600	-0.069, 0.600
0.700, 0.138	0.138, 0.700	-0.138, 0.700
0.800, 0.188	0.188, 0.800	-0.188, 0.800
0.900, 0.238	0.238, 0.900	-0.238, 0.900
1.000, 0.281	0.281, 1.000	-0.281, 1.000
1.500, 0.500	0.500, 1.500	-0.500, 1.500
2.000, 0.731	0.731, 2.000	-0.731, 2.000
2.500, 0.938	0.938, 2.500	-0.938, 2.500
2.900, 1.100	1.100, 2.900	-1.100, 2.900

*: For x = distance along the GLM axis and
 y = radial distance from the GLM axis.

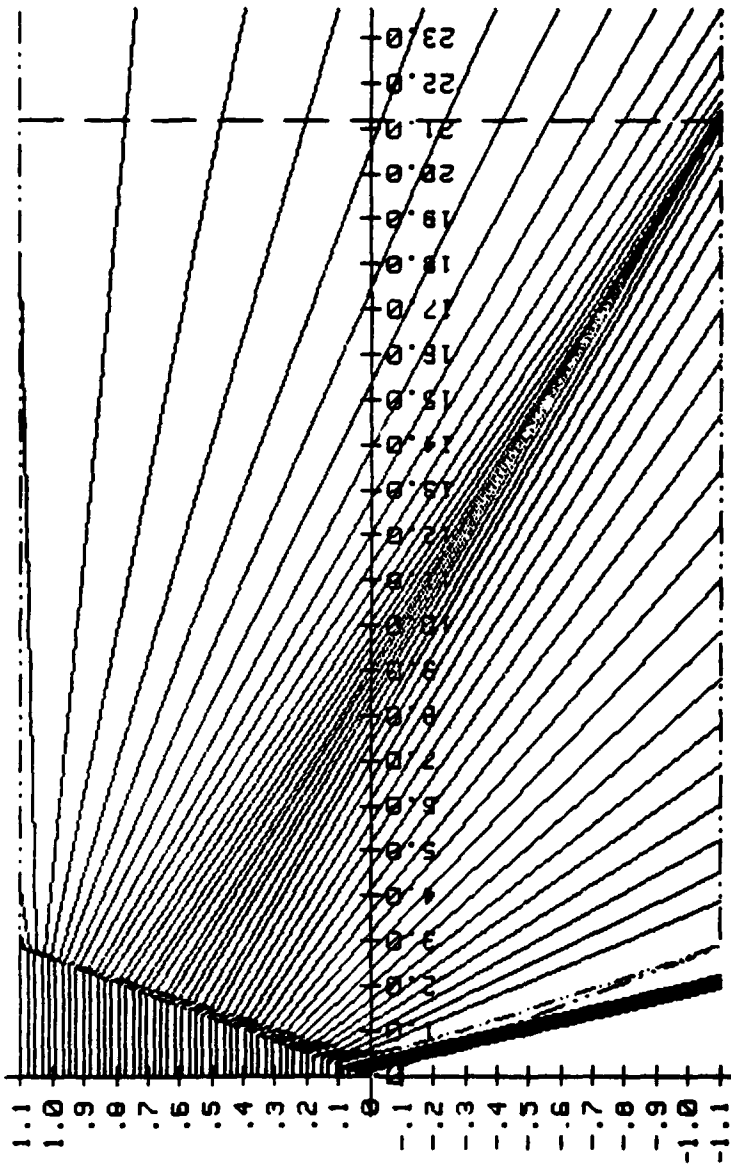
TABLE C-II
POLYNOMIAL COEFFICIENTS FOR CURVE A

Coefficient Number		Positive Branch	Negative Branch
a_i	$y = f(x)^*$	$x = f(y)^*$	$x = f(-y)^*$
a_0	-0.45216186	0.5003067966	0.5003067966
a_1	1.18544007	1.15219319	-1.15219319
a_2	-0.66358797	3.0138759	3.0138759
a_3	0.25054923	-3.4182912	3.4182912
a_4	-0.034174838	1.39217781	1.39217781

*: For x = distance along the GLM axis and
 y = radial distance from the GLM axis.

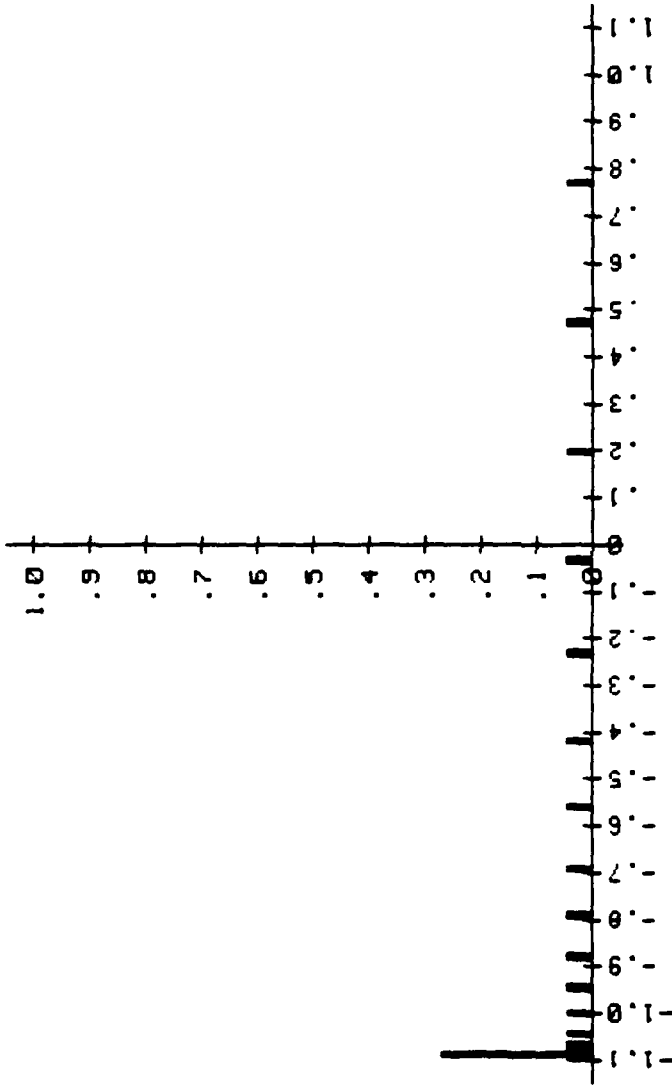
A ray diagram using TRACE, which is shown in figure C-2, demonstrates that curve A has the ability to focus some of the rays to a point near the wall of the GLM at a distance of 21.18 inches along the GLM axis. Figure C-3 is the histogram of the ray distribution for figure C-2 and shows a maximum at 1.08 inches. If this distribution were rotated about the GLM axis, the two dimensional distribution would be a set of concentric rings centered on the GLM axis with the most intense ring at a radius of 1.08 inches. Although this ray pattern is unsatisfactory, the fact that some rays converged to a focus was encouraging.

The converging rays were coming from the middle region of the curve. The slope of the middle region of the curve is slightly larger than the slope of the first surface. The slope of the regions above and below the middle region have slopes which are approximately the same as and greater than the slope of the first surface respectively. The ability of the middle region to focus light rays suggested the existence of a range of slopes which would cause convergence of light rays. The light rays which intercept the second surface in the lower half-plane are totally internally reflected because of the large angle of incidence. Total internal reflection occurs when Snell's Law $\sin\theta_R = (n_2/n_3)\sin\theta_I$ results in $\sin\theta_R \geq 1$. The critical angle of incidence θ_c is where $\sin\theta_R = 1$ and any angle greater than θ_c results in total internal reflection. The range appears to be in a narrow



Curve Number : 1
 Incident Ray Angle : 0.00 deg
 n2 : 1.50000
 Number of Rays : 38
 Image Plane : 21.10 inches
 Aperture : 1.100 inch

Figure C-2. Ray Diagram for a Conical Lens Using Curve A as the Second Surface.



Normalized Number of Hits vs Distance from the Axis

Curve Number : 50
 Total Number of Hits : 22
 Number of Increments (0.1) : 100
 Number of Rays : 50
 % of Rays to Image Plane : 44.00
 Image Plane : 21.18 inches

Figure C-3. Histogram of the Ray Distribution on the Image Plane Shown in Figure C-2.

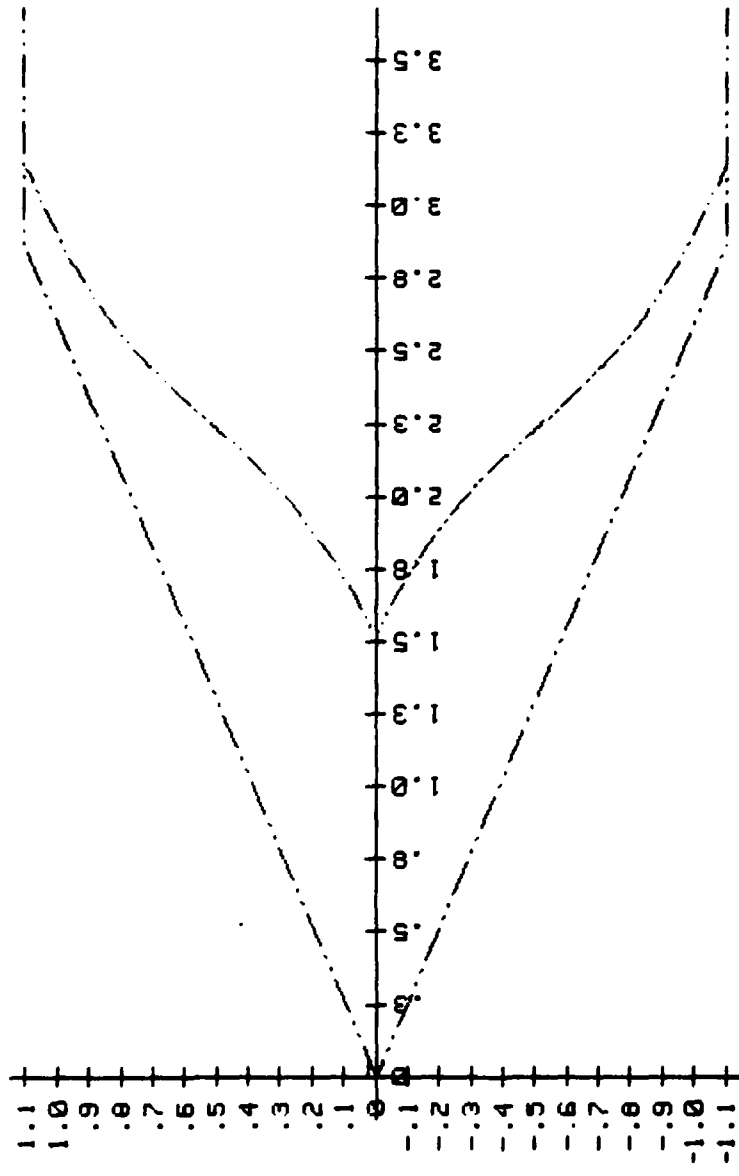
band with the minimum value greater than the value of the cone angle, α . Since the curve is concave with respect to the first surface, the next step of the investigation was to study curves with the appropriate slope comparable with curve A and regions concave and convex with respect to the first surface. These two criteria were the basis for choosing curves B and C for further investigation.

C. CURVE B

Curve B, shown in figure C-4 was chosen because the analytical expression which describes the curve exhibits regions similar to those discussed for curve A. The shape of curve B is smooth with an inflection point providing regions concave and convex with respect to the first surface. The data used to generate the analytical expression for the curve are listed in Table C-III. Three analytic expressions were calculated as for curve A. The coefficients for the three polynomials describing curve B are listed in Table C-IV.

The ray diagram in figure C-5 demonstrates the ability of curve B to cause some of the light rays to converge to a "focal" point. A ray diagram with an image plane located at the point of maximum ray density is shown in figure C-6. Although this ray distribution is not satisfactory the distribution of rays is relatively better than the ray distribution for curve A shown in figure C-2.

The ray distribution of curve B is better than that for curve A because the point of ray convergence is closer to



Curve Number :

Figure C-4. Conical Lens with the Second Surface Defined by Curve B.

TABLE C-III
DATA POINTS FOR CURVE B

$y = f(x)^*$ (Ordinate, Abscissa)	$x = f(y)^*$ (Ordinate, Abscissa)	$x = f(-y)^*$ (Ordinate, Abscissa)
1.500, 0.000	0.000, 1.500	0.000, 1.500
1.700, 0.075	0.075, 1.700	-0.075, 1.700
1.900, 0.200	0.200, 1.900	-0.200, 1.900
2.100, 0.394	0.394, 2.100	-0.394, 2.100
2.300, 0.569	0.569, 2.300	-0.569, 2.300
2.500, 0.744	0.744, 2.500	-0.744, 2.500
2.700, 0.888	0.888, 2.700	-0.888, 2.700
2.900, 1.000	1.000, 2.900	-1.000, 2.900

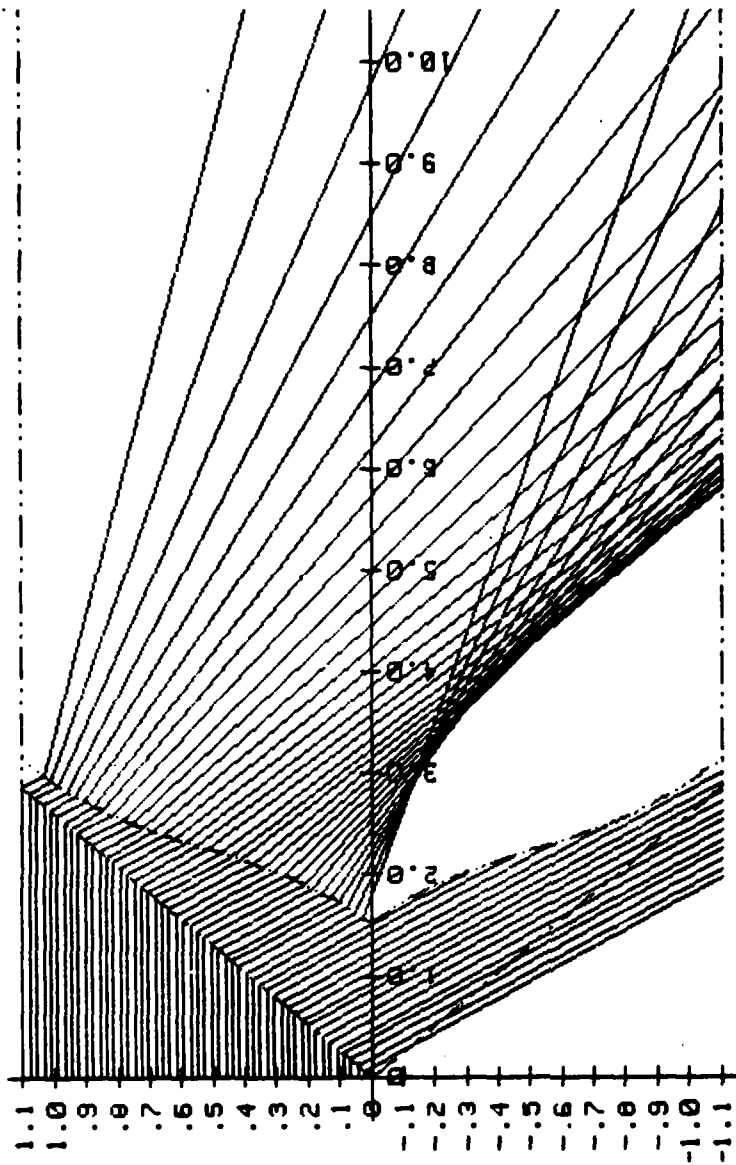
*: For x = distance along the GLM axis and
 y = radial distance from the GLM axis.

TABLE C-IV

POLYNOMIAL COEFFICIENTS FOR CURVE B

Coefficient Number		Positive Branch	Negative Branch
a_i	$y = f(x)^*$	$x = f(y)^*$	$x = f(-y)^*$
a_0	3.3554752	1.5193756399	1.5193756399
a_1	-5.6849365	2.279198152	-2.279198152
a_2	2.959523	-2.5230983	-2.5230983
a_3	-0.4412878	1.63047031	-1.63047031

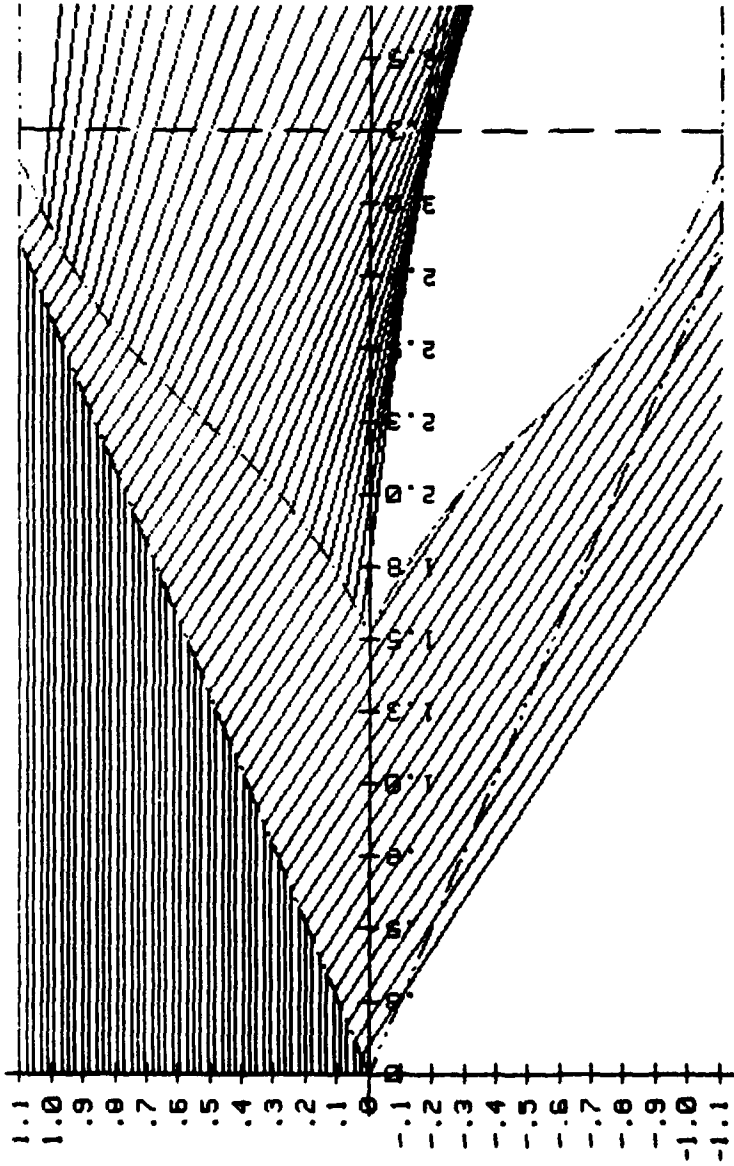
*: For x = distance along the GLM axis and
 y = radial distance from the GLM axis.



Curve Number :

Number of Rays : 30

Figure C-5. Ray Diagram for a Conical Lens Using Curve B as the Second Surface.



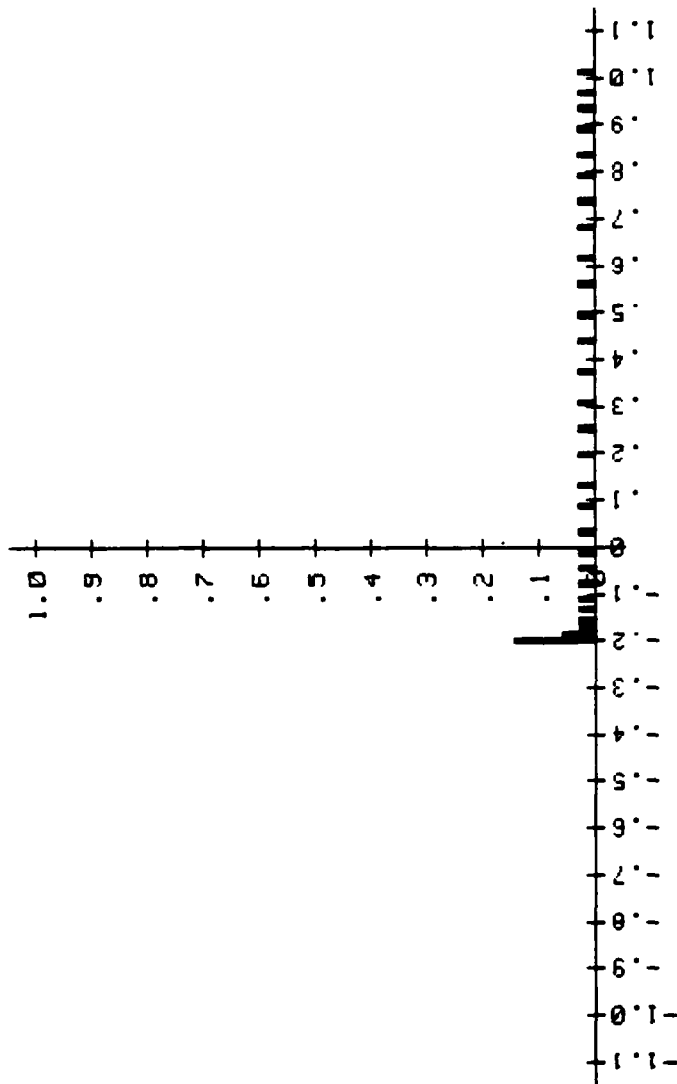
Curve Number : 50 Number of Rays : 50
 Incident Ray Angle : 6.00 deg Image Plane : 3.25 inches
 n2 : 1.50000 Aperture : 1.100 inch

Figure C-6. Ray Diagram Using Curve B with Image Plane at 3.25 Inches.

both the lens and the GLM axis. The histogram for curve B in figure C-7 shows the point of maximum ray density is located at a radius of approximately 0.2 inch from the GLM axis. The point of maximum ray density for curve A is at a radius of approximately 1.08 inch from the GLM axis. Although curve A causes more of the rays which strike the image plane to focus than curve B does, the ability to achieve a short focal length is more desirable and therefore curve B is judged to be better than curve A. A second factor which must be taken into account is the fraction of rays transmitted through the lens. Curve A transmits 84% (42 of 50) of the incident rays through the lens. Curve B transmits 68% (34 of 50) of the light rays through the lens. The fraction of transmitted rays could be increased by moving the second surface forward and making the lens thinner.

The ray diagram and histogram for curve B in figures C-6 and C-7 reveal the absence of a large number of rays in the lower half-plane near the lens. Rotating the histogram about the GLM-axis would generate a set of concentric rings with the most intense at a radius of 0.2 inch from the GLM axis.

Using the ray diagram and histogram for curve A in figures C-2 and C-3 as baseline design figures for the GLM lens curve B is judged to be the superior curve of the two due to the capability of curve B to cause light rays to converge in a region relatively close to the lens and near the GLM axis.



Normalized Number of Hits vs Distance from the Axis

Curve Number : 50
 Total Number of Hits : 34
 Number of Increments (0,1,1) : 100
 Number of Rays : 50
 % of Rays to Image Plane : 68.00
 Image Plane : 3.25 inches

Figure C-7. Histogram of the Ray Distribution and the Image Plane in Figure C-6.

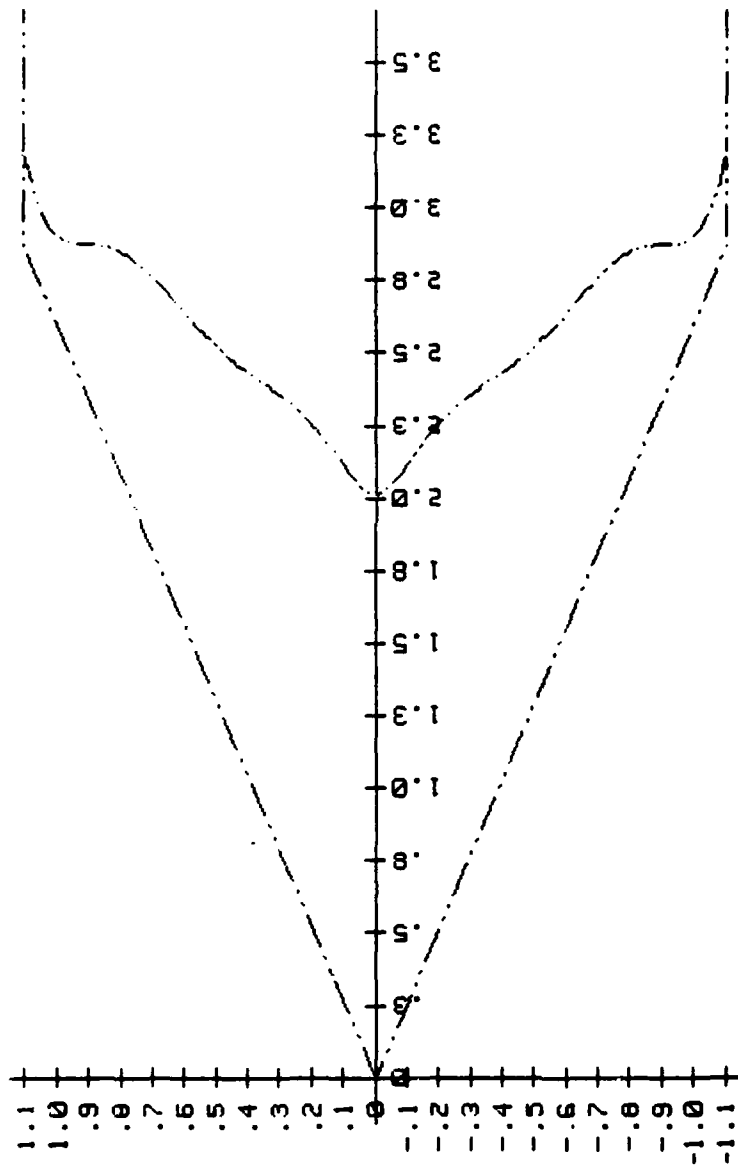
Curve A exhibited one convex region and one focal point. The rays intercepting the second surface in the lower half-plane were totally internally reflected as they were for curve A.

The investigation was now directed to probe the ability of a convex surface to cause convergence of the light rays at a shorter distance along the GLM axis than a concave region. Curve C was chosen because the analytic expression is a higher order polynomial with several inflection points.

D. CURVE C

Curve C shown in figure C-8 was chosen because the higher order polynomial contains several inflection points. The inflection points provide regions of concave and convex surfaces. If the results for curve B are valid then curve C should cause rays to converge to several focal points, one for each convex region. The data points for curve C listed in Table C-V were obtained and the polynomial coefficients in Table C-VI were generated in the same manner as for curve A.

The ray diagram in figure C-9 show two distinct areas where rays exiting the lens from a convex region converge. The focal points possess the same characteristics as those of curve B. The focal points are located in a region close to the lens and are formed from rays emerging from a convex portion of the surface. Light rays refracted from concave regions of the lens do cross other light rays, but do not



Curve Number :

Figure C-8. Conical Lens with the Second Surface Defined by Curve C.

TABLE C-V
DATA POINTS FOR CURVE C

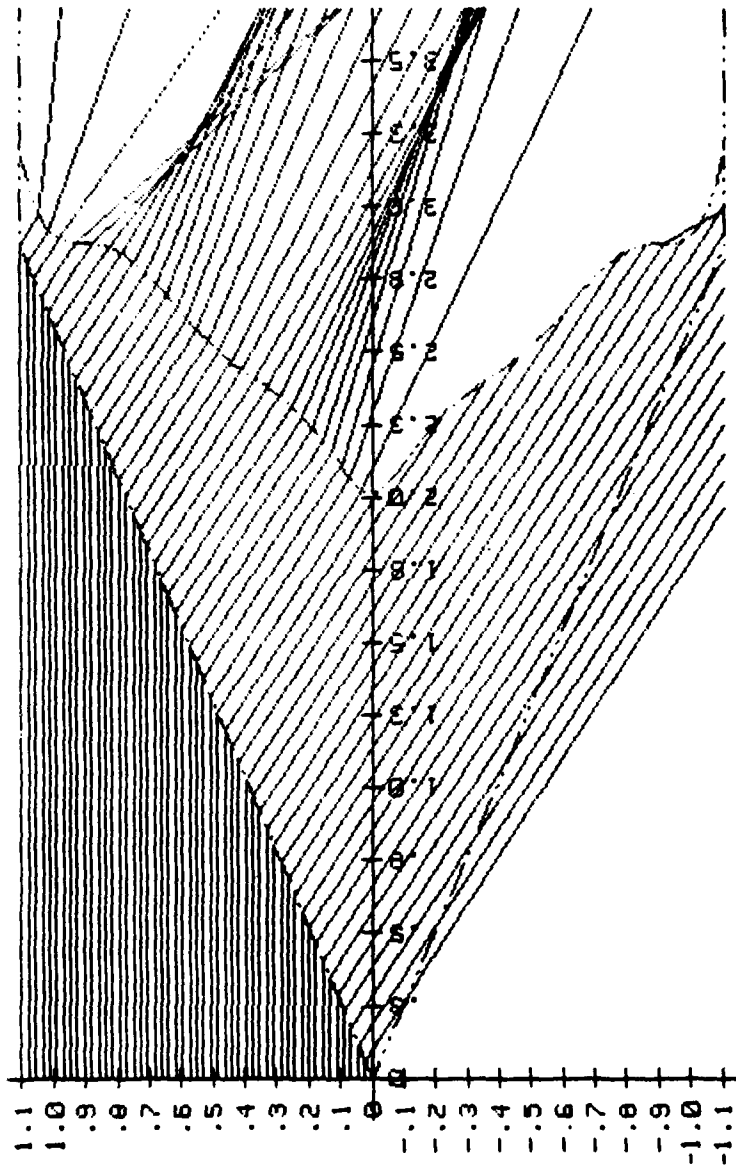
$y = f(x) *$ (Ordinate, Abscissa)	$x = f(y) *$ (Ordinate, Abscissa)	$x = f(-y) *$ (Ordinate, Abscissa)
2.000, 0.00	0.000, 2.000	0.000, 2.000
2.100, 0.081	0.081, 2.100	-0.081, 2.100
2.200, 0.175	0.175, 2.200	-0.175, 2.200
2.300, 0.244	0.244, 2.300	-0.244, 2.300
2.400, 0.331	0.331, 2.400	-0.331, 2.400
2.500, 0.500	0.500, 2.500	-0.500, 2.500
2.600, 0.600	0.600, 2.600	-0.600, 2.600
2.700, 0.612	0.612, 2.700	-0.612, 2.700
2.800, 0.744	0.744, 2.800	-0.744, 2.800
2.850, 0.8125	0.8125, 2.850	-0.8125, 2.850
2.900, 1.000	1.000, 2.900	-1.000, 2.900

*: For x = distance along the GLM axis and
 y = radial distance from the GLM axis.

TABLE C-VI
POLYNOMIAL COEFFICIENTS FOR CURVE C

Coefficient Number a_i	$y = f(x)^*$	Positive Branch $x = f(y)^*$	Negative Branch $x = f(-y)^*$
a_0	-11.205773	2.003622364	2.003622364
a_1	13.18159	0.30397	-0.30397
a_2	-5.328168	12.96206	12.96206
a_3	0.767801	-62.1508	62.1508
a_4	0.00	125.7966	125.7966
a_5	0.00	-114.0765	114.0765
a_6	0.00	38.06104	38.06104

*: For x = distance along the GLM axis and
 y = radial distance from the GLM axis.

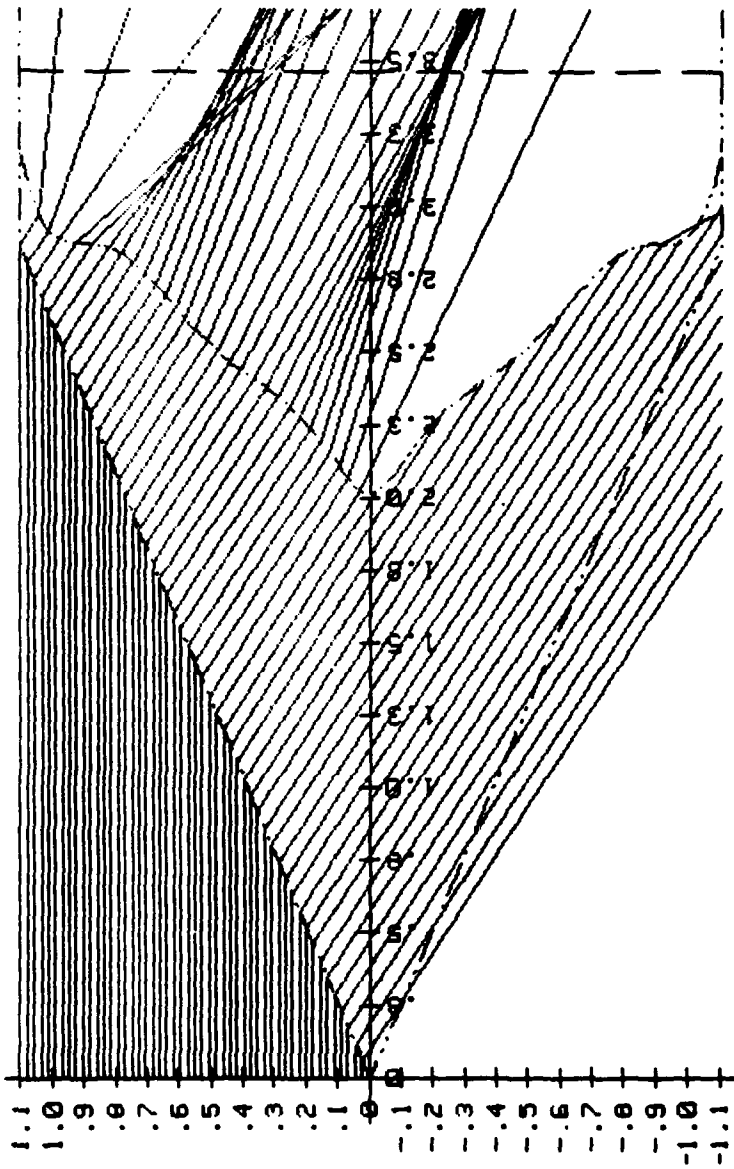


Curve Number : Number of Rays : 50

Figure C-9. Ray Diagram for a Conical Lens Using Curve C as the Second Surface.

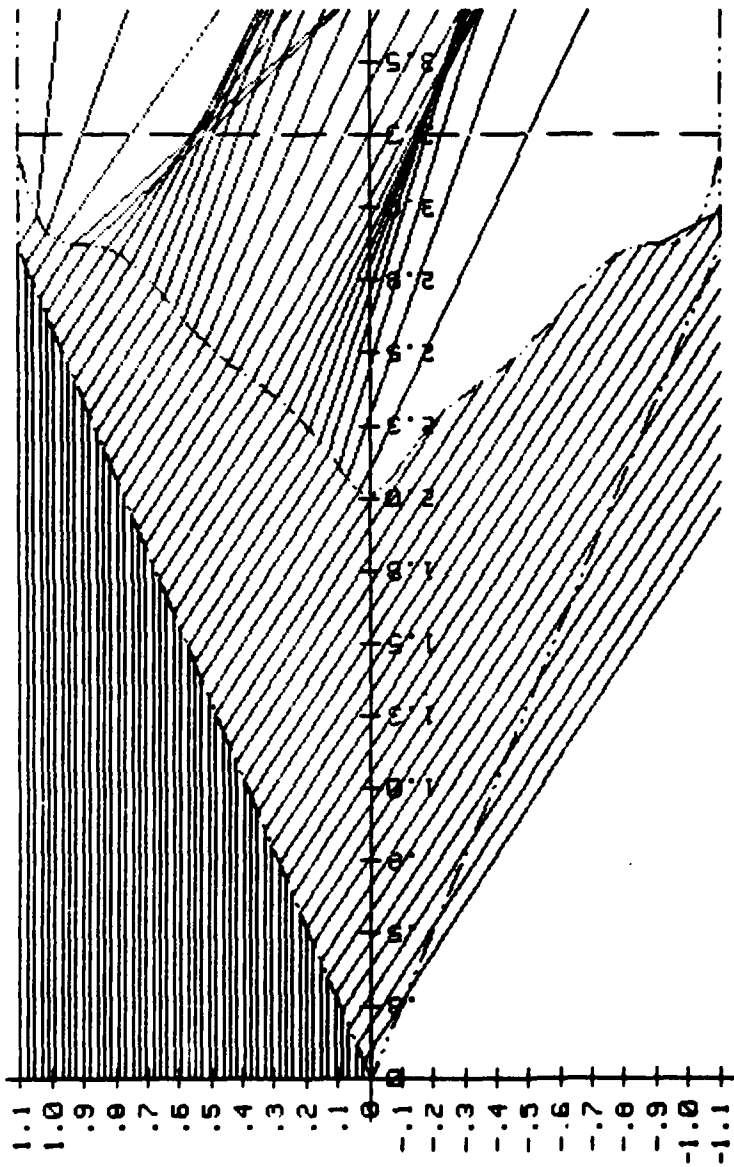
converge as a group as do the light rays from the convex regions.

Comparing the focal points caused by curve C shown in figures C-10 and 11 with figure C-1 for curve A shows that the focal point caused by curve A is located at a point 21.18 inches along the GLM axis and at a radius of -1.08 inches (21.18, - 1.08) inches. The focal points for curve C are positioned at approximately (3.46, -0.25) inches and (3.25, 0.54) inches. If the histogram in figure C-12, drawn for the image plane in figure C-10 was rotated about the GLM axis a set of concentric rings would be formed. The most intense rings would be located at radii of 0.25, 0.34 and 0.44 inch. Rotating the histogram in figure C-13 drawn for the image plane in figure C-11 would produce a similar set of rings, the most intense located at radii of 0.16 and 0.54 inch. Comparing the number of rays transmitted reveals curve A transmits 84% (42 of 50) of the incident rays and curve C transmits 58% (29 of 50) of the incident rays. However, since curve C causes light rays to converge in a region closer to the lens than does curve A, curve C is judged to be better than curve A. Also, all but one ray which intercepted the second surface of the lens using curve C in the lower half-plane experienced total internal reflection at the second surface.



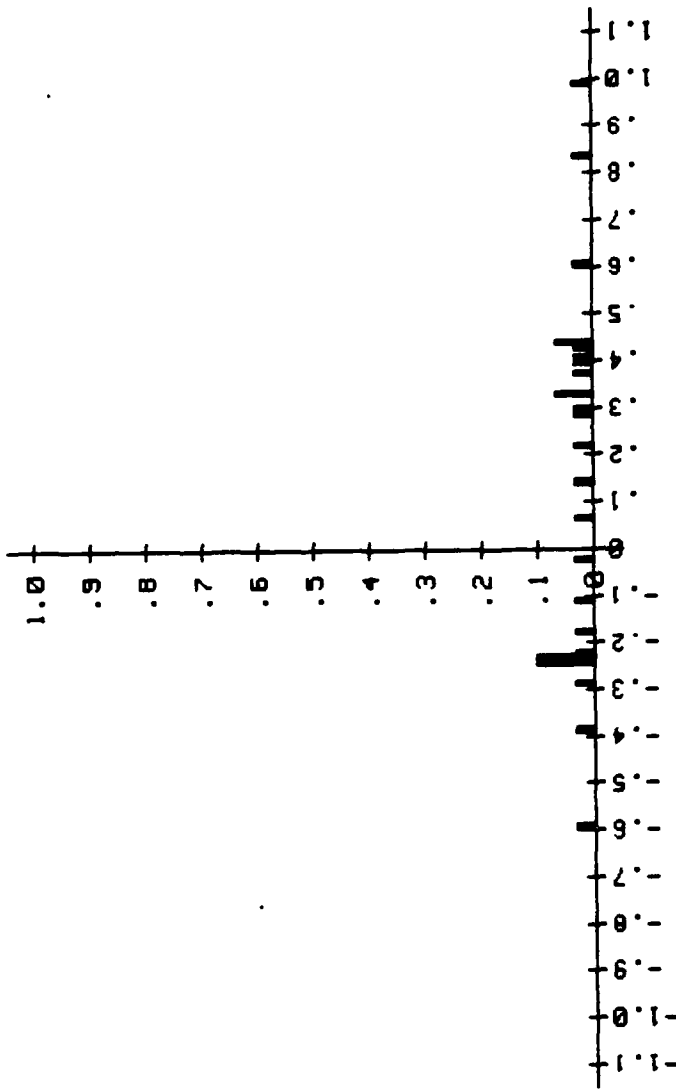
Curve Number : C
 Incident Ray Angle : 0.00 deg
 n2 : 1.50000
 Number of Rays : 50
 Image Plane : 3.46 inches
 Aperture : 1.100 inch

Figure C-10. Ray Diagram Using Curve C with the Image Plane at 3.46 Inches.



Curve Number : C Number of Rays : 58
 Incident Ray Angle : 0.00 deg Image Plane : 3.25 inches
 n2 : 1.50000 Aperture : 1.100 inch

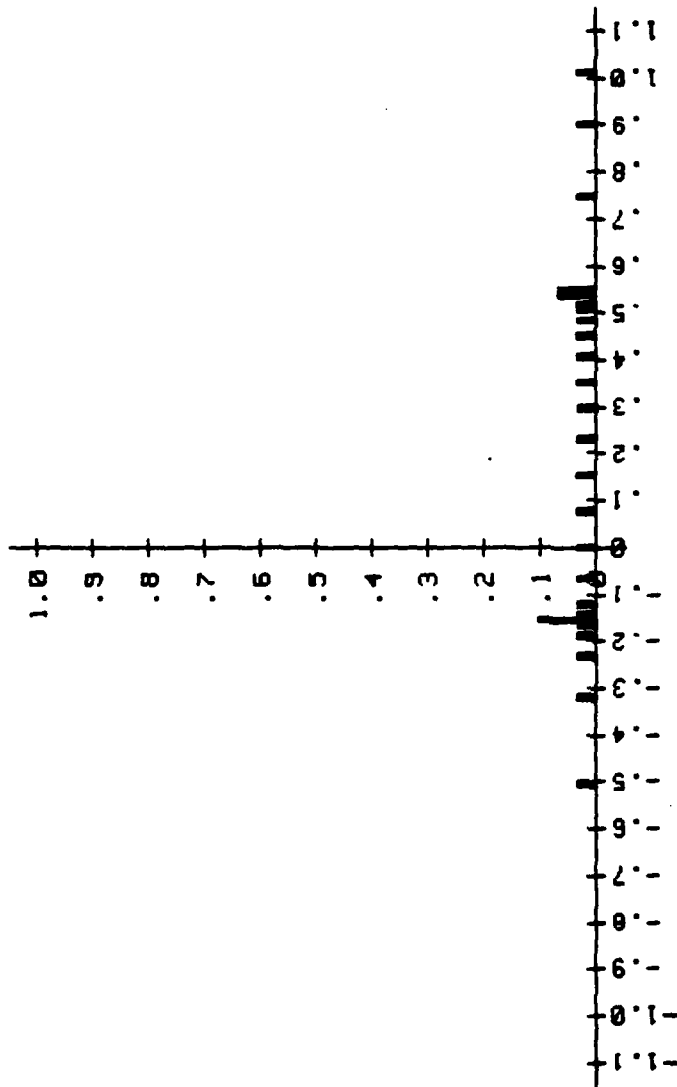
Figure C-11. Ray Diagram Using Curve C with the Image Plane at 3.25 Inches.



Normalized Number of Hits vs Distance from the Axis

Curve Number : 58
 Total Number of Hits : 29
 Number of Increments (0.1) : 100
 Number of Rays : 58
 % of Rays to Image Plane : 58.00
 Image Plane : 3.46 inches

Figure C-12. Histogram of the Ray Distribution on the Image Plane in Figure C-10.



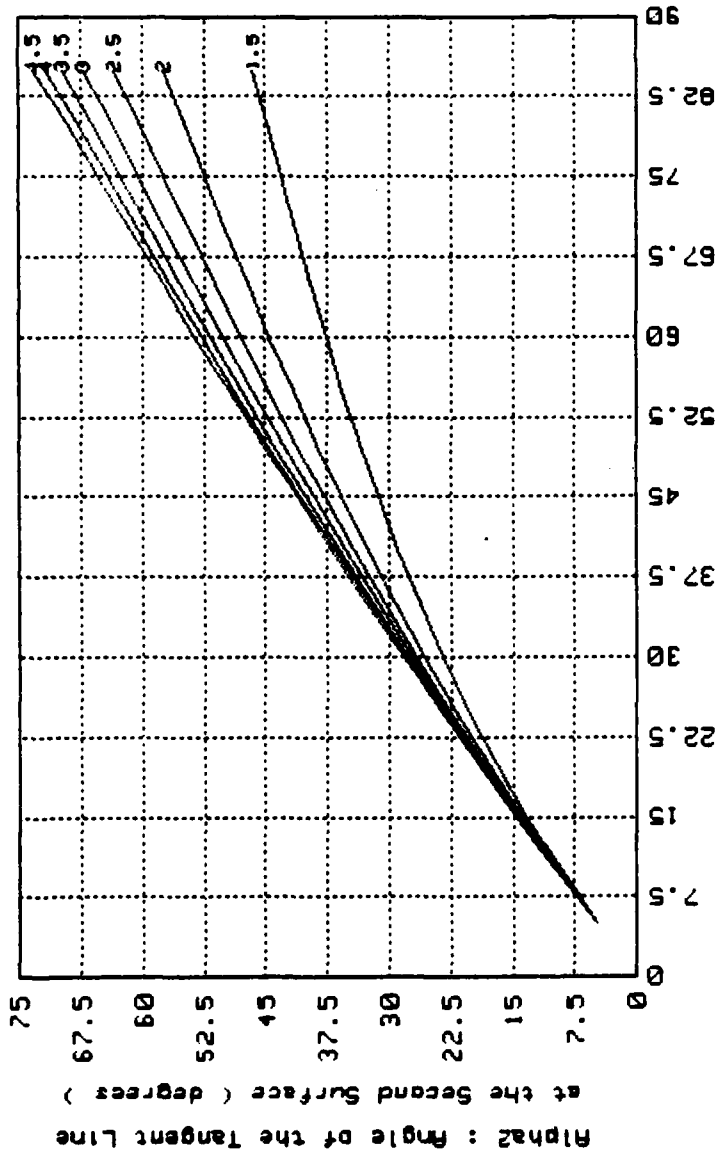
Normalized Number of Hits vs Distance from the Axis

Curve Number : 50
 Total Number of Hits : 29
 Number of Increments [0,1,1] : 100
 Number of Rays : 50
 % of Rays to Image Plane : 50.00
 Image Plans : 3.25 inches

Figure C-13. Histogram of the Ray Distribution on the Image Plane in Figure C-11.

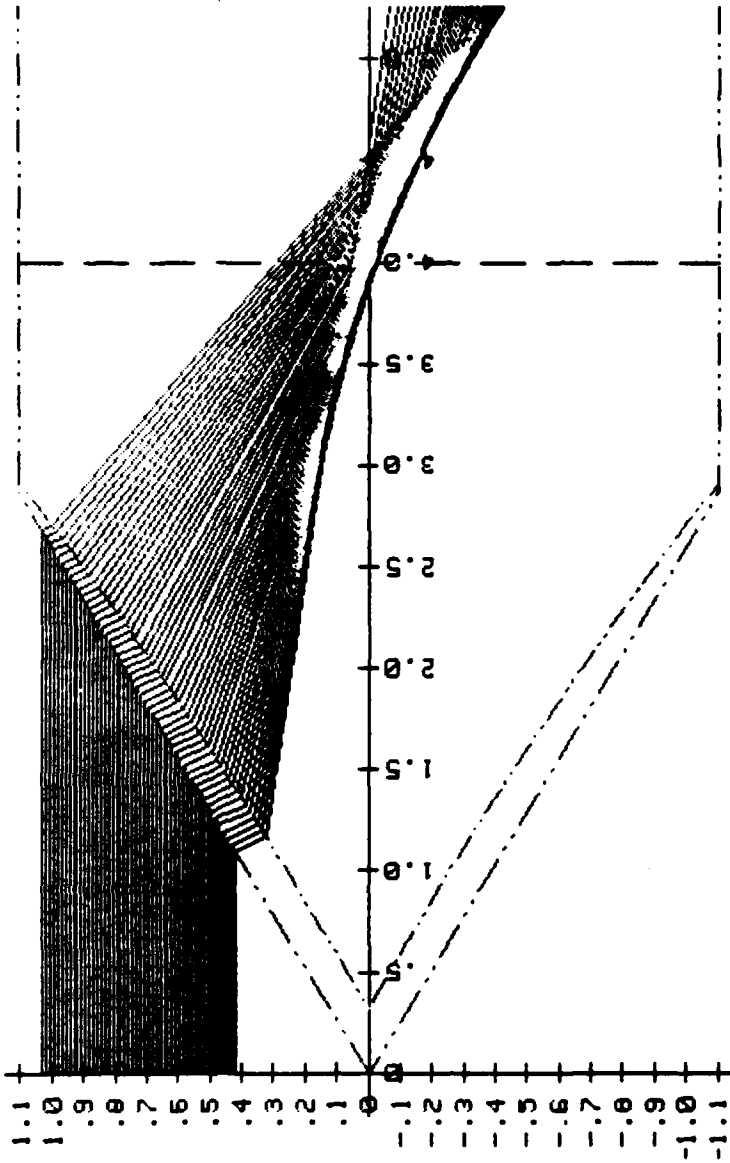
E. CONCLUSIONS

Three conclusions are drawn from the comparison of curves A, B and C. First, a range of slopes for the second surface exists which will enable the second surface to refract light to a focal point. The ray diagrams for curve A, B and C shown in figures C-2, C-5 and C-9 illustrate this relationship as well as the fact the rays which intercepted the second surface in the lower half-plane were almost all totally internally reflected. The relationship between the slopes of the first surface $\tan\alpha_1$ and the second surface $\tan\alpha_2$ is shown in figure C-14. Rays are refracted in the region where $\alpha_2 >$ the functional value for a given index of refraction; rays experience total internal reflection when $\alpha_2 <$ the functional value for a given index of refraction. The second conclusion is that a second surface which is convex with respect to the first surface causes light rays to converge in a region much closer to the lens than a concave lens. The third conclusion is that a single polynomial used to describe the second surface of a lens does not satisfactorily refract rays to a focus. CHART calculated surface D shown in figure C-15 for eleven rays. This is surface number one, illustrated in figure 17. A parabola was fitted to the eleven points using the HP-9845B Utilities Package. The fit appears to be quite good, especially when figure C-15 is compared to figure 17. However, when 50 rays are traced through the lens the ray diagram in figure C-15 is the result. The associated



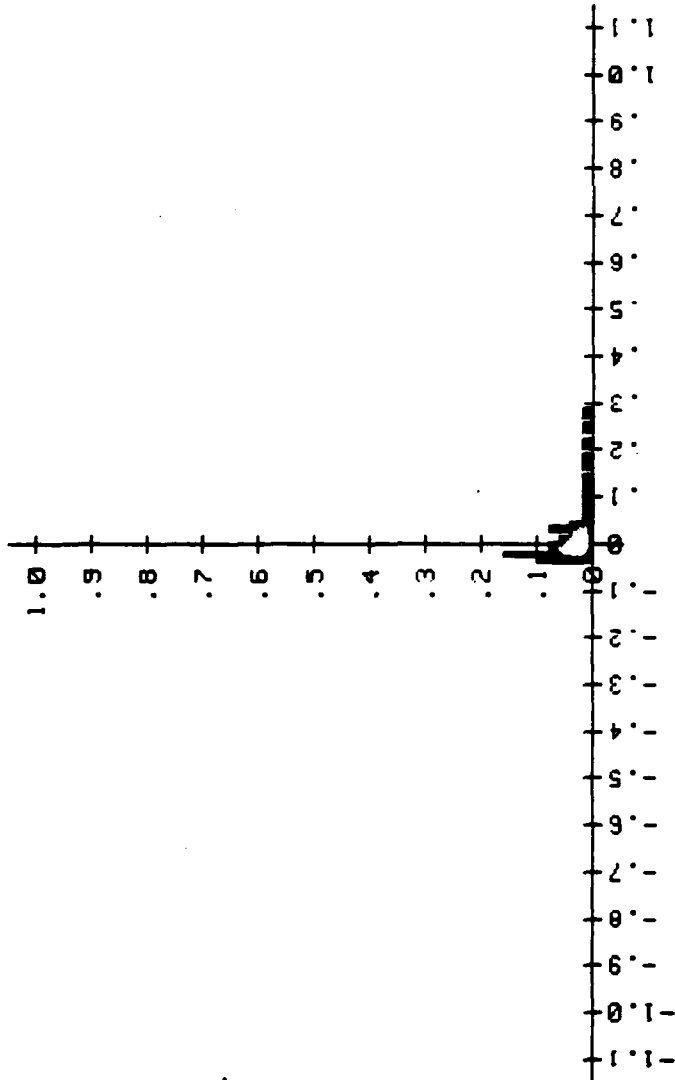
Alpha : Angle of the Tangent Line at the First Surface (degrees)

Figure C-14. The Angle of the Tangent Line of the Second Surface α_2 as a Function of the Angle of the Tangent Line at the First Surface α for Total Reflection at the Second Surface.



Curve Number : 50
 Incident Ray Angle : 0.00 deg
 Image Plane : 4.00 inches
 n2 : 1.00000
 Aperture : .010 inch

Figure C-15. Ray Diagram for a Conical Lens Using Curve D as the Second Surface.



Normalized Number of Hits vs Distance from the Axis

Curve Number : 58 Number of Rays : 58
 Total Number of Hits : 50 % of Rays to Image Plane : 100.00
 Number of Increments [0,1.1] : 100 Image Plane : 1.00 inches

Figure C-16. Histogram of the Ray Distribution on the Image Plane in Figure C-15.

histogram in figure C-16 shows the ray distribution on the
image plane at the design focal point of 4.00 inches.

APPENDIX D

THE USE OF A GENERAL BLOCK OF MATERIAL AS A LENS

LCDR C.L. Burmaster, Naval Postgraduate School, suggested the use of a rhombus shown in figure D-1 as a refracting lens because this type of lens should transmit light without aberration. The following discussion applies Snell's Law to this lens with the following boundary conditions:

- 1) Side ① is parallel to side ④.
- 2) Side ② is parallel to side ③ and symmetrical to the GLM axis.
- 3) The ray in medium 3 is parallel to the incident ray in medium 1.
- 4) the index of refraction of the lens is related to the indices of media 1 and 2 in the following manner:

$$n_1 < n_2 \text{ and } n_2 > n_3$$

The incident ray in medium 1 makes an angle of incidence θ_I with \hat{n}_1 the normal to the first surface. The ray is refracted into the lens at an angle of refraction, θ_{R_1} with respect to \hat{n}_1 , according to the relation $\sin\theta_{R_1} = (n_1/n_2)\sin\theta_I$ Snell's Law. The ray traverses the lens and forms the angle of incidence θ_{I_4} with the normal to surface 4. The ray is refracted according to $\sin\theta_{R_4} = (n_3/n_2)\sin\theta_{I_4}$ noting that since surface ④ is parallel to surface ①, \hat{n}_1 is parallel to \hat{n}_4 and therefore $\theta_{I_4} = \theta_{R_1}$. Since the ray in medium 3 is parallel to the incident ray in medium 1 $\theta_{R_4} = \theta_I$,

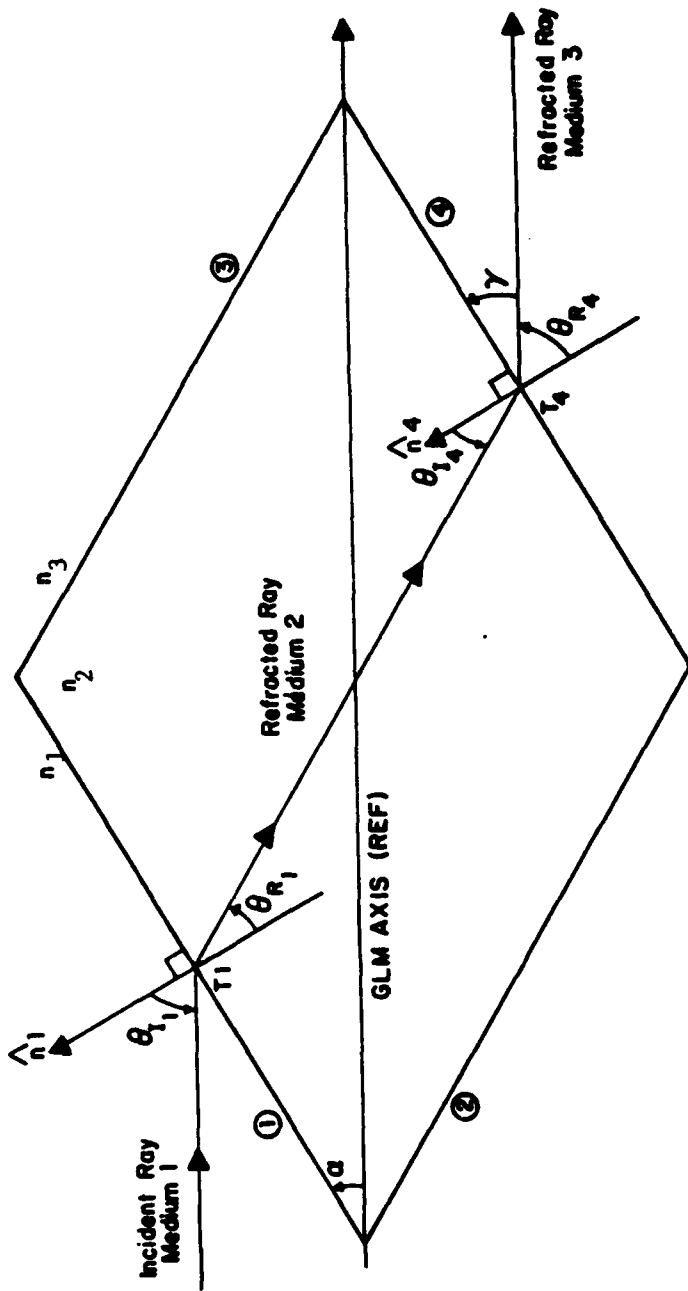


Figure D-1. Rhombus Lens.

and applying Snell's Law at surface number 1

$$\sin\theta_{I_1} = \frac{n_2}{n_1} \sin\theta_{R_1}$$

and again at surface number 4

$$\sin\theta_{R_4} = \frac{n_2}{n_3} \sin\theta_{I_4}$$

therefore equating θ_{I_1} and θ_{R_4}

$$\frac{n_2}{n_1} = \frac{n_2}{n_3}$$

therefore $n_1 = n_3$.

The conclusion for this lens is that the indices of refraction for media 1 and 3 must be equal. The lens causes inversion of the image because the rays are incident in the upper half-plane and exit in the lower half-plane.

A more general lens is shown in figure D-2 which does not have boundary conditions 1) and 2) above. All other boundary conditions apply and in addition the lens is symmetric about the GLM axis.

The incident ray in medium 1 forms an angle of incidence θ_{I_1} with \hat{n}_1 , the normal to surface ①. The ray is refracted according to $\sin\theta_{R_1} = (n_1/n_2)\sin\theta_{I_1}$ and traverses the medium, forming the angle of incidence θ_{I_4} with \hat{n}_4 , the normal to surface ④. The ray is refracted into medium 3 according to $\sin\theta_{R_4} = (n_2/n_3)\sin\theta_{I_4}$ parallel to the incident ray in medium 1. Noting the angular relationship between \hat{n}_1 and \hat{n}_4 in figure D-3 such that $\theta_3 = \theta_2 + \delta$ and $\delta = \alpha - \gamma$, then $\theta_3 = \alpha - \gamma$ where α and γ are the angles of sides

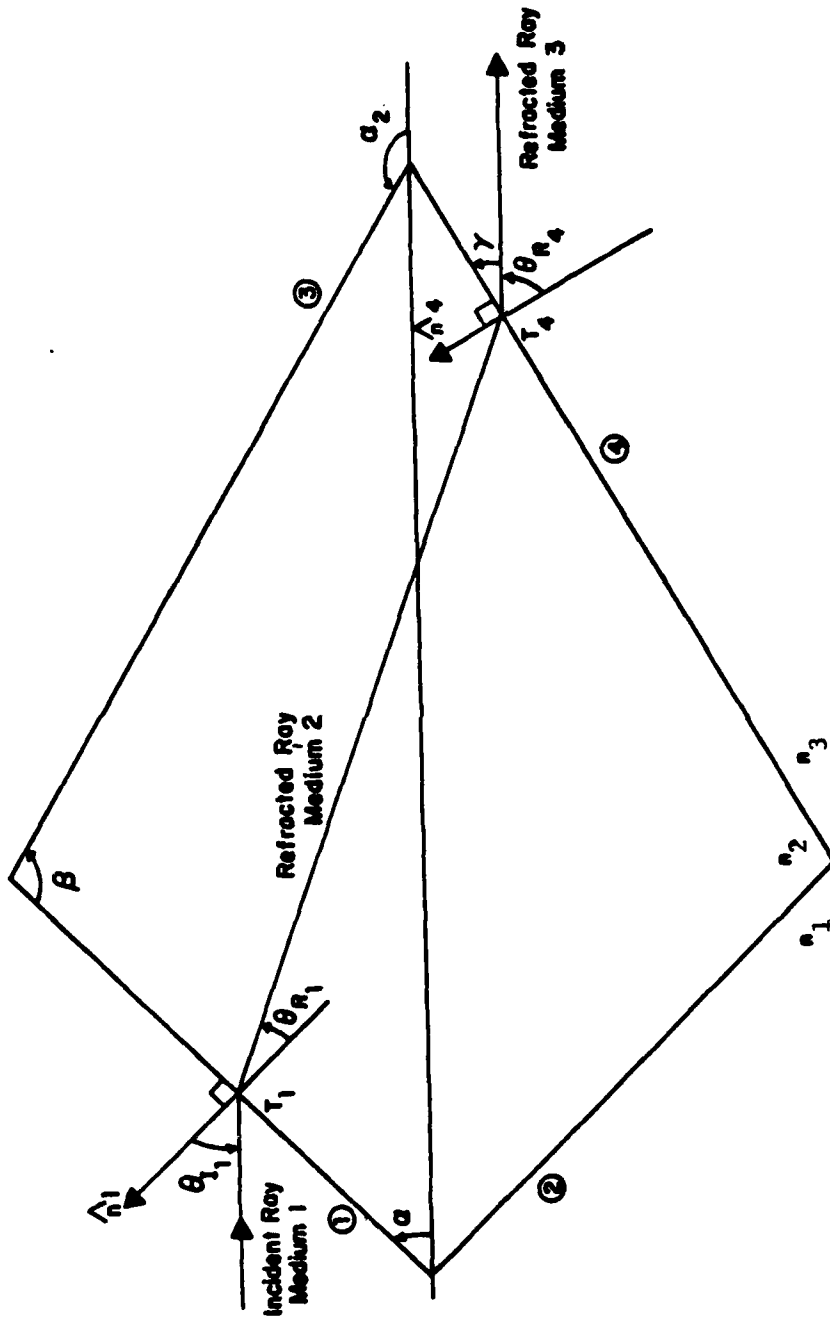


Figure D-2. Shape, Geometry and Symbol Definition for a General Block Lens.

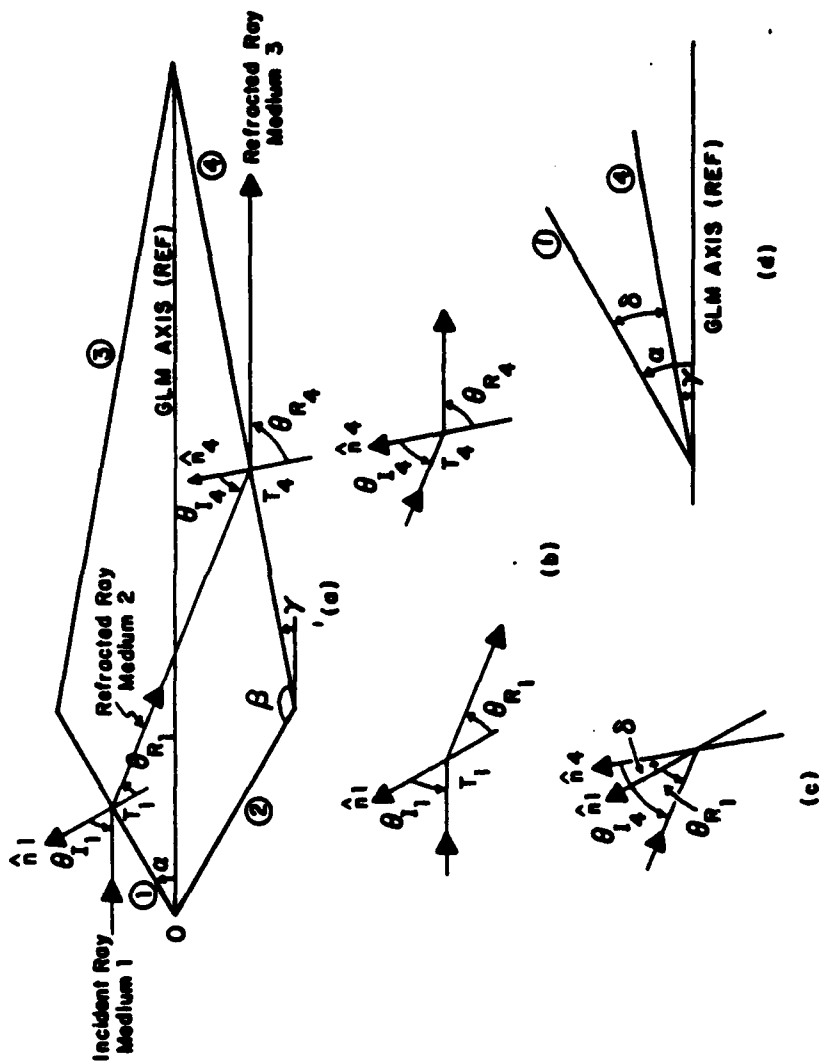


Figure D-3. Angular Relationships for the General Block Lens in Figure D-2.

① and ④ with the GLM axis, respectively.

$$\text{Now } \theta_{R_4} = \frac{\pi}{2} - \gamma$$

$$\text{Hence } \theta_{R_4} = \frac{\pi}{2} - (\alpha - \gamma)$$

$$\text{Similarly } \theta_{I_4} = \theta_{R_1} + \delta = \theta_{R_1} + \alpha - \gamma$$

From Snell's Law applied at side ④ is

$$\sin \theta_{R_4} = \frac{n_2}{n_3} \sin \theta_{I_4}.$$

Noting that $\theta_{I_4} = \theta_{R_1} + \delta$, $\delta = \alpha - \gamma$ and $\gamma = \frac{\pi}{2} - \theta_{R_4}$

$$\sin \theta_{R_4} = \frac{n_2}{n_3} \sin(\theta_{R_1} + \alpha + \theta_{R_4} - \frac{\pi}{2})$$

Simplifying by trigonometric expansions for sine and cosine yields

$$\tan \theta_{R_4} = - \left[\frac{n_3 + n_2 \sin(\theta_{R_1} + \alpha)}{n_2 \cos(\theta_{R_1} + \alpha)} \right] \quad (\text{D-1})$$

$$\text{with } \theta_{I_1} = \arcsin \left[\frac{n_1}{n_2} \sin \theta_{I_1} \right].$$

Equation (D-1) is a necessary but not sufficient condition for the ray in medium 3 to emerge from surface 4 parallel to the incident ray in medium 1. The final condition relates the angles of surfaces ① and ④ and $\theta_{I_4} = \theta_{R_1} + \delta$ as shown in figure D-3.

Applying Snell's Law at surface ④ and using trigonometric expansions yields

$$\tan \gamma = \left(\frac{n_2 \sin(\theta_{R_1} + \alpha) - n_3}{n_2 \cos(\theta_{R_1} + \alpha)} \right) \quad (D-2)$$

with $\theta_{R_1} = \arcsin \left[(n_2/n_1) \sin \theta_{I_1} \right]$.

With equations (D-1) and (D-2) rearranged to relate the $\tan(\theta_{R_1} + \alpha)$ as the independent variable the equations become

$$\tan(\theta_{R_1} + \alpha) = - \left(\tan \theta_{R_4} + \frac{n_3}{n_2} \right) \quad (D-3)$$

and

$$\tan(\theta_R + \alpha) = - \left(\frac{n_3}{\cos(\theta_{R_1} + \alpha)} + \tan \delta \right) \quad (D-4)$$

Since equation (D-3) equals equation (D-4) and solving for $\tan \gamma$ yields

$$\tan \gamma = \tan \theta_{R_4} + \frac{n_3}{\cos(\theta_{R_1} + \alpha)} + \frac{n_3}{n_2} \quad (D-5)$$

With the condition that $\gamma + \theta_{R_4} = \frac{\pi}{2}$ and noting that

$$\theta_{I_1} = \frac{\pi}{2} - \alpha, \quad \delta = \alpha - \gamma \quad \text{and} \quad \theta_{I_4} = \theta_{R_1} + \delta$$

$$\theta_{R_1} = \arcsin \left[\frac{n_1}{n_2} \sin \left(\frac{\pi}{2} - \alpha \right) \right]$$

and

$$\theta_{R_4} = \arcsin \left[\frac{n_3}{n_2} \sin(\theta_{R_1} + \alpha - \gamma) \right]$$

Equation (D-5) is recognized as a transcendental equation of the form

$$\tan \gamma = \tan \left\{ \arcsin \left[\frac{n_3}{n_2} \sin(\theta_{R_1} + \alpha - \gamma) \right] \right\} + \frac{n_3}{\cos(\theta_{R_1} + \alpha)} + \frac{n_3}{n_2} \quad (D-6)$$

which must be solved iteratively. The constraints on the solution are that $(\theta_{R_1} + \alpha) < \frac{\pi}{2}$ and

$$(n_3/n_2) \sin(\theta_{R_1} + \alpha + \gamma) \leq 1 \quad \text{and} \quad \theta_{R_4} + \gamma = \frac{\pi}{2}.$$

The appearance of the configuration of this lens in 3-dimensions would be two cones fit base to base. The image formed would be inverted with the center missing; i.e. an annulus. Therefore a substantial amount of energy could be lost in the image if the energy distribution of the object is Gaussian with the maximum at the center of the object. Therefore equations (D-1) and (D-6) are necessary and sufficient conditions to insure the incident ray in medium 1 is parallel to the exit ray in medium 3. If the condition that $\theta_{R_2} = \theta_{I_1}$ then the general lens reduces to the rhombus of figure D-1, or that of a parallelopiped in figure D-4. The position a block lens would occupy in the GLM is shown in figure D-5.

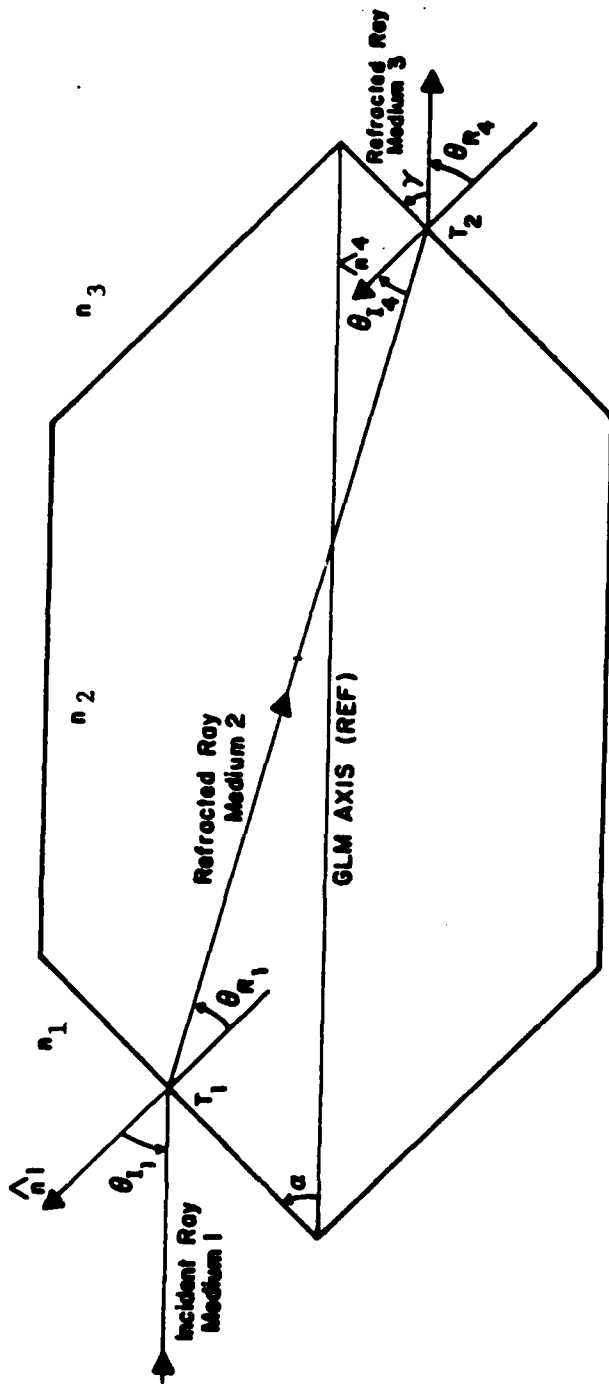


Figure D-4. Parallelepiped Block Lens.

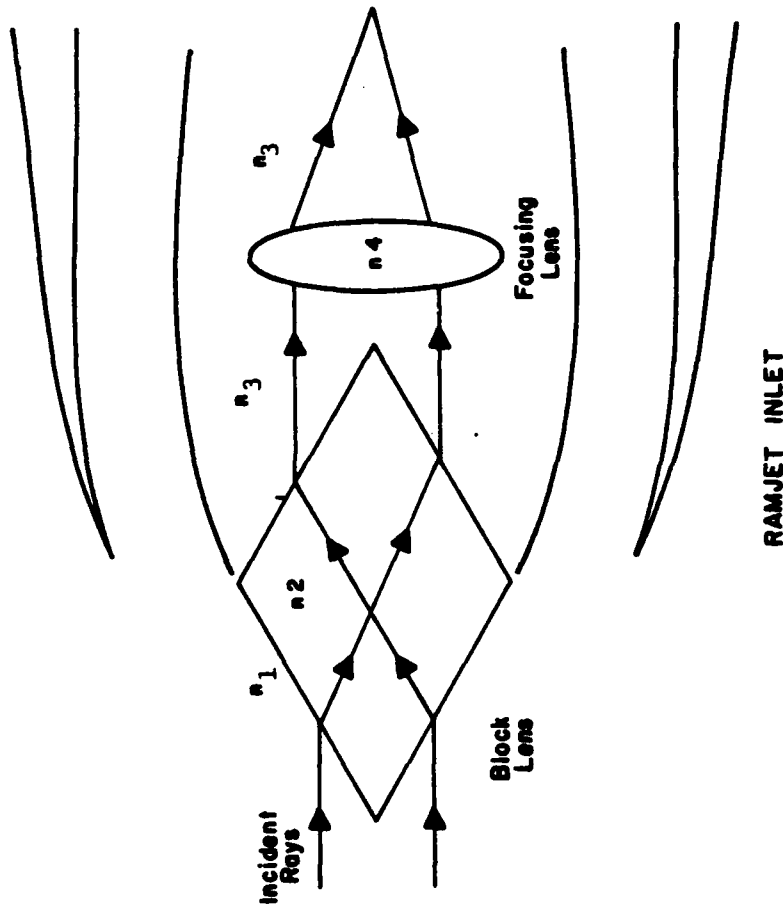


Figure D-5. Position of a Block Lens in the GLM.

APPENDIX E

GRADIENT INDEX OPTICS

The development of material which exhibits a continuous change in the optical index of refraction over distance has opened a new area in the field of optics. Gradient index (GRIN) material has been applied in the field of fiber optics communications and integrated circuits with expanding numbers of applications. GRIN has the effect of replacing individual lenses in an optical system. Theoretically GRIN material has the ability to refract light because of the continuous change in index of refraction in the medium. Practically the amount of refraction is proportional to the change in the relative index from macroscopic region to macroscopic region.

GRIN material is produced with one of three types of gradients in the index of refraction referenced to the optical axis:

1. Axial
2. Cylindrical
3. Spherical

Axial GRIN varies the index of refraction along the optical axis. Cylindrical GRIN varies the index of refraction radially from the optical axis. Hence, in three dimensions the surfaces of constant index form concentric cylinders centered on the optical axis. Spherical GRIN varies the index of refraction radially from the origin. The surfaces of constant index form a set of concentric spheres [8].

Born and Wolf [9] discuss the general properties of light rays in GRIN material with spherical symmetry. The trajectory of the light ray is described by Bouguer's relation, $nr \sin \phi = \text{constant}$, where ϕ is the angle between the position vector \vec{r} and the tangent at point P as shown in figure E-1 and is illustrated inside the GLM lens in figure E-2. For two dimensions using polar coordinates, the angle can describe explicitly as

$$\sin \phi = \frac{r(\phi)}{\sqrt{r^2(\phi) + \left(\frac{dr}{d\theta}\right)^2}} \quad (\text{E-1})$$

where $dr/d\theta = (r/c) \sqrt{n^2 r^2 - c^2}$; θ is the angle between two consecutive radii and c is Bouguer's constant. In three dimensions using spherical coordinates the relation for the change in θ , illustrated in figure E-3, over a range of radius is given by

$$\theta - \theta_0 = c \int_{r_0}^r \frac{dr}{\sqrt{n^2 r^2 - c^2}} \quad (\text{E-2})$$

Given a sphere of GRIN material shown in figure E-4 with a spherical gradient, a GLM lens can be selectively cut from the material. The lens can be customized with an index of refraction profile suitable for the application. A possible profile for the GLM conical lens, is shown in figure E-5, with a minimum and maximum located at a specific radius from the origin. Hence the ability to customize the GLM lens

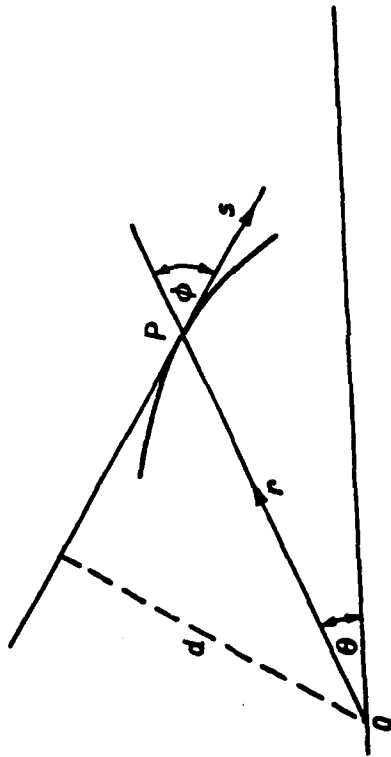


Figure E-1. Illustrating Bouguer's Formula $nd = \text{constant}$, for Rays in a Medium with Spherical Symmetry.

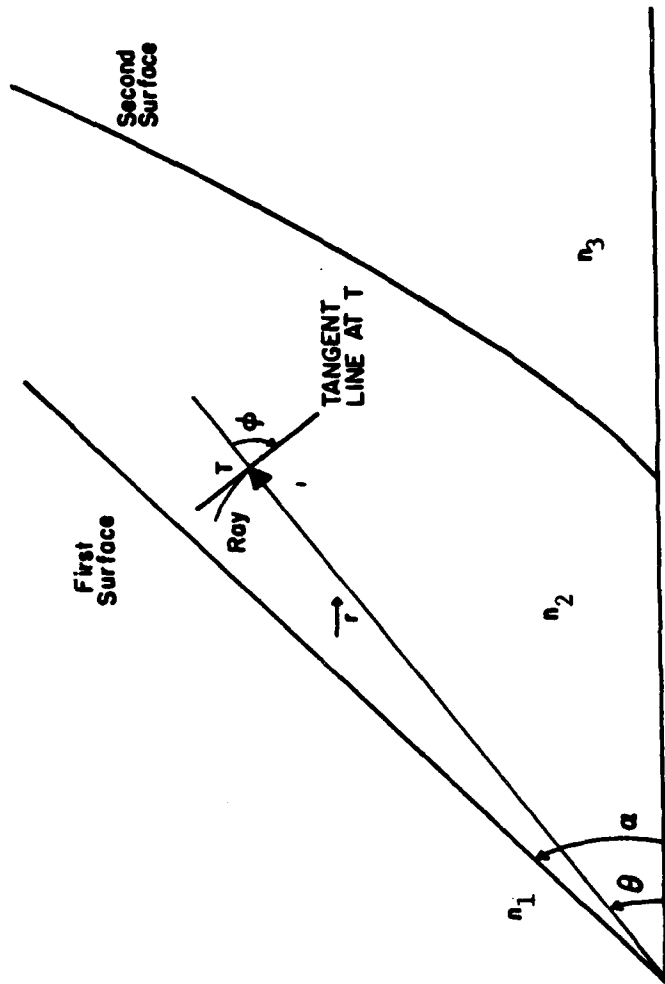


Figure E-2. Illustration of Bouguer's Formula in the GLM Conical Lens.

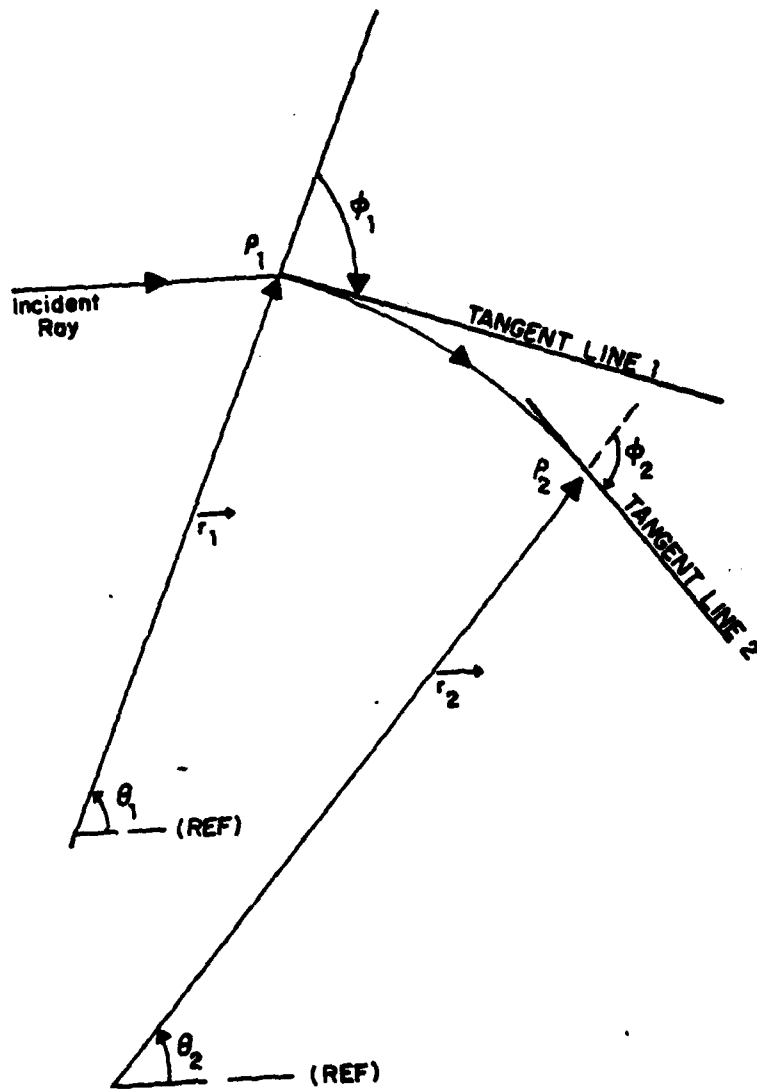


Figure E-3. Illustration of the Relationship Between \hat{r} and ϕ Between Adjacent Rays in the GLM GRIN Lens.

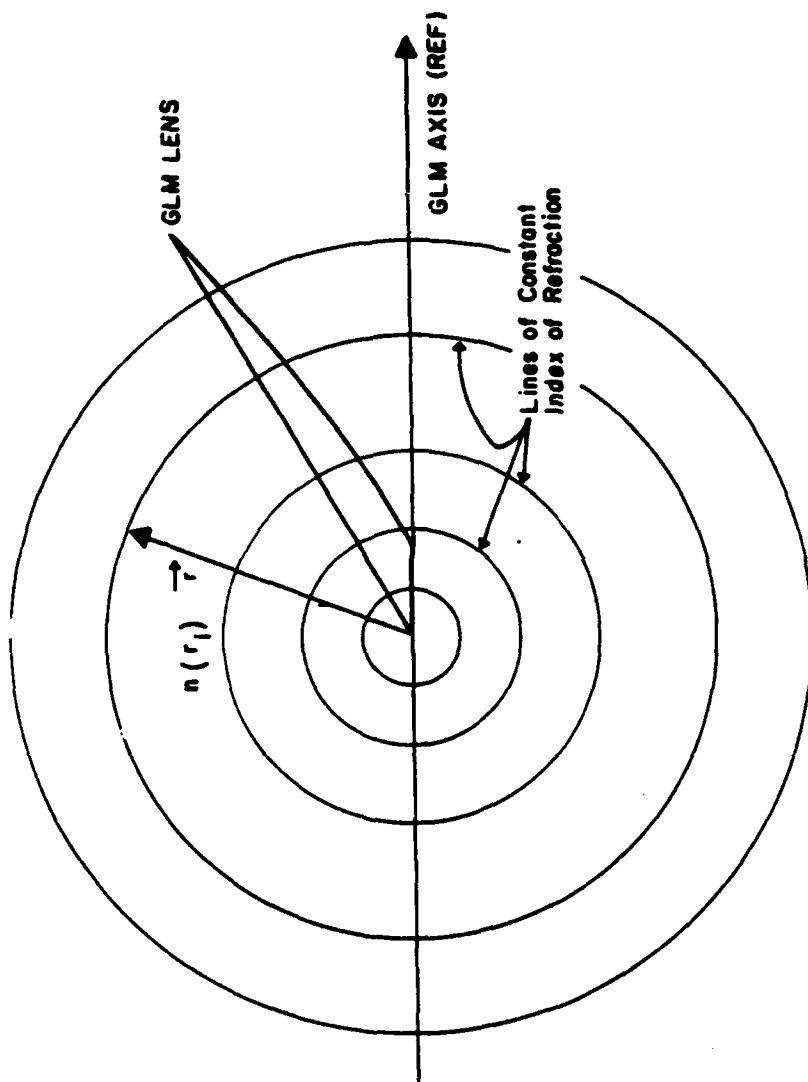


Figure E-4. Illustration of a GLM Lens as a Section of GRIN Material Exhibiting Spherical Symmetry.

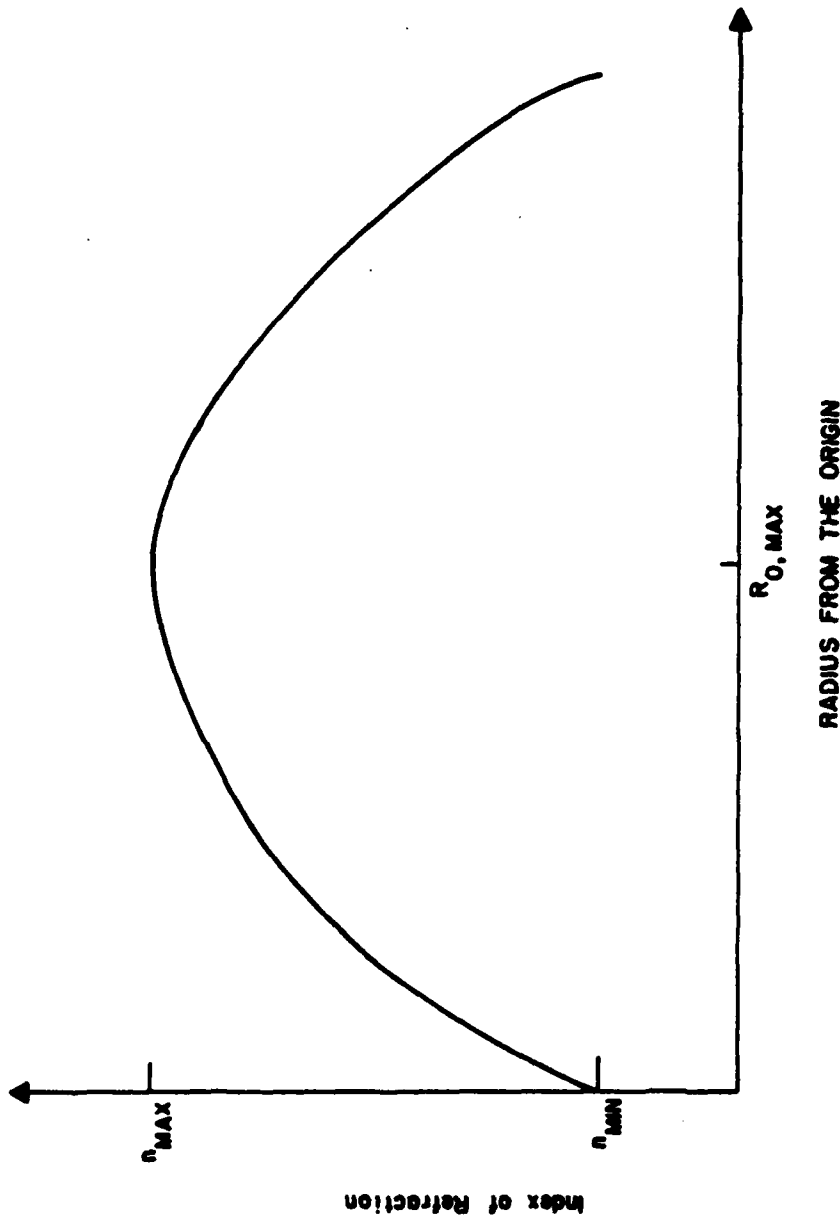


Figure E-5. Index of Refraction Profile as a Function of Radius from the Origin.

enables the lens designer to place the maximum value of the index of refraction at the desired location. The profile shown in figure E-5 can be applied to the GLM conical lens with the index profile varying along the first surface shown in figure E-6.

Bouguer's constant, defined by the relation $n r \sin \phi = c$ is a function of the radius, index of refraction at that radius and the angle ϕ defined earlier. However, once the ray enters the GRIN medium, the constant is invariant along the ray. Therefore the constant can theoretically be determined explicitly at any point. Practically, two points exist at which the constant can be determined. These are at the intercept of the incident ray and the first surface and the intercept of the ray in the conical lens and the second surface. The most convenient position to calculate c is the first surface because n , r and ϕ can all be determined explicitly on the first surface. Table E-I is a tabulation of values of Bouguer's constant c . Figure E-7 shows the relationship between the constant c and the radius from the origin along the first surface of the GLM.

Calculating the ray paths through a conical lens composed of GRIN material must be accomplished by solving equation (E-2) at each point in the lens. A complete algorithm was not written because of the time constraints, but TRACE can calculate the value of Bouguer's constant and refract the ray at the first surface shown in figure E-8 using the value of

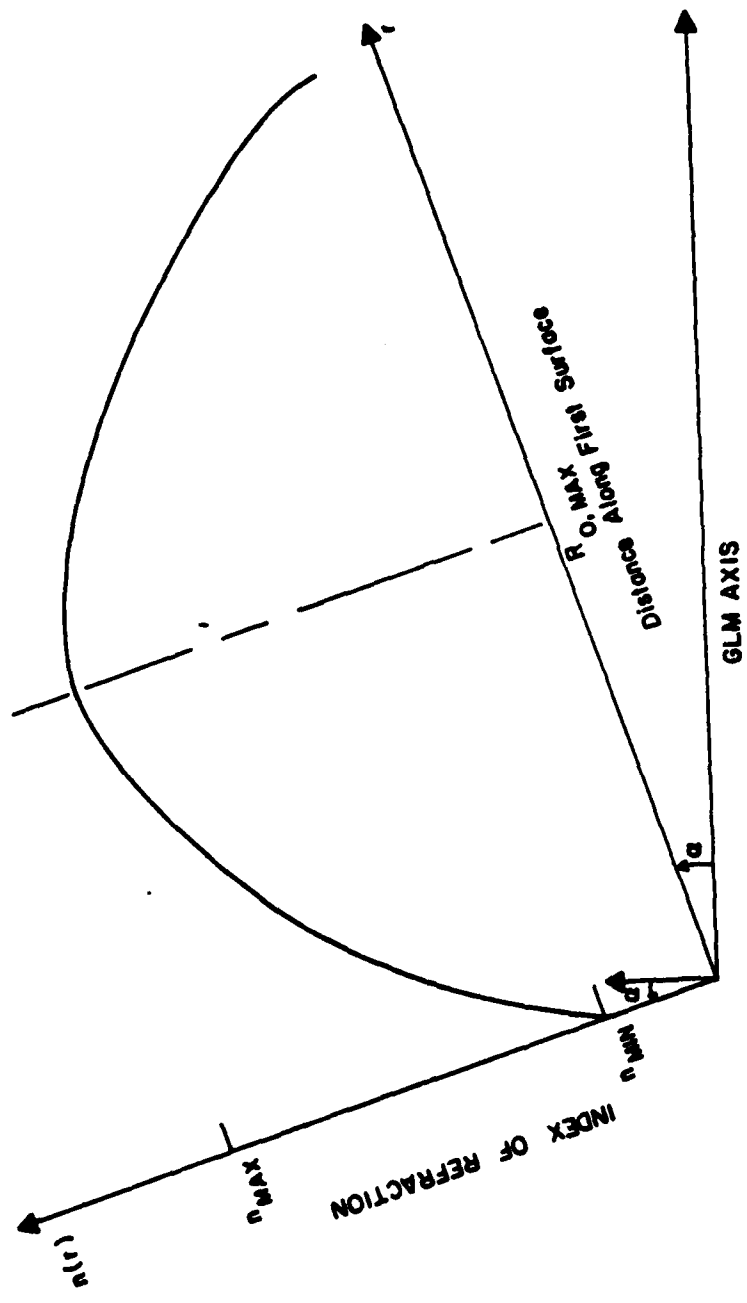


Figure E-6. Index of Refraction as a Function of Distance Along the First Surface of the GLM Lens.

TABLE E-I
BOUGUER'S GRIN CONSTANT

I	n(I)	n'(I)	Phi(I)	Sin(Phi)	c(I)
1	2.4406	.0614	67.5096	.9239	.1304
2	2.6170	.1228	69.0997	.9342	.1302
3	2.7401	.1842	70.1402	.9405	.14760
4	2.8551	.2456	70.9137	.9450	.16625
5	2.9461	.3069	71.5251	.9485	.18577
6	3.0254	.3683	72.0263	.9512	1.0600
7	3.0956	.4297	72.4472	.9534	1.2683
8	3.1583	.4911	72.8067	.9553	1.4818
9	3.2147	.5525	73.1174	.9569	1.6996
10	3.2656	.6139	73.3882	.9583	1.9210
11	3.3116	.6753	73.6258	.9594	2.1456
12	3.3534	.7367	73.8352	.9605	2.3727
13	3.3911	.7981	74.0200	.9614	2.6017
14	3.4252	.8595	74.1834	.9621	2.8324
15	3.4560	.9208	74.3277	.9628	3.0641
16	3.4835	.9822	74.4549	.9634	3.2965
17	3.5081	1.0436	74.5664	.9639	3.5291
18	3.5298	1.1050	74.6637	.9644	3.7616
19	3.5488	1.1664	74.7477	.9648	3.9935
20	3.5651	1.2278	74.8193	.9651	4.2245
21	3.5789	1.2892	74.8792	.9654	4.4541
22	3.5902	1.3506	74.9279	.9656	4.6820
23	3.5991	1.4120	74.9659	.9658	4.9079
24	3.6055	1.4733	74.9935	.9659	5.1310
25	3.6096	1.5347	75.0109	.9660	5.3514
26	3.6114	1.5961	75.0184	.9660	5.5683
27	3.6108	1.6575	75.0159	.9660	5.7815
28	3.6079	1.7189	75.0034	.9659	5.9904
29	3.6026	1.7803	74.9809	.9658	6.1946
30	3.5949	1.8417	74.9482	.9657	6.3936
31	3.5849	1.9031	74.9049	.9655	6.5869
32	3.5723	1.9645	74.8506	.9652	6.7738
33	3.5573	2.0259	74.7850	.9649	6.9539
34	3.5396	2.0872	74.7073	.9646	7.1265
35	3.5193	2.1486	74.6168	.9642	7.2908
36	3.4962	2.2100	74.5125	.9637	7.4461
37	3.4701	2.2714	74.3933	.9631	7.5915
38	3.4410	2.3328	74.2578	.9625	7.7261
39	3.4086	2.3942	74.1042	.9618	7.8488
40	3.3727	2.4556	73.9384	.9609	7.9583
41	3.3330	2.5170	73.7338	.9600	8.0533
42	3.2892	2.5784	73.5100	.9589	8.1319
43	3.2408	2.6397	73.2573	.9576	8.1921
44	3.1872	2.7011	72.9675	.9561	8.2315
45	3.1278	2.7625	72.6337	.9544	8.2467
46	3.0615	2.8239	72.2454	.9524	8.2337
47	2.9870	2.8853	71.7873	.9499	8.1867
48	2.9022	2.9467	71.2357	.9468	8.0975
49	2.8039	3.0081	70.5519	.9429	7.9532
50	2.6864	3.0695	69.6639	.9377	7.7317

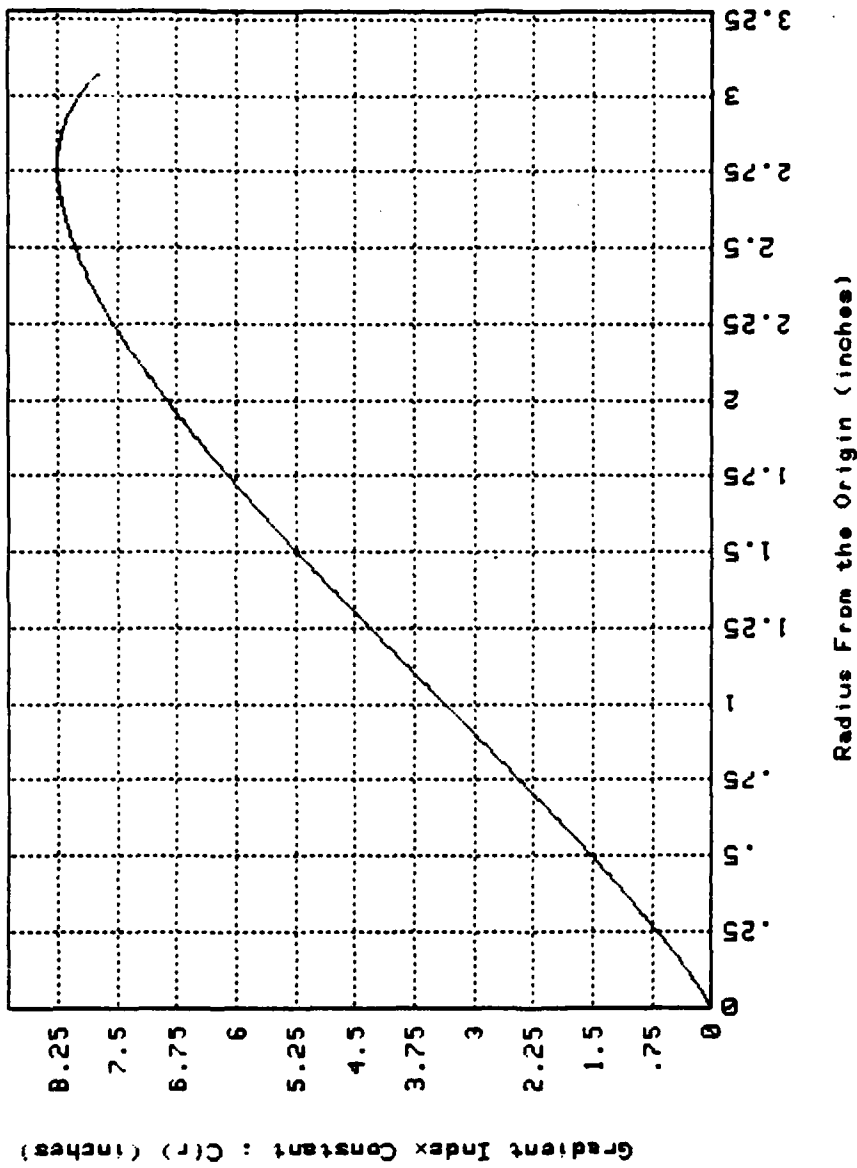
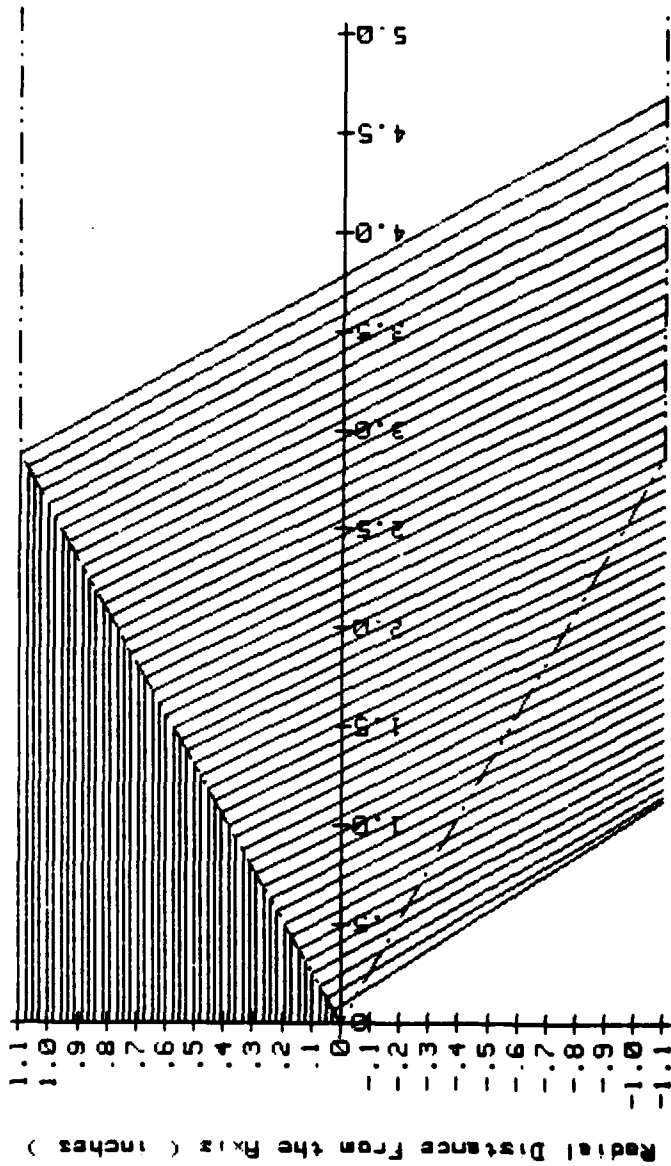


Figure E-7. Bouguer's GRIN Constant as a Function of Radius from the Origin.



GRIN TRACE

$n1 : 1.00000$

$n3 : 1.00000$

Number of Rays : 46

Figure E-8. Ray Diagram Showing the Change in Refracted Ray Angle at the First Surface of the GRIN Lens Using GRIN Material for the Lens.

the index of refraction at that point. The calculated data for the ray diagram is tabulated in Tables E-II and E-III.

TABLE E-II

INITIAL PARAMETER VALUES

RHO(INITIAL) = 0.00 degrees
 TAN(RHO-INITIAL) = 0.00

Alpha = 21.00 degrees
 Tan(Alpha) = .38

n1 = 1.00000

n3 = 1.00000

Nmin = 2.00000

n2(1) = 2.44494	n2(2) = 2.62297	n2(3) = 2.75522
n2(4) = 2.86301	n2(5) = 2.95465	n2(6) = 3.03445
n2(7) = 3.10497	n2(8) = 3.16790	n2(9) = 3.22441
n2(10) = 3.27535	n2(11) = 3.32137	n2(12) = 3.36296
n2(13) = 3.40051	n2(14) = 3.43436	n2(15) = 3.46474
n2(16) = 3.49189	n2(17) = 3.51596	n2(18) = 3.53710
n2(19) = 3.55543	n2(20) = 3.57106	n2(21) = 3.58406
n2(22) = 3.59449	n2(23) = 3.60241	n2(24) = 3.60785
n2(25) = 3.61083	n2(26) = 3.61138	n2(27) = 3.60949
n2(28) = 3.60516	n2(29) = 3.59836	n2(30) = 3.58907
n2(31) = 3.57723	n2(32) = 3.56280	n2(33) = 3.54569
n2(34) = 3.52582	n2(35) = 3.50309	n2(36) = 3.47735
n2(37) = 3.44845	n2(38) = 3.41619	n2(39) = 3.38033
n2(40) = 3.34060	n2(41) = 3.29663	n2(42) = 3.24798
n2(43) = 3.19407	n2(44) = 3.13415	n2(45) = 3.06722
n2(46) = 2.99185	n2(47) = 2.90593	n2(48) = 2.80612
n2(49) = 2.68635	n2(50) = 2.68635	n2(51) = 0.00000

R0_max = 1.61147 inches

Aperture = 1.100

Ya = 0.000 inch

Yb = 1.100 inch

Number of Rays = 50

TABLE E-III

RAY DIAGRAM DATA CALCULATED FOR FIGURE E-8

(X0, Y0)	(X1, Y1)	(X3, Y3)	(Xc, Yc)	N2	RHO
0.00 .02	.06 .02	4.06 -4.20	.08 0.00	2.44	-46.51
0.00 .04	.11 .04	3.96 -4.24	.15 0.00	2.62	-48.10
0.00 .07	.17 .07	3.91 -4.26	.23 0.00	2.75	-49.14
0.00 .09	.23 .09	3.89 -4.26	.30 0.00	2.86	-49.91
0.00 .11	.29 .11	3.89 -4.26	.38 0.00	2.95	-50.53
0.00 .13	.34 .13	3.90 -4.26	.45 0.00	3.03	-51.03
0.00 .15	.40 .15	3.92 -4.26	.52 0.00	3.10	-51.45
0.00 .18	.46 .18	3.94 -4.25	.60 0.00	3.16	-51.81
0.00 .20	.52 .20	3.97 -4.24	.67 0.00	3.21	-52.12
0.00 .22	.57 .22	4.00 -4.22	.74 0.00	3.27	-52.39
0.00 .24	.63 .24	4.03 -4.21	.82 0.00	3.31	-52.63
0.00 .26	.69 .26	4.07 -4.20	.89 0.00	3.35	-52.84
0.00 .29	.75 .29	4.11 -4.18	.96 0.00	3.39	-53.02
0.00 .31	.80 .31	4.15 -4.16	1.03 0.00	3.43	-53.18
0.00 .33	.86 .33	4.19 -4.15	1.11 0.00	3.46	-53.33
0.00 .35	.92 .35	4.24 -4.13	1.18 0.00	3.48	-53.45
0.00 .37	.97 .37	4.29 -4.11	1.25 0.00	3.51	-53.57
0.00 .40	1.03 .40	4.33 -4.09	1.32 0.00	3.53	-53.66
0.00 .42	1.09 .42	4.38 -4.08	1.40 0.00	3.55	-53.75
0.00 .44	1.15 .44	4.43 -4.06	1.47 0.00	3.57	-53.82
0.00 .46	1.20 .46	4.49 -4.04	1.54 0.00	3.58	-53.88
0.00 .48	1.26 .48	4.54 -4.02	1.61 0.00	3.59	-53.93
0.00 .51	1.32 .51	4.59 -4.00	1.69 0.00	3.60	-53.97
0.00 .53	1.38 .53	4.65 -3.97	1.76 0.00	3.61	-53.99
0.00 .55	1.43 .55	4.70 -3.95	1.83 0.00	3.61	-54.01
0.00 .57	1.49 .57	4.76 -3.93	1.91 0.00	3.61	-54.02
0.00 .59	1.55 .59	4.82 -3.91	1.99 0.00	3.61	-54.02
0.00 .62	1.60 .62	4.88 -3.89	2.05 0.00	3.61	-54.00
0.00 .64	1.66 .64	4.93 -3.86	2.13 0.00	3.60	-53.98
0.00 .66	1.72 .66	5.00 -3.84	2.20 0.00	3.59	-53.95
0.00 .68	1.78 .68	5.06 -3.82	2.27 0.00	3.58	-53.90
0.00 .70	1.83 .70	5.12 -3.79	2.35 0.00	3.57	-53.85
0.00 .73	1.89 .73	5.18 -3.77	2.42 0.00	3.56	-53.78
0.00 .75	1.95 .75	5.25 -3.74	2.50 0.00	3.54	-53.71
0.00 .77	2.01 .77	5.31 -3.72	2.57 0.00	3.52	-53.62
0.00 .79	2.06 .79	5.38 -3.69	2.65 0.00	3.50	-53.51
0.00 .81	2.12 .81	5.45 -3.67	2.73 0.00	3.47	-53.39
0.00 .84	2.18 .84	5.52 -3.64	2.80 0.00	3.44	-53.26
0.00 .86	2.24 .86	5.59 -3.61	2.88 0.00	3.41	-53.10
0.00 .88	2.29 .88	5.66 -3.58	2.96 0.00	3.37	-52.93
0.00 .90	2.35 .90	5.74 -3.55	3.04 0.00	3.33	-52.73
0.00 .92	2.41 .92	5.82 -3.52	3.12 0.00	3.29	-52.51
0.00 .95	2.46 .95	5.90 -3.49	3.20 0.00	3.24	-52.26
0.00 .97	2.52 .97	5.99 -3.46	3.28 0.00	3.19	-51.97
0.00 .99	2.58 .99	6.07 -3.43	3.36 0.00	3.13	-51.63
0.00 1.01	2.64 1.01	6.17 -3.39	3.45 0.00	3.06	-51.25
0.00 1.03	2.69 1.03	6.27 -3.35	3.54 0.00	2.99	-50.79
0.00 1.06	2.75 1.06	6.38 -3.31	3.63 0.00	2.90	-50.24
0.00 1.08	2.81 1.08	6.51 -3.26	3.73 0.00	2.80	-49.55
0.00 1.10	2.87 1.10	6.65 -3.20	3.83 0.00	2.69	-48.66

APPENDIX F

SECOND SURFACE GENERATION: ITERATIVE SOLUTION

A. INTRODUCTION

One of the conclusions reached as a result of the investigation of curves A, B and C in Appendix C was that using a single polynomial to describe the second surface of a conical lens cannot satisfactorily refract light to a single, distinct focal point. Hence, a satisfactory image of an object cannot be formed.

Three options for further study remained. First, continue to try and find a suitable polynomial to describe the second surface. This option was not pursued because of the infinite number of trials which would be required to determine if such an analytic expression existed. The second option would be to attempt to optimize a given polynomial by manipulating the coefficients of that polynomial to change the refracting properties of the polynomial such that a single, distinct focal point could be formed. This option was pursued by using Control Program for Engineering Synthesis (COPEs) developed by Dr. G.N. Vanderplaats, Naval Postgraduate School. The study was halted because of time constraints. However, initial results concurred with the previously mentioned results of Appendix C.

The third option was provided by an inquiry made by Dr. E.C. Crittenden, Naval Postgraduate School, concerning the capability of the TRACE program to draw rays backward;

i.e. could TRACE begin a set of light rays at a design focal point and draw them through the lens and into the medium ahead of the lens and emerging parallel to the GLM axis? Accomplishing the "backwards" ray trace would design the lens. Conceptually, at least two methods of generating the second surface of a conical lens exist and are available for investigation. The first method consisted of picking the initial point of the second surface to be the GLM axis-intercept of a refracted ray in the lens medium, noting that the ray must be refracted along the GLM axis to pass through the axis. Therefore, the slope of the second surface at the first point must be equal to the slope of the first surface. The derivation of this relationship is performed in Appendix A. The second point on the surface is calculated by extending a straight line by using the slope at the first point to intercept the next ray in the lens. Since the second point is not on the GLM axis, the slope at the second point required to satisfy Snell's Law will not be equal to the slope of the first surface. This process was chosen as the preferred method and is discussed in Chapter III and Appendix A.

The second method of generating a second surface for a conical lens is similar to the first method. The difference is that a parabola is used instead of a straight line to predict the second and succeeding points on the second surface. A different parabola is used for every pair of points. A nonlinear predictor is desired because the shape of the

second surface is nonlinear. The following discussion describes this method of second surface generation for a conical lens.

B. ITERATIVE SOLUTION

1. Derivation of Expressions for θ_I and α_2

The iterative solution is motivated by the ability of a computer to perform a great many calculations in a small amount of time. Referring to figure F-1 for the geometry and symbol definitions, the most significant steps in the iterative solution are:

(1) Initialization:

(a) Choose a focal point on the GLM axis.

(b) Choose an initial lens point T1.

(c) Choose an initial change in ρ_2 , $\Delta\rho_2$.

(2) Calculate the ray parameters θ_I , ρ_2 and α_2 for the initial lens point by applying Snell's Law at T1.

(3) Calculate the second lens point T2 by fitting a parabola through T1 and predict the coordinate values of T2. Iterate this prediction until the error is reduced below an acceptable tolerance. The error is defined to be the distance at which T2 intercepts the GLM axis.

(4) Calculate the ray parameters θ_I , ρ_2 and α_2 for T2.

(5) Continue until the lens has been designed to the GLM axis.

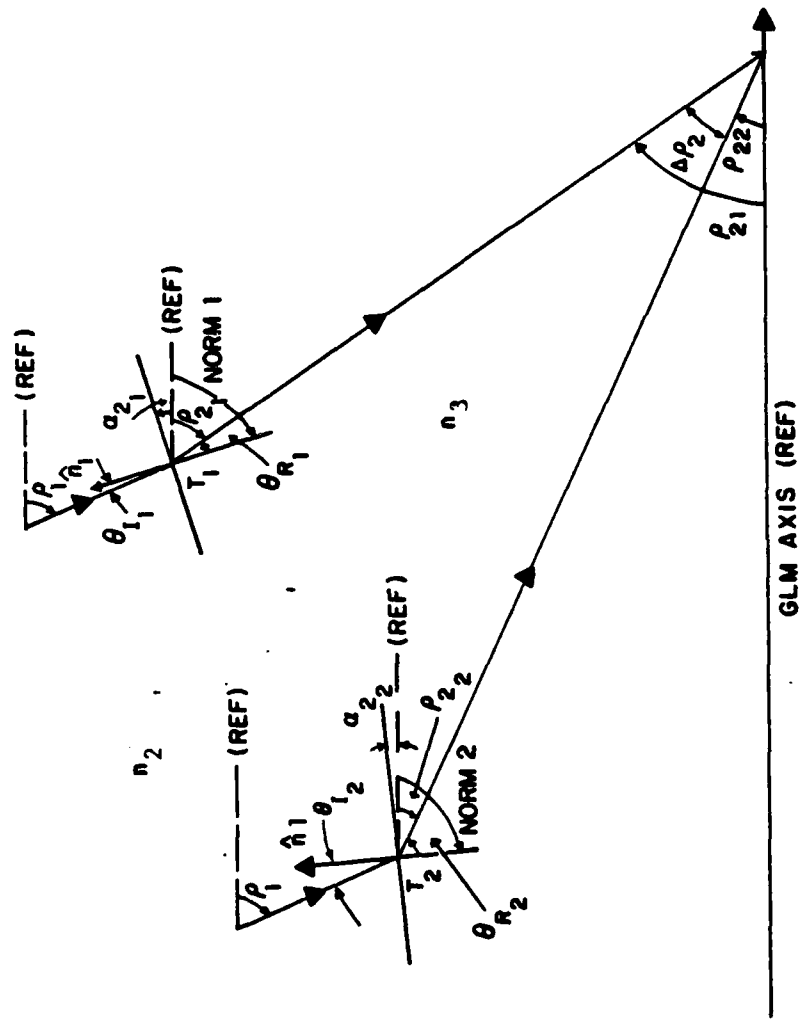


Figure F-1. Geometry and Symbol Definition Used for the Iterative Solution Method of Second Surface Generation.

NOTE: All coordinate values are referenced to a right hand system. All angles are referenced to the GLM axis and are positive for counter-clockwise rotation from the axis to the point in question. The coordinate values (abscissa, ordinate) are referred to as (x,y) with $x \equiv$ the distance along the GLM axis and $y \equiv$ the radius from the GLM axis. The subscripts are either single or double. The single and the first subscript in the double subscripts, the number refers to the surface at which the application of Snell's Law occurred. If the subscript is a letter the subscript refers to the operation of Snell's Law; I for angle of incidence and R for angle of refraction. The second subscript refers to the point number in the lens. For example α_{2_2} is the slope of the second surface at point number two. Any exceptions to this convention for subscripts will be made clear within the context of the discussion.

The investigation consisted of deriving the analytical expressions relating the quantities shown in figure F-2. The primary variables of interest are the angle of incidence θ_I , α_2 the angle of the tangent line at T and ρ_2 the refracted ray angle in medium 3. The assumptions made in the derivation are that the following quantities are known:

(1) ρ_1 ; the ray angle in the lens medium, measured with respect to the GLM axis.

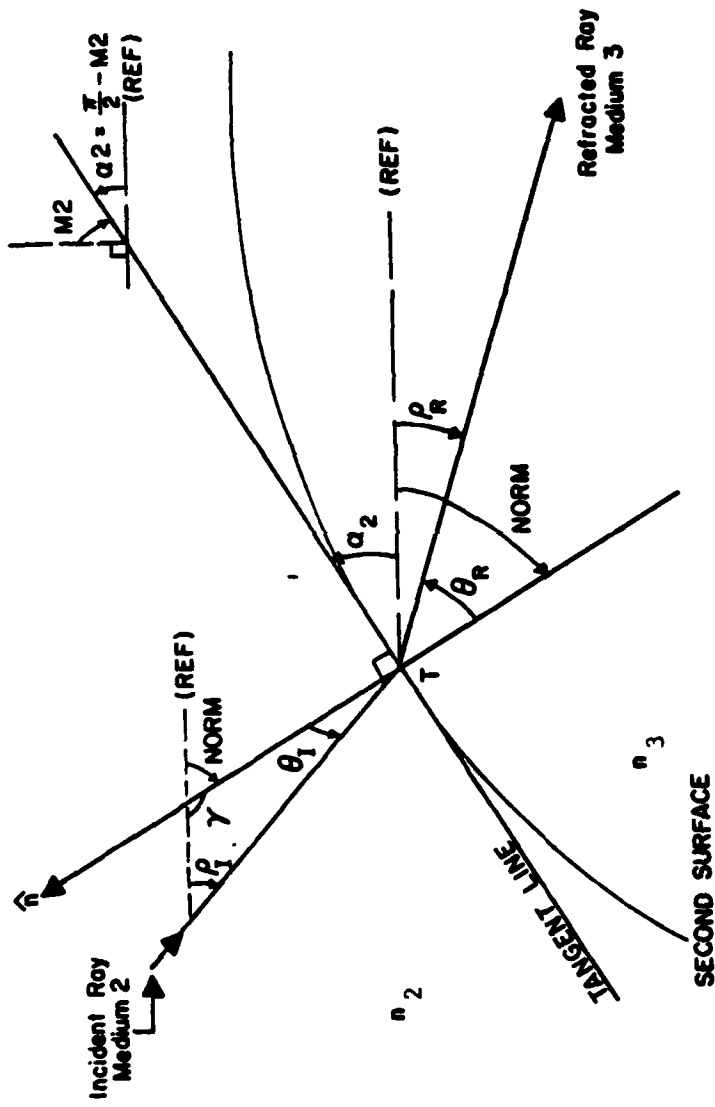


Figure F-2. Geometry and Symbols Used for Snell's Law in the Low Region as Applied to the Iterative Solution Methods for Second Surface Generation.

(2) ρ_2 ; the ray angle in medium 3 measured with respect to the GLM axis.

(3) n_2 ; the index of refraction of the lens medium.

(4) n_3 ; the index of refraction of medium 3.

(5) f ; the design focal point on the GLM axis.

(6) (x,y) ; the coordinate values of the Point T.

(7) the ray is transmitted without loss in all media.

(8) the ray is either refracted or totally reflected at the boundary of two media.

As discussed in Chapter III there exist two regions where the refracted ray in the lens can be refracted at point T. Point T is located in the low region as defined by the area below a line QP shown in figure F-3. In the low region $|\rho_1|$ is always greater than or equal to $|\beta|$. Point T is located in the high region when $|\rho_1|$ is less than $|\beta|$ as shown in figure F-4.

Each point on the lens' second surface must satisfy Snell's Law $\sin\theta_R = n_2/n_3 \sin\theta_I$ or be totally reflected at T. Therefore referring to figure F-2 the angle of incidence in the low region is

$$\theta_I = \left(\frac{\pi}{2} - \alpha_2 \right) - |\rho_1| \quad (F-1)$$

and the ray angle in medium 3 is

$$|\rho_2| = \frac{\pi}{2} - (\theta_R + \alpha_2) \quad (F-2)$$

Subtracting equation (F-2) from (F-1) and substituting Snell's Law for θ_R yields

$$\theta_I = |\rho_2| - |\rho_1| - \arcsin \left[\frac{n_2}{n_3} \sin \theta_I \right] \quad (F-3)$$

Now $\alpha_2 = \frac{\pi}{2} - (|\rho_2| - \theta_R)$ hence

$$\alpha_2 = \frac{\pi}{2} - \left[|\rho_2| + \arcsin \left(\frac{n_2}{n_3} \sin \theta_I \right) \right] \quad (F-4)$$

Equation (F-3) is a transcendental equation in θ_I and therefore can be solved graphically or by numerical methods. Therefore, equations (F-3) and (F-4) must both be solved for each iteration of θ_I until a satisfactory value of α_2 is determined. Experience from using the CHART algorithm shows that an initial guess of $\theta_I = \theta_c - 2^\circ$ should allow the algorithm to converge quickly. The critical angle θ_c is the angle of incidence at which $\sin \theta_R = 1$. Changing equations (F-3) and (F-4) into a form suitable for a numerical algorithm yields

$$\theta_{I,n+1} = |\rho_2| - |\rho_1| + \arcsin \left[\frac{n_2}{n_3} \sin \theta_{I,n} \right] \quad (F-5)$$

$$\alpha_{2,n} = \frac{\pi}{2} - \left[|\rho_2| + \arcsin \left(\frac{n_2}{n_3} \sin \theta_{I,n+1} \right) \right] \quad (F-6)$$

for the angle of incidence and angle of the tangent line at Point T in the low region.

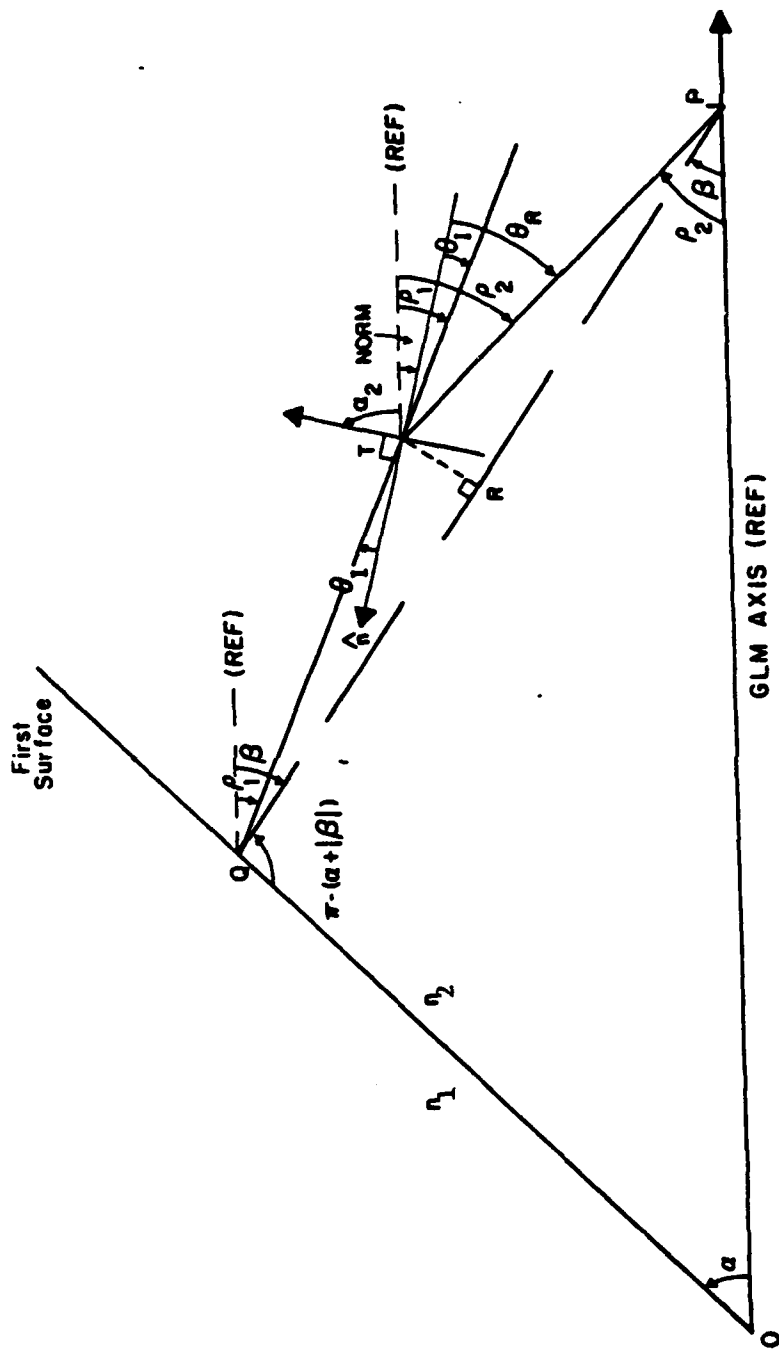


Figure F-4. Geometry and Symbols Used for Snell's Law in the High Region as Applied to the Iterative Solution Method for Second Surface Generation.

As shown in figure F-4 the angle of incidence in the high region is

$$\theta_I = |\rho_2| - |\rho_1| \quad (F-7)$$

and the ray angle in medium 3 is

$$\rho_2 = \frac{\pi}{2} - \alpha_2 + \theta_R \quad (F-8)$$

Adding equations (F-7) and (F-8) and substituting Snell's Law for θ_R yields

$$\theta_I = \frac{\pi}{2} - (|\rho_1| + \alpha_2) + \arcsin\left(\frac{n_3}{n_2} \sin\theta_I\right) \quad (F-9)$$

now $\alpha_2 = \frac{\pi}{2} - |\text{NORM}|$

hence

$$\alpha_2 = \frac{\pi}{2} - |\rho_1| + \theta_I \quad (F-10)$$

Equation (F-9) is a transcendental equation in θ_I and must be solved graphically or by numerical methods. Therefore equations (F-9) and (F-10) must be solved for each iteration of θ_I until a satisfactory value of α_2 is determined. From the geometry in figure F-4 an initial guess for $\theta_I = 2 |\rho_1|$ should cause fast convergence to the desired value of α_2 . Changing equations (F-9) and (F-10) into a form suitable for numerical applications yields

$$\theta_{I,n+1} = \frac{\pi}{2} - (|\rho_1| + \alpha_{2,n}) + \arcsin\left(\frac{n_3}{n_2} \sin\theta_{I,n}\right) \quad (F-11)$$

$$\alpha_{2,n+1} = \frac{\pi}{2} - |\rho_1| + \theta_{I,n+1} \quad (F-12)$$

for the angle of incidence and angle of the tangent line at Point T in the high region.

2. Predicting Succeeding Points on the Second Surface

The iterative solution method must involve a regression routine to use a parabola to predict the next point on the second surface. The regression routine solves a set of simultaneous equations consisting of the equation of the parabola and first derivative at $T_1(x_1, y_1)$ and $T_2(x_2, y_2)$ in the form

$$\begin{aligned}
 a + bx_1 + cx_1^2 &= y_1 \\
 b + 2cx_1 &= y'_1 \\
 a + bx_2 + cx_2^2 &= y_2 \\
 a + 2cx_2 &= y'_2
 \end{aligned}
 \tag{F-13}$$

The set of equations is nonlinear in x , but is linear in the coefficients. Therefore, the techniques of linear algebra can be used on equation (F-13). The method used here is the Gaussian-Jordan row-reduction technique discussed in Anton [10]. The first step is to form the augmented matrix whose determinant is set equal to zero

$$\begin{vmatrix}
 1 & x_1 & x_1^2 & y_1 \\
 0 & 1 & 2x_1 & y'_1 \\
 1 & x_2 & x_2^2 & y_2 \\
 0 & 1 & 2x_2 & y'_2
 \end{vmatrix} = 0
 \tag{F-14}$$

The row-reduction technique diagonalizes the first three columns of determinant (F-14) with, in general, non-zero quantities in the fourth column in the form

$$\begin{vmatrix} 1 & 0 & 0 & A \\ 0 & 1 & 0 & B \\ 0 & 0 & 1 & C \\ 0 & 0 & 0 & \Delta \end{vmatrix} = 0 \quad (\text{F-15})$$

Since four equations have been used to determine the three coefficients a, b and c the determinant is over-specified and nonhomogeneous. Utilizing the fact that the expression represented by D at location (4,4) in (F-15) is equal to zero

$$D = x_1 y_2' - x_1 y_1' + x_2 y_2' - x_2 y_1' - 2y_2 + 2y_1 = 0 \quad (\text{F-16})$$

if $x_2 \neq x_1$, which is reasonable, since the problem demands that $x_2 \neq x_1$. Simplifying equation (F-16) and solving for

$$\frac{y_2 - y_1}{x_2 - x_1} \quad \text{yields}$$

$$\frac{\Delta Y}{\Delta X} = \frac{y_2 - y_1}{x_2 - x_1} = \frac{y_2^1 + y_1^1}{2} \quad (\text{F-17})$$

Equation (F-17) states that the slope of the straight line connecting T1 and T2 in figure F-5 is the average of the slope of the parabola used to predict T2 evaluated at T1 and T2. This result is very simple, yet provides a tool to use in predicting the value of T2. Experience gained in using CHART has shown that the second surface of the conical lens is a smooth convex surface with no discontinuities; compare

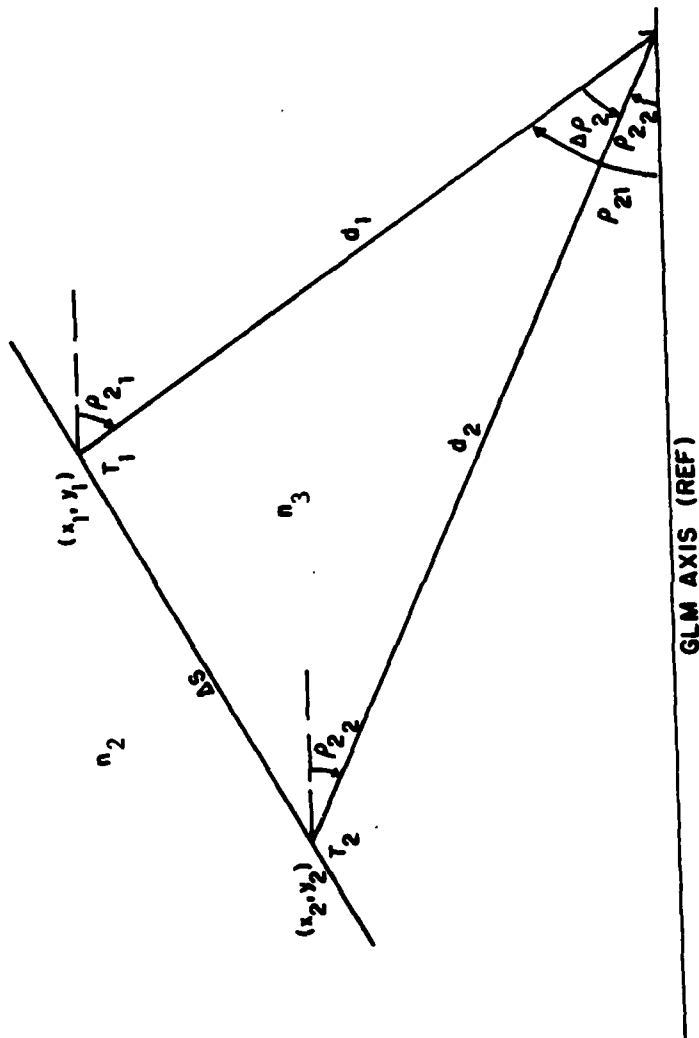


Figure F-5. Illustration of the Result of the Solution of the Simultaneous Equations Used to Predict Point T2 on the Second Surface Using the Iterative Method.

figures 14 and 20 in Chapter III. The exact shape of the second surface is a function of the cone half-angle α , and the indices of refraction n_1, n_2 and n_3 . The first guess of where T2 is generated by coordinate values of the intersection of the ray in the lens and the ray in medium 3 is shown in figure F-1. The set of equations (F-13) is solved using (x_1, y_1) and (x_2, y_2) to find $(\Delta Y/\Delta X)$ in equation (F-17). Since the slope at T1 is known the next guess of the actual location of T2 is aided by the experience of using CHART. The slope at T2 will increase as the first surface is approached. Therefore, calculating the slope of the line connecting T1 and T2 and comparing that value with the value from equation (F-17) will determine whether to increase or decrease $\Delta \rho_2$ to predict the next position of T₂. This procedure is continued until the coordinate values of T2 are determined within a specified tolerance.

C. NEWTON'S METHOD

The recommended numerical method used to solve the transcendental equations for θ_I and α_2 in section B-1 is Newton's method. A detailed explanation of the technique is not provided here. Scores of texts on applied numerical methods exist and should be consulted for further study.

Newton's method is simple and converges quickly if the function does not have any of the characteristics illustrated in figure F-6. If the function describing θ_I exhibits a local minimum in the range of interest, Newton's method will

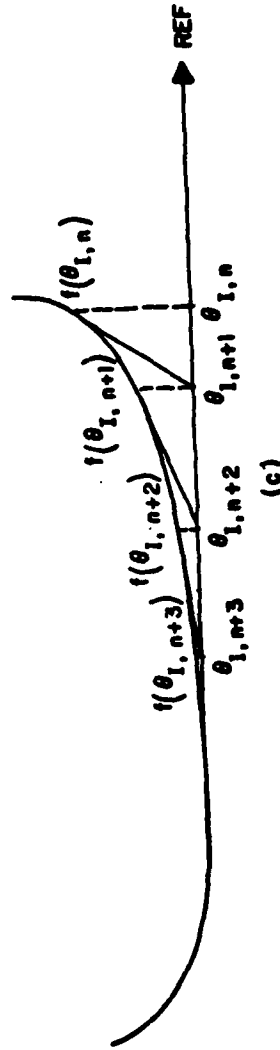
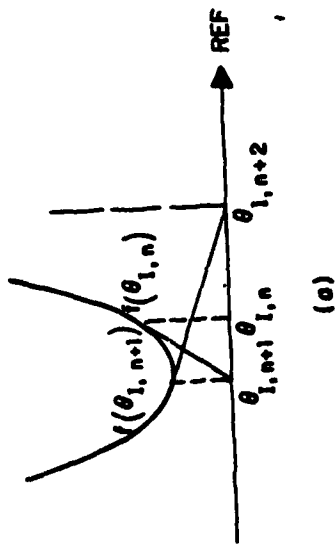
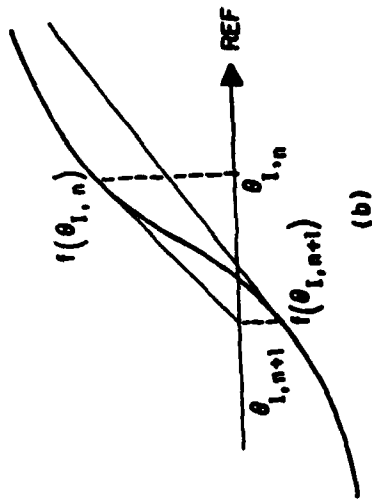


Figure F-6. Three undesirable characteristics in Functions $f(\theta)$ Which Cause Newton's Method to Diverge.

diverge as illustrated in figure F-6a. If the function exhibits an inflection point, Newton's method will diverge as shown in figure F-6b. If the function has multiple roots in the range of interest, Newton's Method cannot determine which value is correct. The special case of a multiple root is shown in figure F-6c. Newton's method will approach the roots from one side then overshoot and oscillate back and forth, never converging on the desired value. A function which is "well behaved" is shown in figure F-7; compare the characteristics of the curve in figure F-7 and those of figure F-6.

The application of Newton's method as shown in figure F-7 involves the selection of a value of θ_I as the first guess θ_{I_1} , finding the functional value $f(\theta_{I_1})$ and the slope $f'(\theta_{I_1})$. The prediction of the correct value of θ_{I_2} is via the relation

$$\theta_{I_2} = \theta_{I_1} - \frac{f(\theta_{I_1})}{f'(\theta_{I_1})} \quad (F-18)$$

The process is repeated until the difference between two succeeding values of θ_I , $|\theta_{I_n} - \theta_{I_{n-1}}|$ is less than an acceptable tolerance. Transforming equation (F-18) into general form yields

$$\theta_{I_{n+1}} = \theta_{I_n} - \frac{f(\theta_{I_n})}{f'(\theta_{I_n})} \quad (F-19).$$

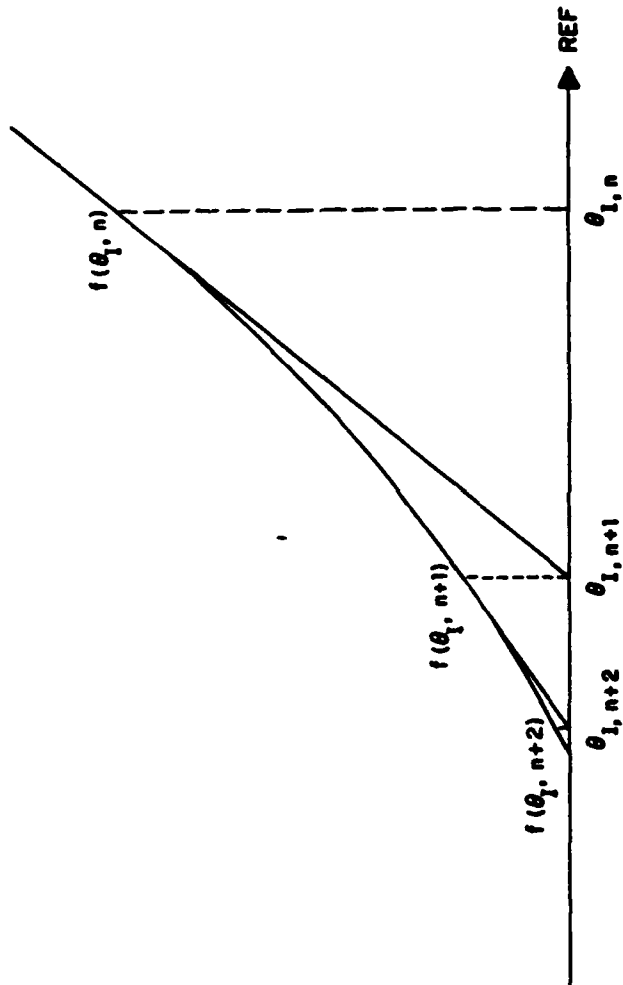


Figure F-7. A Desirable Function $f(\theta_I)$ to Use with Newton's Method.

APPENDIX G

LIMIT PROGRAM DESCRIPTION AND LISTING

The derivation of the relationship between the slopes encountered of the first and second surfaces of a GLM lens composed of homogenous material by the ray shown in figure G-1 is the subject of this appendix. The derivation is applicable to the case in which total reflection occurs at the second surface.

The incident ray in medium 1 forms an angle θ_{I_1} with the first surface normal \hat{n}_1 , at point T1 and is refracted according to Snell's Law $\sin\theta_{R_1} = (n_1/n_2)\sin\theta_{I_1}$. The first surface normal \hat{n}_1 , is defined as the normal to the tangent line at T1. The angle which the tangent line makes with respect to the GLM axis is α_1 . The ray traverses the lens and intercepts the second surface at T2. The ray is refracted at T2 according to Snell's Law $\sin\theta_{R_2} = (n_2/n_3)\sin\theta_{I_2}$. For total reflection at T2

$$\sin\theta_{R_2} = 1 = \left(\frac{n_3}{n_2}\right) \sin\theta_{I_2} \quad (G-1)$$

Now the angular difference between \hat{n}_1 and \hat{n}_2 is $(\alpha - \alpha_2)$ and therefore $\theta_{I_2} = \theta_{R_1} + (\alpha - \alpha_2)$ Hence

$$\theta_{R_1} + (\alpha - \alpha_2) = \arcsin\left(\frac{n_3}{n_2}\right) \quad (G-2)$$

The angle with respect to the GLM axis of the tangent line at T2, α_2 , is then defined by

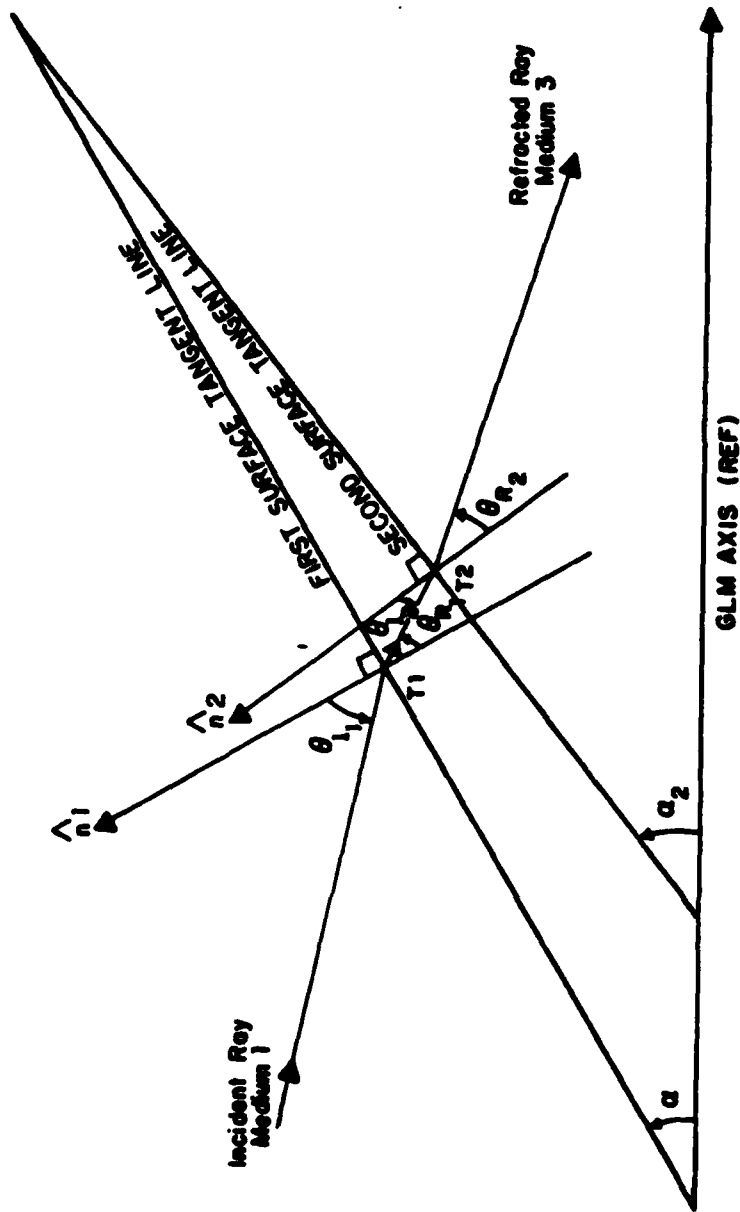


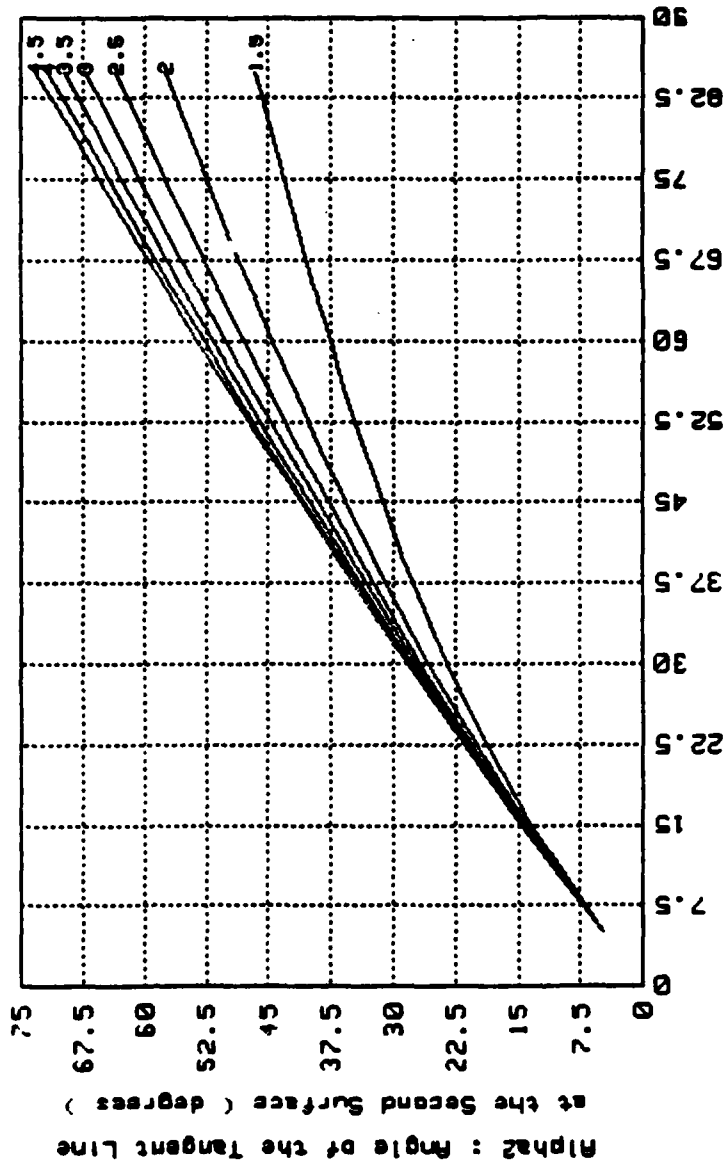
Figure G-1. Geometry and Symbol Definition for the Relationship of the Slope of the Second Surface as a Function of the Slope of the First Surface.

$$\alpha_2 = \arcsin \left(\frac{n_1}{n_2} \sin \theta_{I_1} \right) + \alpha - \arcsin \left(\frac{n_3}{n_2} \right) \quad (G-3)$$

Noting that $\theta_{I_1} = \frac{\pi}{2} - \alpha$ then

$$\alpha_2 = \arcsin \left[\frac{n_1}{n_2} \sin \left(\frac{\pi}{2} - \alpha \right) \right] - \arcsin \left(\frac{n_3}{n_2} \right) + \alpha \quad (G-4)$$

Equation (G-4) is illustrated in figure G-2.



Alpha 1 : Angle of the Tangent Line at the First Surface (degrees)

Figure G-2. The Slope of the Second Surface as a Function of the Slope of the First Surface for Various Values of the Lens Index of Refraction and the Case of Total Reflection at the Second Surface.

LIMIT PROGRAM LISTING

```

10 PRINT "*****"
20 PRINT " "
30 PRINT " "
40 PRINT " "
50 PRINT "*****"
60 DISP "THIS IS LIMIT"
70 WAIT 2500
80 OPTION BASE 0
90 INTEGER I,Linecount,Lineax
100 DEG
110 FIXED 2
120 PRINTER IS 16
130 Linecount=0
140 Lineax=48
150 N1=1
160 N3=1
170 INPUT "DO YOU WANT A HARD COPY? Y/N",Ys
180 IF Ys="Y" THEN PRINTER IS 0
190 GOSUB Header
200 CALL Graph
210 FOR N2=1.5 TO 4.5 STEP .5
220 Alpha=5
230 Thetal_1=90-Alpha
240 Sin_thetar1=N1/N2*SIN(Thetal_1)
250 Thetar_1=ASN(Sin_thetar1)
260 Alpha2=Alpha+ASN(N1/N2*SIN(90-Alpha))-ASN(N3/N2)
270 Thetal_2=Thetar_1+Alpha-Alpha2
280 IF Linecount>Lineax THEN GOSUB Header
290 PRINT USING 410;N2,Thetal_1,Thetar_1,Thetal_2,Alpha,Alpha2
300 Linecount=Linecount+1
310 MOVE Alpha,Alpha2
320 FOR Alpha=5 TO 85 STEP 5
330 Thetal_1=90-Alpha
340 Sin_thetar1=N1/N2*SIN(Thetal_1)
350 Thetar_1=ASN(Sin_thetar1)
360 Alpha2=Alpha+ASN(N1/N2*SIN(Thetal_1))-ASN(N3/N2)
370 Thetal_2=Thetar_1+Alpha-Alpha2
380 IF Linecount>Lineax THEN GOSUB Header
390 PRINT USING 410;N2,Thetal_1,Thetar_1,Thetal_2,Alpha,Alpha2
400 Linecount=Linecount+1
410 IMAGE SX,DD.DD,5(SX,DDDD.DDD)
420 DRAW Alpha,Alpha2
430 NEXT Alpha
440 LDIR 0
450 LOG 2
460 CSIZE 2.5
470 LABEL USING 480;N2
480 IMAGE K
490 IF Linecount>Lineax THEN GOSUB Header
500 PRINT
510 Linecount=Linecount+1
520 NEXT N2
530 GOSUB Header_end
540 PRINTER IS 16
550 PRINT LIN(2),"PRESS CONT"
560 BEEP
570 WAIT 250
580 BEEP
590 PAUSE
600 EXIT GRAPHICS
610 GOTO Finished
620 Header: IF Linecount>Lineax THEN GOSUB Header_end
630 IF Linecount>Lineax THEN PRINT PAGE;TAB(20);"TABLE I (CONT)";LIN(
2)
640 IF Linecount<=Lineax THEN PRINT PAGE;TAB(35);"TABLE I ";LIN(2)
650 Linecount=0
660 PRINT LIN(2)

```

```

670      GOSUB Char
680      PRINT LIN(1);SPR(5);" n2      ThetaI(1)      ThetaR(1)      ThetaI(2)
      Alpha      Alpha2";LIN(1)
690      GOSUB Char
700      PRINT LIN(2)
710      RETURN
720 Char: FOR I=0 TO 79
730      IF I=79 THEN PRINT CHR$(220)
740      IF I=79 THEN 760
750      PRINT CHR$(220);
760      NEXT I
770      RETURN
780 Header_end: PRINT LIN(2)
790      GOSUB Char
800      RETURN
810 Dump_it: PRINTER IS 0
820      PRINT CHR$(27)&"&100T"
830      DUMP GRAPHICS
840      PRINT CHR$(27)&"&136T"
850      PRINTER IS 16
860      RETURN
870 Finished: Dump_crt$="N"
880      INPUT "DO YOU WANT A HARD COPY OF THE PLOT ? Y/N",Dump_crt$
890      IF (Dump_crt$="Y") OR (Dump_crt$="y") THEN GOSUB Dump_it
900      DISP "FINISHED"
910      END
920 SUB Graph
930 OPTION BASE 0
940 DEG
950 !
960 !
970 ! THE EXPRESSIONS USED TO DERIVE THE TIC MARKS WERE OBTAINED FROM THE
980 ! HP-9845B UTILITIES LIBRARY, TAPE NR 89845-10205, PROGRAM "REGPLT"
990 !
1000 !
1010 GCLEAR
1020 PLOTTER IS 13,"GRAPHICS"
1030 LDIR 0
1040 LOGC 5
1050 LIMIT 0,104,0,100
1060 !
1070 DATA -2,-1,1,2
1080 READ Ua,Da,Rd,Mu
1090 DATA .39794,.69897,.07506
1100 READ Log2,Log5,Log7
1110 !
1120 Xorg=Xain=Yorg=Yain=0
1130 Xmax=90
1140 Ymax=80
1150 Alpha: INPUT "WHAT IS THE MAXIMUM VALUE OF ALPHA ( DEFAULT = 90 DEGREES) ?"
,Xmax
1160 Alpha2: INPUT "WHAT IS THE MAXIMUM VALUE OF ALPHA2 ( DEFAULT = 90 DEGREES)
?",Ymax
1170 IF Xmax<=Xain THEN BEEP
1180 IF Xmax<=Xain THEN DISP "ALPHA MUST BE > 0. PLEASE RE-ENTER ALPHA."
1190 IF Xmax<=Xain THEN WAIT 2500
1200 IF Xmax<=Xain THEN Alpha
1210 IF Ymax<=Yain THEN BEEP
1220 IF Ymax<=Yain THEN DISP "ALPHA2 MUST BE > 0. PLEASE RE-ENTER ALPHA2."
1230 IF Ymax<=Yain THEN WAIT 2500
1240 IF Xmax<=Xain THEN Alpha2
1250 GRAPHICS
1260 !
1270 LIMIT 0,104,0,140
1280 LOCATE 20,132,20,100
1290 Lx=LGT(Xmax-Xain)
1300 Ly=LGT(Ymax-Yain)

```

```

1310 Xfudge=.02*(Xmax-Xmin)
1320 Yfudge=.02*(Ymax-Ymin)
1330 Ticmarks: Testxtic=FRACT(Lx)+<Lx<0>
1340 Testytic=FRACT(Ly)+<Ly<0>
1350 Xtic=10^(INT(Lx)-1)*(1+1.5*(Testxtic>Log2) AND (Testxtic<Log5)) +
4*(Testxtic>Log5) AND (Testxtic<Log7))+6.5*(Testxtic>Log7))
1360 Ytic=10^(INT(Ly)-1)*(1+1.5*(Testytic>Log2) AND (Testytic<Log5)) +
4*(Testytic>Log5) AND (Testytic<Log7))+6.5*(Testytic>Log7))
1370 Scale: SCALE Xmin,Xmax+.25*ABS(Xtic),Ymin,Ymax+.25*ABS(Ytic)
1380 CLIP Xmin,Xmax,Ymin,Ymax
1390 LINE TYPE 3
1400 Xmaj=Ymaj=1
1410 Mnticsize=4
1420 GRID Xtic,Ytic,Xorg,Yorg,Xmaj,Ymaj,Mnticsize
1430 LINE TYPE 1
1440 FRAME
1450 Labelx: LDIR 90
1460 LOG 8
1470 FOR A=Xorg TO Xmax STEP ABS(Xtic)
1480 MOVE A,Yorg-Yfudge
1490 LABEL USING 1570;A
1500 NEXT A
1510 Labely: LDIR 0
1520 LOG 8
1530 FOR A=Yorg TO Ymax STEP ABS(Ytic)
1540 MOVE Xorg-Xfudge,A
1550 LABEL USING 1570;A
1560 NEXT A
1570 IMAGE 0,K
1580 LABEL USING 1590;"
1590 IMAGE /,K
1600 Label_: SETGU
1610 LDIR 0
1620 LOG 5
1630 Centerx=72
1640 Centery=64
1650 CSIZE 3
1660 MOVE Centerx,10
1670 LABEL "Alpha : Angle of the Tangent Line at the First Surface ( deg
rees )"
1680 LDIR 90
1690 MOVE 1.45,Centery
1700 LABEL "Alpha2 : Angle of the Tangent Line"
1710 MOVE 6.45,Centery
1720 LABEL "at the Second Surface ( degrees )"
1730 LDIR 0
1740 CSIZE 15/4.54
1750 SETUU
1760 SUBEXIT

```

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