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A Method for Designing a Redirector/ Reconcentrator for Use at the Central Receiver Test Facility

C. Maxwell Ghanbari, G. P. Mulholland, J. V. Otts

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A Method for Designing a Redirector/Reconcentrator for Use at the Central Receiver Test Facility

C. Maxwell Ghanbari
Technadyne Engineering Consultants, Inc.
Albuquerque, NM 87108

G. P. Mulholland
New Mexico State University
Las Cruces, NM 88003

J. V. Otts
Solar Thermal Test Facility Division
Sandia National Laboratories
Albuquerque, NM 87185

Abstract

The Central Receiver Test Facility (CRTF), operated for the Department of Energy by Sandia National Laboratories in Albuquerque, New Mexico, was constructed to evaluate design concepts for solar central receivers. The facility consists of an array of 222 heliostats in a northfield configuration that reflects and focuses the sun's energy toward a tower 60 m high. Throughout the history of the CRTF, there has been an interest in beam redirectors or reconcentrators. The objective of this paper is to discuss the numerous code modifications required for the facility code HELIOS to be able to model the redirector-radome configuration. This model simulates the solar flux-density pattern from reflecting concentrators and follows the incident solar radiation through the atmosphere, the collection system, and finally onto the target. The model includes most pertinent factors that influence the optical performance of a collector system. Although the standard output contains information concerning sun shape distributions and atmospheric attenuation, probably the most useful output is the flux-density pattern at a grid of points on a receiver surface and the integral of this distribution over the surface to obtain power.

Foreword

The research and development described in this document was conducted within the U.S. Department of Energy's (DOE) Solar Thermal Technology Program. The goal of the Solar Thermal Technology Program is to advance the engineering and scientific understanding of solar thermal technology, and to establish the technology base from which private industry can develop solar thermal power production options for introduction into the competitive energy market.

Solar thermal technology concentrates solar radiation by means of tracking mirrors or lenses onto a receiver where the solar energy is absorbed as heat and converted into electricity or incorporated into products as process heat. The two primary solar thermal technologies, central receivers and distributed receivers, employ various point and line-focus optics to concentrate sunlight. Current central receiver systems use fields of heliostats (two-axis tracking mirrors) to focus the sun's radiant energy onto a single tower-mounted receiver. Parabolic dishes up to 17 meters in diameter track the sun in two axes and use mirrors to focus radiant energy onto a receiver. Troughs and bowls are line-focus tracking reflectors that concentrate sunlight onto receiver tubes along their focal lines. Concentrating collector modules can be used alone or in a multi-module system. The concentrated radiant energy absorbed by the solar thermal receiver is transported to the conversion process by a circulating working fluid. Receiver temperatures range from 100°C in low-temperature troughs to over 1500°C in dish and central receiver systems.

The Solar Thermal Technology Program is directing efforts to advance and improve promising system concepts through the research and development of solar thermal materials, components, and subsystems, and the testing and performance evaluation of subsystems and systems. These efforts are carried out through the technical direction of DOE and its network of national laboratories who work with private industry. Together they have established a comprehensive, goal directed program to improve performance and provide technically proven options for eventual incorporation into the nation's energy supply.

To be successful in contributing to an adequate national energy supply at reasonable cost, solar thermal energy must eventually be economically competitive with a variety of other energy sources. Components and system-level performance targets have been developed as quantitative program goals. The performance targets are used in planning research and development activities, measuring progress, assessing alternative technology options, and making optimal component developments. These targets will be pursued vigorously to insure a successful program.

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Nomenclature

A_1,A_2	Distance described by Equation (D-1)
A_s,B_s,C_s	Components of unit-normal vector, Equation (1)
$\hat{B},\hat{B}1$	Unit vectors describing reflected ray from heliostat
$\vec{C}$	Unit vector describing location of target center
$\vec{C}C$	Vector equation, Equation (13)
d,D	Distances between heliostat facet plane and redirector plane, Equation (D-43)
DX,DZ	Distances on target, Equations (8) and (9)
$\hat{e}_1,\hat{e}_2$	Unit vectors in plane of heliostat facet
$\hat{H},\hat{H}_1$	Unit vectors describing intersection point on redirector facet plane
$\hat{I}N$	Unit vector describing intersection point on target
$\hat{I}$	Unit vector describing sun position
$\hat{i}_s,\hat{j}_s,\hat{k}_s$	Unit vectors in sun-facet coordinate system
L_1,L_2	Heliostat dimensions
ℓ	Distance from heliostat to aimpoint
$\hat{N}$	Unit-normal vector from heliostat facet
$\hat{N}_H$	Unit-normal vector from redirector facet
$\hat{N}_t$	Unit-normal vector from target point
N_x,N_y,N_z	Components of unit-normal vector
P	Distance from redirector to heliostat
$\vec{P}L$	Vector locating corner of target, Equation (6)
$\vec{P}I$	Vector equation describing an arbitrary point on heliostat facet plane, Equation (D-43)
$\vec{Q}$	Vector equation describing point in heliostat plane
$\hat{R}_1$	Unit vector describing reflected ray from heliostat
$\hat{R}_2$	Unit vector describing reflected ray from redirector to target
$\vec{R}V$	Vector describing position on target, Equation (7)
$\vec{U}TV$	Unit vector describing reflected ray from heliostat
$\hat{V}1,\hat{V}2,\hat{V}3$	Unit vectors on target
X_A,Y_A,Z_A	Heliostat aimpoint
X_F,Y_F,Z_F	Target center coordinates
$X_{F_{RU}},Y_{F_{RU}},Z_{F_{RU}}$	Intersection point on the target surface for the reference heliostat
$X_{F_{RL}},Y_{F_{RL}},Z_{F_{RL}}$	Intersection point on the target surface for the reference heliostat
X_H,Y_H,Z_H	Intersection point on redirector plane
X_{HR},Y_{HR},Z_{HR}	Point where the ray from reference heliostat pierces the redirector plane
XI, YI, ZI	Intersection point on target
X_p,Y_p,Z_p	Center point of center facet on heliostat
X_{PR},Y_{PR},Z_{PR}	Center point of center facet on reference heliostat
X_{ps},Y_{ps},Z_{ps}	Tower coordinates of the upper and lower corner facets of the heliostats
X_o,Y_o,Z_o	Heliostat foundation position
XO,YO,ZO	Center point of target, Equation (49)

Nomenclature (Continued)

ΔY_L	Reference distance, Equation (D-29)
ΔZ_u	Reference distance, Equation (D-13)
ΔZ_L	Reference distance, Equation (D-24)
α	Normalization factor
$\propto_1, \propto_2$	Angles described by Equations (11) and (12)
ρ_s	Elevation angle of sun
ρ_t	Elevation angle of reflected ray from heliostat
ϕ_s	Azimuth angle of sun
ϕ_t	Azimuth angle of reflected ray from heliostat
ψ_L	Reference angle for redirector, Equation (D-28)

A Method for Designing a Redirector/Reconcentrator for Use at the Central Receiver Test Facility

1. Introduction

Throughout the history of the Central Receiver Test Facility, Albuquerque, New Mexico, there has been interest in a beam redirector/reconcentrator. A redirector/reconcentrator is a reflective surface (or array of surfaces) that will redirect energy coming from solar collectors onto a target positioned at an orientation that would otherwise be impossible to irradiate or reconcentrate "spilled" energy back onto a target. Since the solar beam reflected from the heliostats is much larger than many of the specimens that are tested, and since many experimenters have requested higher peak flux levels on their experiments than can be produced with the "raw" beam, a redirector could be very useful. In fact, a solar receiver tested by McDonnell Douglas used redirecting/reconcentrating panels on the sides of the receiver panels to "catch the spilled energy" and redirect it back onto the target. To date this has been the only time that redirectors/reconcentrators have been used at the CRTF.

Recently, Applied Physics Laboratory (APL), Laurel, Maryland, proposed another application for a redirector. APL is conducting a radome (nose cone) test program for the Army. The program so far has been limited to measuring the boresight error of re-entry radomes while simulating aerodynamic heating using the heliostat field. APL has been asked by the Army to expand the scope of work in the test program to include thermally shocking the radomes. To produce the thermal shock, a uniform flux (over the entire surface of the radome) of greater than 300 W/cm^2 is required. Although it is possible to achieve this flux level using a single aimpoint, the 360° geometry of a radome makes the problem impossible using only the incident flux from the heliostat beam. Hence, a redirector is needed to uniformly irradiate the entire surface of the radome.

Since a nose cone is probably one of the most difficult geometries to uniformly irratiate using the "raw" beam from the heliostats, the latest revisions to the HELIOS computer code[1] required to make flux predictions from the redirector onto the radome are presented.

The HELIOS model simulates the solar flux density pattern from reflecting concentrators, and the computer code HELIOS implements the model. This model follows the incident solar radiation through the atmosphere, the collection system, and finally onto the target. The model includes most pertinent factors that influence the optical performance of a collector system. Although the standard output contains information concerning sun shape distributions, focusing and alignment of concentrators, heliostat locations, and atmospheric attenuation, probably the most useful output is the flux-density pattern at a grid of points on a receiver surface and the integral of this distribution over the surface to obtain power.

Two codes are required to make flux predictions on the radome (a third code is provided to help optimize the location of the cone in the reflected beam). The first code, OPTICS, was written by G. P. Mulholland, D. Arvizu, and W. Phipps[2]; however, major changes were required to make this code applicable to the radome. (It was then renamed REDIR.) By providing the target location and the redirector plane location, this code calculates the normal vectors (required by HELIOS) between the redirector plane and the target. The modified code is presented in Appendix A. The second code, BCONE, (Appendix B), contains the modifications to the HELIOS code that are required for the redirector and the nose cone. By running the modified code with the appropriate data file, BCONED, (Appendix C), HELIOS will calculate the flux on the cone from the redirectors as well as from the incident beam. The third code, PLATE, (which also contains modifications to the HELIOS code) predicts the flux density from the redirectors that is incident on a flat plate oriented at an angle (with respect to the redirectors) specified by the user. By making flux predictions on a flat plate, we can tell where the cone should be located so that the flux distribution is maximized on the surface of the cone. Since the nose cone that we were asked to make predictions for is very small (base diameter –

.1143 m; length – .57 m) compared to the size of the reflected beam from the heliostats (diameter – 3 m), it is difficult to know whether the cone has been located in the optimal position of the reflected beam from the redirector. Therefore, the code, PLATE, is very useful for locating the cone with respect to the redirectors. (All codes are available to the public and can be obtained by contacting the authors.)

The optical theory for designing a redirector/reconcentrator is very detailed. Therefore, it is included in Appendix D for interested readers.

2. HELIOS Code Modifications

After the redirector geometry is determined from the code REDIR, the next step in the analysis is to enter this information into the HELIOS code. The flux-density distribution on the redirector facets and the target can then be determined. There are two basic modifications to the code; one for a flat target and the second for a target that is a surface of revolution.

2.1 Flat Plate Target

The HELIOS code is structured so that the intersection point and the unit reflected ray on the redirector are determined as well as the intersection point on the target plane; see Figure 1. One then has to determine if this intersection point (XI, YI, ZI) is located within the extents of the target. These calculations are made in the subroutine BASKET in the HELIOS code.

The unit normal to the target $\hat{N}_T$ and the location of the target center $\vec{C}$ are HELIOS inputs, and the intersection point on the target plane (XI, YI, ZI) is determined by HELIOS. For later reference, we define the unit normal by

$$\hat{N}_T = N_X\hat{i} + N_Y\hat{j} + N_Z\hat{k}\,, \tag{1}$$

the vector $\vec{C}$ by

$$\vec{C} = XO\hat{i} + YO\hat{j} + ZO\hat{k}\,, \tag{2}$$

and the vector that describes the intersection point by

$$\vec{T}N = XI\hat{i} + YI\hat{j} + ZI\hat{k}\,. \tag{3}$$

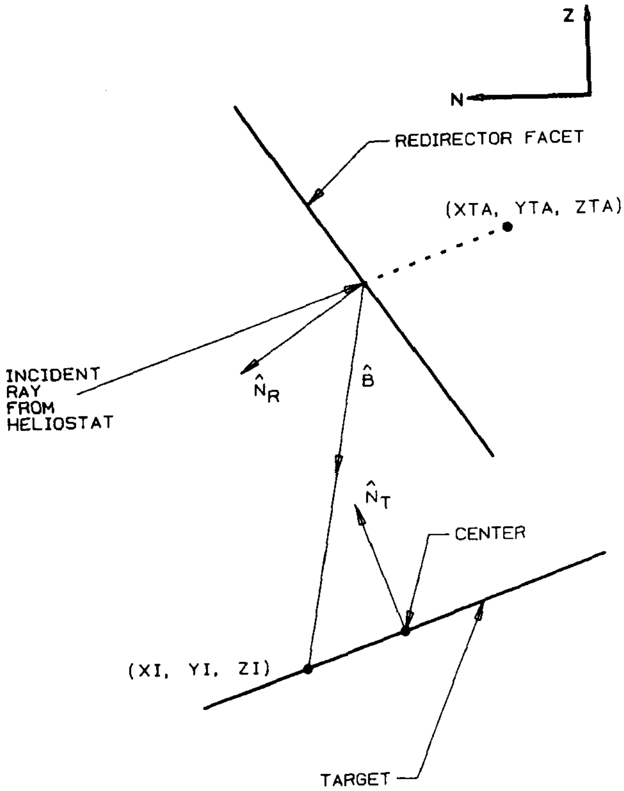

Figure 1. Redirector/Target Geometry

The information in the remainder of this section is used in the subroutine BASKET. We assume the target surface is a flat rectangle with dimension XEXT and ZEXT. A unit vector in the target plane is formed by projecting the unit normal into the horizontal plane and rotating it 90° counterclockwise, as shown in Figure 2.

$$\hat{e}_1 = \frac{-N_y\hat{i}}{b} + \frac{N_x\hat{j}}{b}\,, \tag{4}$$

where

$$b = (N_x^2 + N_y^2)^{1/2}\,.$$

If N_x and N_y are zero, then $\hat{e}_1$ is defined as $-\hat{i}$ (horizontal target). Since $\hat{e}_1$ and $\hat{e}_3$ (or $\hat{N}_T$) are known, then

$$\hat{e}_2 = \hat{N}_T \times \hat{e}_1 = \frac{-N_z N_x}{b}\hat{i} - \frac{N_z N_y}{b}\hat{j} + \frac{(N_x^2 + N_y^2)}{b}\hat{k}\,. \tag{5}$$

The corner of the target denoted by PL in Figure 2 can now be located in space.

$$\vec{P}L = \vec{C} - \frac{(XEXT)}{2}\hat{e}_1 + \frac{(ZEXT)}{2}\hat{e}_2 , \quad (6)$$

where the vector $\vec{C}$ is given by Equation (2). The vector $\vec{R}V$ in the target plane is defined by

$$\vec{R}V = (XI-XO)\,\hat{i} + (YI-YO)\,\hat{j} + (ZI-ZO)\,\hat{k} + \frac{(XEXT)}{2}\hat{e}_1 - \frac{(ZEXT)}{2}\hat{e}_2 . \quad (7)$$

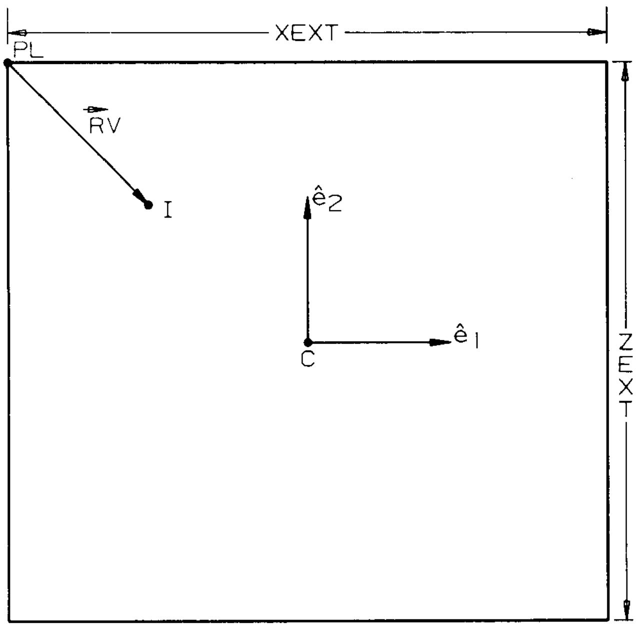

Figure 2. Flat Plate Target Plane

The intersection point (XI, YI, ZI) is an input to the BASKET subroutine. We next define the distances DX and DZ to determine if the intersection point is within the target;

$$DX = \vec{R}V \cdot \hat{e}_1 \quad , \quad (8)$$

and

$$DZ = \vec{R}V \cdot (-\hat{e}_2) . \quad (9)$$

If O $\leq$DX $\leq$XEXT and O $\leq$DZ $\leq$ZEXT, the ray pierces the target plane and is counted. However, if any of the following events occur, the ray is not counted:

DX<O,
DX>XEXT,
DZ<O, or
DZ>ZEXT.

A listing of the code modifications and data file for this case is given in Appendices B and C.

2.2 Surface of Revolution Target

Calculating the flux-density distribution on a surface of revolution is similar to that for the flat plate, except that the HELIOS subroutine TCIRPC (where the unit vector $\hat{B}$ is determined) must be modified. Also, the integration schemes in Program C and subroutine POWER must be adjusted.

Consider the following situation, in which $\vec{B}B$ is a vector to the center of the rear plane, $\vec{F}$ is a vector to the center of the front plane, and $\vec{O}$ is a vector to the midpoint of the axis of revolution, shown in Figure 3.

The vector $\hat{B}$ is determined in the usual manner.

$$\hat{B} = U\hat{T}V - 2\,(U\hat{T}V \cdot \hat{N}_{HR})\hat{N}_{HR} , \quad (10)$$

where the unit vector $U\hat{T}V$ is determined in HELIOS, and the unit-normal $\hat{N}_H$ is an input to the code.

To eliminate needless computation, we first determine if the reflected ray will miss the target. An imaginary sphere of radius R with center at 0, which completely encloses the target, is constructed; see Figure 4. If the extension of $\hat{B}$ is to strike the target, it must fall within the cone described in Figure 4, where the angles α_1 and α_2 are defined by

$$\alpha_1 = \sin^{-1}\frac{(R)}{|V\vec{T}A|} \quad , \quad (11)$$

and

$$\alpha_2 = \cos^{-1}\left(\hat{B} \cdot \frac{V\vec{T}A}{|VTA|}\right) . \quad (12)$$

The vector $V\vec{T}A$ is from the point on the redirector (XTA, YTA, ZTA) to the midpoint on the axis of revolution.

If $\alpha_2 > \alpha_1$, then the ray can be ignored; however, if $\alpha_2 \leq \alpha_1$, then the intersection point must be determined.

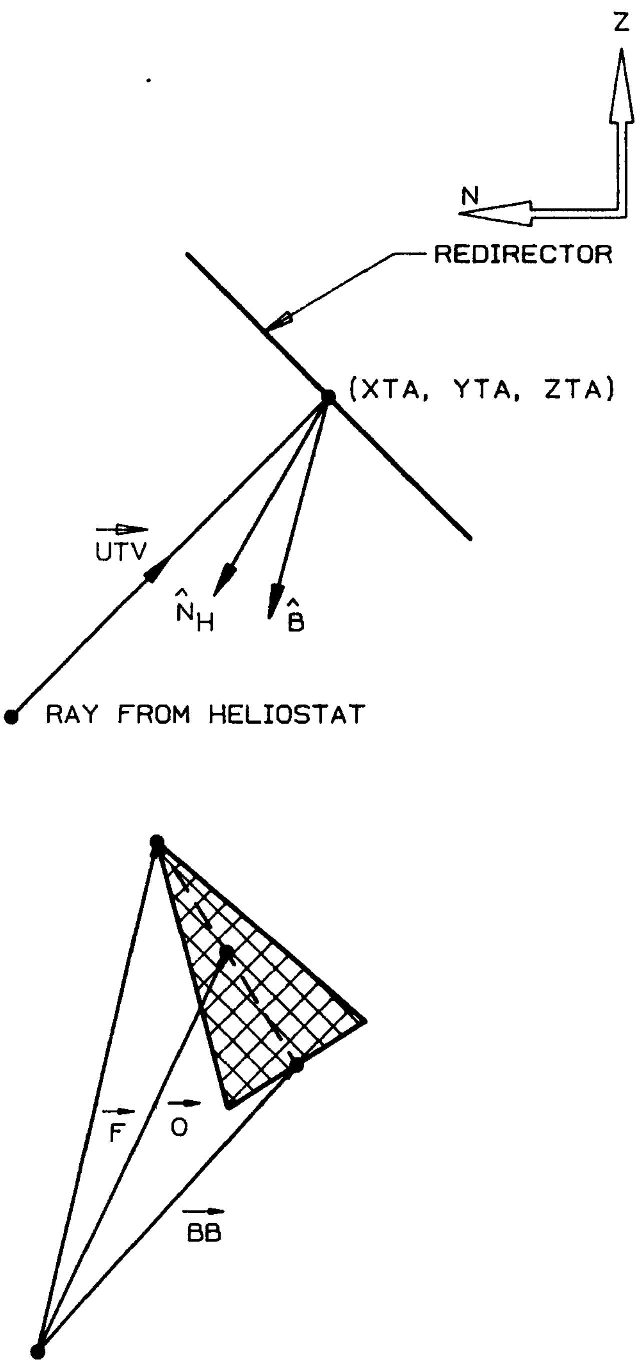

Figure 3. Redirector/Target Geometry

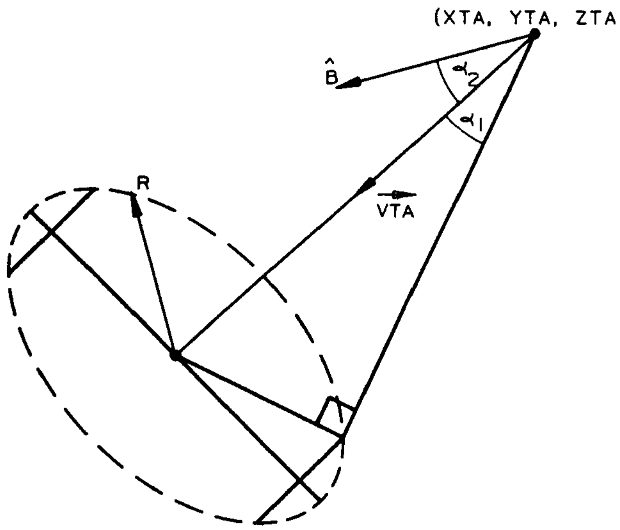

Figure 4. Imaginary Sphere Construction

To determine the intersection point (XI, YI, ZI), we construct the vectors shown in Figure 5.

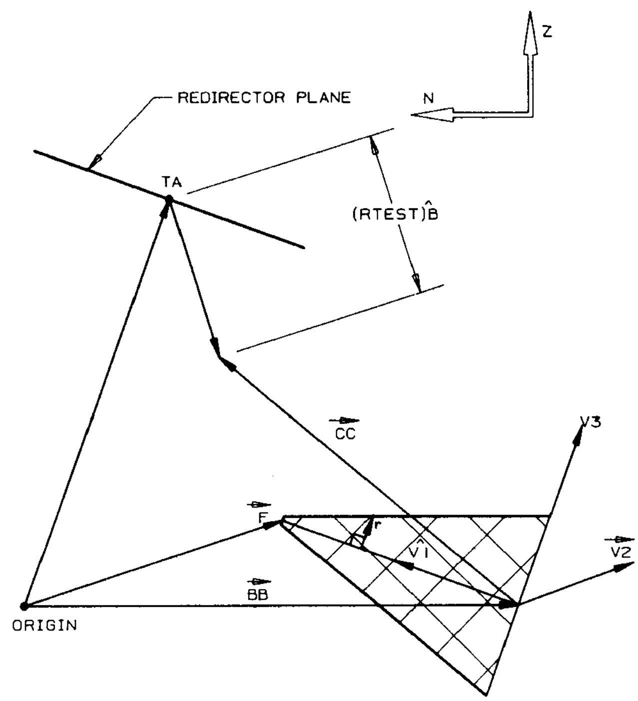

Figure 5. Vector System Used to Determine Intersection Point

The vector $\vec{C}C$ is defined as

$$\vec{C}C = \vec{T}A' - \vec{B}B + (RTEST)\,\hat{B}\ , \quad (13)$$

where $\hat{B}$, $\vec{B}B$, and $\vec{T}A$ are known, and $\vec{C}C$ is to be determined by assuming various values for RTEST. In addition, unit vectors $\hat{V}1$, $\hat{V}2$, and $\hat{V}3$ are evaluated in the following manner:

$$\hat{V}1 = \frac{\vec{F} - \vec{B}B}{|\vec{F} - \vec{B}B|} = V1X\,\hat{i} + V1Y\,\hat{j} + V1Z\,\hat{k}\ , \quad (14)$$

$$\hat{V}2 = \frac{V1Y\,\hat{i} - V1X\,\hat{j}}{(V1X^2 + V1Y^2)^{1/2}}\ , \quad (15)$$

and

$$\hat{V}3 = \hat{V}2 \times \hat{V}1\ . \quad (16)$$

The remainder of the procedure is a trial-and-error process in which a value for RTEST is chosen and the vector $\vec{C}C$ is determined for that value of RTEST. The vector $\vec{C}C$ is then projected along the $\hat{V}1$, $\hat{V}2$, and $\hat{V}3$ directions; see Figure 6.

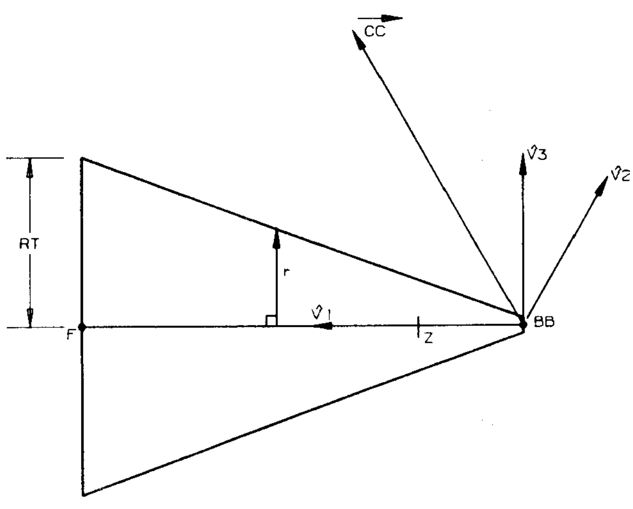

Figure 6. Nose Cone Geometry

Because we know a functional relation of the form

$$r = f(\xi)\ , \quad (17)$$

which describes the surface for any target, the ξ value can be obtained by projecting $\vec{C}C$ along the V1 direction;

$$\xi = \vec{C}C \cdot \hat{V1}\ . \quad (18)$$

Obviously if

$\xi < 0$

or

$\xi > |\vec{F} - \vec{B}B|$,

then RTEST should be incremented and a new vector $\vec{C}C$ determined.

We next project $\vec{C}C$ along $\hat{V}2$ and $\hat{V}3$ to determine the perpendicular distance the point $\vec{C}C$ is from the axis of revolution;

$$RT = [(\vec{C}C \cdot \hat{V}2)^2 + (\vec{C}C \cdot \hat{V}3)^2]^{1/2}\ . \quad (19)$$

If $r = RT$, the intersection point is on the target surface and

$$XI\,\hat{i} + YI\,\hat{j} + ZI\,\hat{k} = \vec{T}A + (RTEST)\,\hat{B}\ . \quad (20)$$

However, if $r \neq RT$, RTEST must be incremented and the procedure repeated.

As mentioned previously, the value RTEST is usually found by an iterative technique. Thus, a judicious choice for an initial guess of RTEST is wise to avoid excessive computer usage. The proper choice depends on the problem being considered.

3. Numerical Example

The following numerical example is presented to demonstrate the design process. The specific problem to be discussed is a nose cone designed by the Applied Physics Laboratory (APL); Figure 7. As discussed earlier, this configuration is difficult to irradiate uniformly with the solar beam produced by the CRTF heliostats. The nose cone is small (0.1143 m base diameter by 0.57 m long) relative to the size of the solar beam, which is about 3 m in diameter. As a result, much of the energy does not impinge on the surface of the nose cone. Therefore, to direct some of this energy back onto the cone and to have a uniform distribution of energy on the cone, it was proposed to design a redirector.

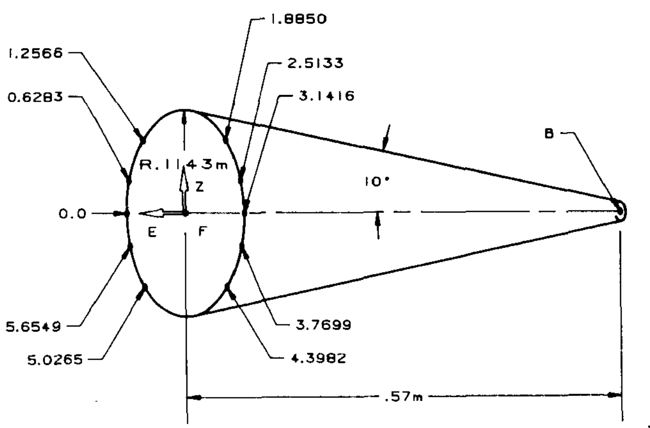

Figure 7. Geometry of APL Nose Cone Showing Locations (in radians) Where Flux is Predicted

The design process consisted of two steps. To optimize the redirector configuration, the computer code REDIR (Appendix A) was used. Once the configuration was decided upon, the HELIOS[1] code with the necessary changes (Appendix B) to model the redirector-radome configuration was used. The HELIOS output gave the flux density distribution on the surface of the radome. If the distribution was acceptable, the design process was complete. However, if the flux-density distribution was not acceptable, the design process was repeated until a suitable distribution was obtained.

The first design we chose used two redirector panels. Each panel was made up of eight 2-ft × 2-ft facets. Each facet was to be mounted on a framework in a way that it could be adjusted so that the reflected energy could be aimed at the radome. The redirector facets were to be mounted facing the heliostat field and the radome mounted facing the redirector (Figure 8).

Since we knew that many HELIOS predictions would be required and that predictions made using all 221 CRTF heliostats would be expensive, we chose to divide that heliostat field into 22 "cells" (Figure 9). From each cell we chose one representative heliostat (this represents one-tenth of the heliostat field). We used this strategy assuming that when we were satisfied with the distribution from these heliostats, we would make a prediction using the entire 221 heliostats, giving each heliostat in the cell the same aimpoint as that used by the representative heliostat.

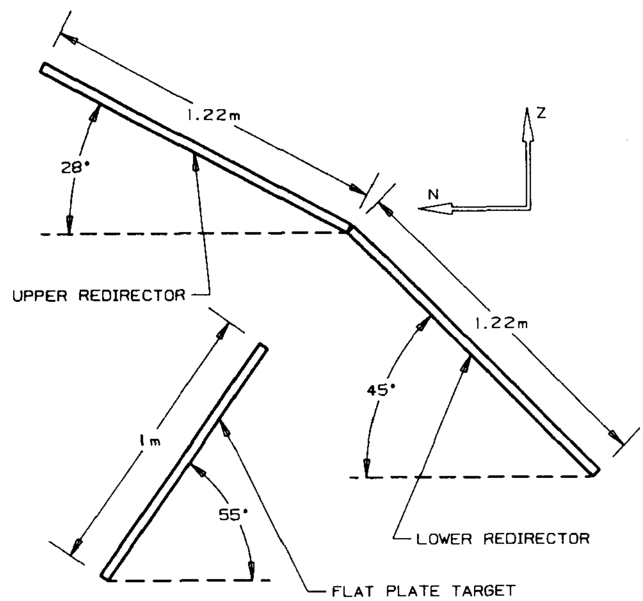

Figure 8. Redirector/Target Geometry: Orientation #1

As mentioned earlier, the nose cone is small; therefore it was critical that it be located in exactly the correct position to intercept the reflected energy from the redirectors. To aid us in locating the nose cone we made our preliminary predictions on a flat plate, 1 m × 1 m. By examining the flux distribution on the plate, we could then more accurately locate the nose cone. Therefore, the first step in this exercise was to locate the redirector and the flat plate in the tower coordinate system.

The upper redirector panel (consisting of eight facets) was positioned facing north at an angle of 28° from the horizontal. The lower panel is mounted at an angle of 135°. Note that the angles are somewhat arbitrarily chosen. Figure 10 shows the coordinates on the redirector in the tower coordinate system.

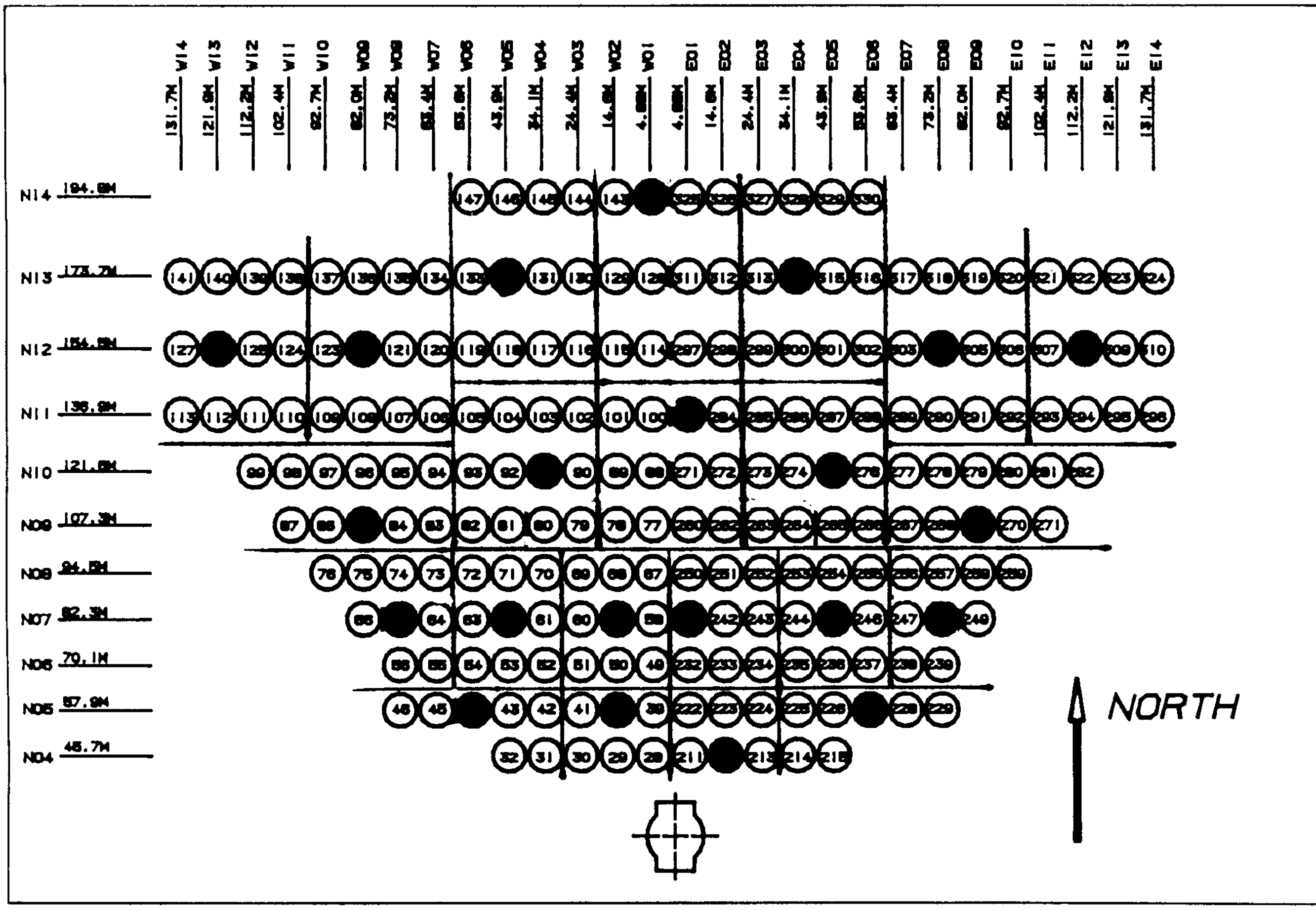

Figure 9. "Cell" Division and Representative Heliostats in CRTF Field

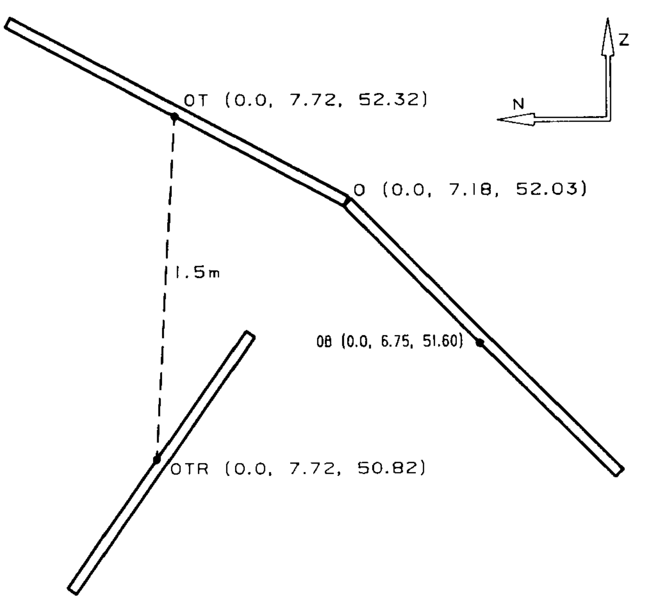

Figure 10. Tower Coordinates of Redirectors and Target

The flat plate (1 m × 1 m) is mounted at an angle of 55° from the horizontal. The coordinates of the lowest edge of this plate are shown. There are three target points along the target; they are the aimpoints used by the redirector.

The input data file submitted to the code REDIR is shown in Appendix A. This data file is called TAPE 1 and the output from the code, TAPE 2. The results of this configuration are shown in Figure 11. The first column is the heliostat number; the second, third and fourth columns are the coordinates (x, y, z) of the pierce point (the point at which the central ray from the heliostat pierces the redirector plane). Note that this point may or may not be the aimpoint for the heliostat. The next three columns are the components of the vector normal to the facet. The last column is the angle (in degrees) between the incident ray and the normal.

```
TARGET IS LOCATED   1.50000  METERS BELOW  ZH(1) ON REDIRECTOR PLANE
TARGET IS LOCATED   -.40603 METERS NORTH OF  YH(  11) ON REDIRECTOR PLANE
```

18 AIM POINTS, 260 BAY; 22 HLSTS, PHI=55 DEG, UPPER & LOWER REDIRECTORS

HELIOSTAT NUMBER	PIERCE POINT			FACET NORMAL			ANGLE
242	.00	7.72	52.32	.09	.47	-.88	28.9
40	.30	7.44	52.17	-.27	.39	-.88	22.2
44	.91	7.44	52.17	-.68	.30	-.67	17.2
59	.30	7.98	52.46	-.25	.29	-.93	39.1
62	.91	7.98	52.46	-.60	.25	-.76	33.7
65	.91	7.98	52.46	-.70	.18	-.69	30.9
212	-.30	7.44	52.17	.28	.32	-.90	18.3
227	-.91	7.44	52.17	.69	.30	-.66	17.5
245	-.30	7.98	52.46	.42	.24	-.88	38.0
248	-.91	7.98	52.46	.70	.19	-.69	31.3
283	.93	7.58	51.60	-.81	.49	-.31	56.9
275	-.68	7.13	51.15	.68	.71	-.15	24.7
269	-.38	7.11	51.13	.71	.70	-.08	13.5
91	-.47	7.12	51.15	.35	.92	-.17	37.8
85	-.16	7.10	51.12	-.12	.99	-.08	35.6
126	-.21	7.59	51.61	-.47	-.42	-.78	79.8
122	-.05	7.59	51.61	-.71	-.31	-.63	75.6
132	-.47	7.61	51.63	.16	.67	-.72	38.7
142	-.32	7.63	51.65	.20	.66	-.72	35.8
314	-.77	7.62	51.64	.52	.62	-.59	32.8
304	-.59	7.60	51.63	.95	.21	-.23	49.2
308	1.39	7.18	51.20	-.44	.90	.05	64.5

```
PIERCE POINTS FOR CENTER FACET OF HELIOSTAT # 242
(   .00000, 7.72000,52.32000)
```

PIERCE POINTS			THETA	HELIOSTAT POINTS
-.40570	9.42711	53.20128	.00000	1
-.35422	9.21395	53.09133	30.00000	1
-.20444	9.05385	53.02059	60.00000	1
.00346	8.99010	53.00822	90.00000	1
.21342	9.03997	53.05761	120.00000	1
.36884	9.18987	53.15536	150.00000	1
.42812	9.39922	53.27506	180.00000	1
.37573	9.61175	53.38458	210.00000	1
.22605	9.77074	53.45473	240.00000	1
.01915	9.83400	53.46693	270.00000	1
-.18991	9.78475	53.41798	300.00000	1
-.34542	9.63597	53.32062	330.00000	1

Figure 11. Output from Program REDIR (continued)

PIERCE POINTS			THETA	HELIOSTAT POINTS
.18034	9.31250	53.20168	.00000	2
.23080	9.10141	53.09274	30.00000	2
.38088	8.94574	53.02442	60.00000	2
.59013	8.88761	53.01525	90.00000	2
.80223	8.94271	53.06770	120.00000	2
.96000	9.09600	53.16754	150.00000	2
1.02126	9.30600	53.28780	180.00000	2
.96997	9.51634	53.39624	210.00000	2
.82018	9.67092	53.46399	240.00000	2
.61194	9.72872	53.47310	270.00000	2
.40066	9.67439	53.42115	300.00000	2
.24266	9.52218	53.32188	330.00000	2

PIERCE POINTS			THETA	HELIOSTAT POINTS
-.44989	9.02500	52.97880	.00000	3
-.40016	8.82413	52.87531	30.00000	3
-.25671	8.67312	52.80882	60.00000	3
-.05802	8.61279	52.79733	90.00000	3
.14234	8.65948	52.84397	120.00000	3
.29040	8.80046	52.93611	150.00000	3
.34650	8.99760	53.04885	180.00000	3
.29595	9.19792	53.15195	210.00000	3
.15259	9.34794	53.21792	240.00000	3
-.04520	9.40783	53.22927	270.00000	3
-.24475	9.36170	53.18302	300.00000	3
-.39289	9.22170	53.09141	330.00000	3

PIERCE POINTS			THETA	HELIOSTAT POINTS
.17028	8.90533	52.98010	.00000	4
.21922	8.70635	52.87755	30.00000	4
.36304	8.55949	52.81335	60.00000	4
.56313	8.50446	52.80487	90.00000	4
.76553	8.55610	52.85441	120.00000	4
.91572	8.70033	52.94853	150.00000	4
.97355	8.89815	53.06183	180.00000	4
.92388	9.09644	53.16393	210.00000	4
.78028	9.24234	53.22763	240.00000	4
.58115	9.29709	53.23606	270.00000	4
.37949	9.24614	53.18697	300.00000	4
.22907	9.10287	53.09335	330.00000	4

PIERCE POINTS FOR CENTER FACET OF HELIOSTAT # 308
(1.38840, 7.17625.51.20022)

Figure 11. Continued

PIERCE POINTS			THETA	HELIOSTAT POINTS
-.80305	5.98278	53.38722	.00000	1
-.12815	6.33982	52.89510	30.00000	1
.75343	6.78751	52.57493	60.00000	1
1.60391	7.20529	52.50983	90.00000	1
2.19957	7.48342	52.71394	120.00000	1
2.38651	7.55020	53.13189	150.00000	1
2.11625	7.38838	53.65431	180.00000	1
1.45717	7.03914	54.14451	210.00000	1
.58011	6.59324	54.47188	240.00000	1
-.28166	6.16943	54.54611	270.00000	1
-.89314	5.88349	54.34393	300.00000	1
-1.08460	5.81492	53.91877	330.00000	1

PIERCE POINTS			THETA	HELIOSTAT POINTS
.15467	6.46220	53.15896	.00000	2
.88738	6.84771	52.66138	30.00000	2
1.82625	7.32348	52.33791	60.00000	2
2.71821	7.76148	52.27226	90.00000	2
3.32922	8.04696	52.47845	120.00000	2
3.50195	8.10659	52.90058	150.00000	2
3.19171	7.92498	53.42841	180.00000	2
2.47680	7.54826	53.92406	210.00000	2
1.54231	7.07416	54.25549	240.00000	2
.63691	6.62904	54.33102	270.00000	2
.00809	6.33478	54.12675	300.00000	2
-.16902	6.27348	53.69666	330.00000	2

PIERCE POINTS			THETA	HELIOSTAT POINTS
-.63994	6.06813	53.28442	.00000	3
.02332	6.41910	52.79936	30.00000	3
.88830	6.85857	52.48175	60.00000	3
1.72174	7.26819	52.41405	90.00000	3
2.30444	7.54042	52.61113	120.00000	3
2.48589	7.60509	53.01951	150.00000	3
2.21905	7.44549	53.53233	180.00000	3
1.57139	7.10222	54.01545	210.00000	3
.71078	6.66447	54.34017	240.00000	3
-.13388	6.24886	54.41692	270.00000	3
-.73217	5.96892	54.22177	300.00000	3
-.91800	5.90254	53.80628	330.00000	3

PIERCE POINTS			THETA	HELIOSTAT POINTS
.37517	6.57652	53.03846	.00000	4
1.09643	6.95606	52.54765	30.00000	4
2.01882	7.42368	52.22638	60.00000	4
2.89374	7.85356	52.15780	90.00000	4
3.49170	8.13311	52.35675	120.00000	4
3.65881	8.19055	52.76926	150.00000	4
3.35180	8.01107	53.28762	180.00000	4
2.64814	7.64021	53.77649	210.00000	4
1.72996	7.17419	54.10562	240.00000	4
.84164	6.73722	54.18401	270.00000	4
.22607	6.44899	53.98700	300.00000	4
.05476	6.38995	53.56663	330.00000	4

Figure 11. Concluded

Additional information is printed to assist in optimizing the size of the redirector facets. For each facet, REDIR calculates the pierce point (the point where a ray reflected from the center of a heliostat pierces the redirector plane). A cone of energy is also traced after reflection from each of the four corners of the heliostat. We chose to trace 12 individual rays ($\Delta\Theta = \pi/6$) on the surface of the reflected cone of energy. The coordinates for the intersection point on the redirector for each of these 12 rays are printed for each corner of the heliostat. Thus for each heliostat, we have 49 points on the redirector surface that define the extent of the solar beam on that surface due to the particular heliostat being considered.

We are now ready to make flux predictions using the HELIOS code. To do this, data must be entered into two files. Listings of both files are found in Appendix C. The first file contains the modifications that must be made to the HELIOS code, and the second is the data file that is submitted with the code. The lines that must be changed in these files are clearly marked; however, comments regarding these inputs are made below. Note that all dimension statements must be checked.

1. In subroutine USTG1
   The statement numbers must be equivalent to the number of redirector facets. For each redirector facet we must enter the coordinates of the facet center (XTA, YTA, ZTA) and the components of the unit normal to the facet (ANX, ANY, ANZ) (determined by OPT3).
2. In subroutine INDATA
   The coordinates of the target center, the components of the normal to the target, the target extents (two dimensions) and the extents of each redirector facet.
3. In subroutine BASKET
   We enter the components of the unit normal to the target (ANX, ANY, ANZ) and the coordinates of the center of the target (PCX, PCY, PCZ).

In the data file, the first data that must be entered are in Group 3; they give the general direction of the unit normal to the target. This variable is IVMD, and the possible values for it can be found in Ref. 3. Also in Group 3 we enter the number of aimpoints on the redirector facets and the coordinates of each aimpoint.

The next data that are changed are in Group 5. We enter the number of the first heliostat, the total number of heliostats to be evaluated, and the alignment point and aimpoint for the first heliostat. The alignment and aimpoints for the remaining heliostats are entered following Group 7.

The results of running this case are shown in Figures 12 and 13. Figure 12 is the flux on the upper surface of the flat plate target, and Figure 13 on the lower surface. The flux on this plate is a result of the contribution from the "raw" beam reflected from the heliostats as well as that from the redirector facets.

Since the flux reflected from the upper redirector facets is much greater than that from the lower redirector facets, we decided to change our strategy and delete the lower redirector and heat the bottom of the plate with the incident beams from the heliostats. The top of the plate will be heated with beams from the redirector facets. The geometry is shown in Figure 14.

The results from the configuration are shown in Figure 15. The flux from the reconcentrator is not as high as we had hoped. This is due to the large angles between the incident rays on the target and those normal to the target surface. Therefore, we decided to lower the target to a horizontal position. As seen in Figure 16, this increased the flux on the upper surface of the plate.

Now, we are ready to make predictions on the surface of the nose cone by using another modified version of the HELIOS code, CONE.

The geometry of the cone is shown in Figure 17. The file that contains the modifications to the HELIOS code and the data file are shown in Appendix B.

The changes required are clearly marked in these files. The results from this run are shown in Figure 17. The flux on the top surface of the cone was greater than on the bottom (although we had some heliostats aimed on the bottom of the cone). This occurred because the heliostat beams were large compared to the size of the cone. Therefore, much of the energy passed the cone initially, was intercepted by the redirector and then reflected down onto the upper surface of the cone. By carefully aiming the heliostats, one can get a desirable distribution around as well as along the cone.

W/SQ CM ON TARGET SURFACE FOR DAY 180. AND TIME 0.0000 HOURS.

TOTAL POWER DENSITY UPON RECEIVER

Z METERS	X(I)= .5000	.4000	.3000	.2000	.1000	0.0000	-.1000	-.2000	-.3000	-.4000	-.5000 M
.5000	.106E+02	.114E+02	.116E+02	.114E+02	.131E+02	.138E+02	.139E+02	.131E+02	.114E+02	.941E+01	.892E+01
.4000	.885E+01	.971E+01	.112E+02	.122E+02	.130E+02	.162E+02	.162E+02	.139E+02	.125E+02	.999E+01	.889E+01
.3000	.766E+01	.922E+01	.121E+02	.144E+02	.161E+02	.189E+02	.178E+02	.156E+02	.121E+02	.975E+01	.866E+01
.2000	.683E+01	.922E+01	.132E+02	.170E+02	.188E+02	.199E+02	.191E+02	.164E+02	.120E+02	.847E+01	.763E+01
.1000	.631E+01	.960E+01	.141E+02	.179E+02	.202E+02	.206E+02	.189E+02	.176E+02	.128E+02	.836E+01	.637E+01
0.0000	.650E+01	.890E+01	.142E+02	.171E+02	.194E+02	.195E+02	.185E+02	.173E+02	.138E+02	.832E+01	.606E+01
-.1000	.581E+01	.772E+01	.125E+02	.159E+02	.171E+02	.175E+02	.169E+02	.160E+02	.131E+02	.795E+01	.535E+01
-.2000	.508E+01	.642E+01	.100E+02	.134E+02	.154E+02	.159E+02	.150E+02	.137E+02	.104E+02	.673E+01	.426E+01
-.3000	.421E+01	.561E+01	.768E+01	.105E+02	.126E+02	.128E+02	.119E+02	.104E+02	.802E+01	.531E+01	.391E+01
-.4000	.336E+01	.469E+01	.568E+01	.660E+01	.855E+01	.854E+01	.760E+01	.659E+01	.600E+01	.472E+01	.346E+01
-.5000	.256E+01	.343E+01	.395E+01	.424E+01	.470E+01	.489E+01	.431E+01	.414E+01	.418E+01	.424E+01	.302E+01

TOWER COORDINATES OF TARGET POINTS 1, 11, 111, AND 121

.500E+00	.716E+01	.508E+02	UPPER LEFT CORNER
-.500E+00	.716E+01	.508E+02	UPPER RIGHT CORNER
.500E+00	.774E+01	.500E+02	LOWER LEFT CORNER
-.500E+00	.774E+01	.500E+02	LOWER RIGHT CORNER

INTEGRAL OF POWER DENSITY IS 116422.190 WATTS

TIME FOR C IS 579.643000

Figure 12. Flux Profile on Upper Surface of Flat Plate Target at 55° Angle. Upper and lower redirectors used.

W/SQ CM ON TARGET SURFACE FOR DAY 180. AND TIME 0.0000 HOURS.

TOTAL POWER DENSITY UPON RECEIVER

Z METERS / X(I)=	-.5000	-.4000	-.3000	-.2000	-.1000	0.0000	.1000	.2000	.3000	.4000	.5000 M
.5000	.490E+00	.766E+00	.697E+00	.556E+00	.879E+00	.645E+00	.876E+00	.666E+00	.535E+00	.697E+00	.466E+00
.4000	.615E+00	.547E+00	.765E+00	.792E+00	.634E+00	.107E+01	.699E+00	.682E+00	.863E+00	.424E+00	.434E+00
.3000	.433E+00	.619E+00	.805E+00	.726E+00	.928E+00	.776E+00	.771E+00	.966E+00	.470E+00	.450E+00	.530E+00
.2000	.447E+00	.505E+00	.860E+00	.878E+00	.871E+00	.781E+00	.928E+00	.772E+00	.637E+00	.547E+00	.276E+00
.1000	.315E+00	.551E+00	.867E+00	.933E+00	.741E+00	.854E+00	.892E+00	.834E+00	.817E+00	.367E+00	.282E+00
0.0000	.351E+00	.487E+00	.865E+00	.105E+01	.821E+00	.799E+00	.840E+00	.865E+00	.816E+00	.349E+00	.381E+00
-.1000	.290E+00	.479E+00	.816E+00	.925E+00	.652E+00	.746E+00	.774E+00	.819E+00	.707E+00	.502E+00	.349E+00
-.2000	.361E+00	.529E+00	.733E+00	.888E+00	.681E+00	.846E+00	.754E+00	.752E+00	.676E+00	.454E+00	.333E+00
-.3000	.306E+00	.469E+00	.606E+00	.104E+01	.821E+00	.702E+00	.822E+00	.728E+00	.626E+00	.474E+00	.401E+00
-.4000	.352E+00	.470E+00	.720E+00	.801E+00	.914E+00	.807E+00	.650E+00	.617E+00	.465E+00	.514E+00	.477E+00
-.5000	.291E+00	.545E+00	.489E+00	.777E+00	.889E+00	.706E+00	.800E+00	.553E+00	.495E+00	.515E+00	.441E+00

TOWER COORDINATES OF TARGET POINTS 1, 11, 111, AND 121

-.500E+00	.716E+01	.508E+02	UPPER LEFT CORNER
.500E+00	.716E+01	.506E+02	UPPER RIGHT CORNER
-.500E+00	.774E+01	.500E+02	LOWER LEFT CORNER
.500E+00	.774E+01	.500E+02	LOWER RIGHT CORNER

INTEGRAL OF POWER DENSITY IS 6892.440 WATTS

TIME FOR C IS 540.978000

Figure 13. Flux Profile on Bottom Surface of Flat Plate Target at 55° Angle. Upper and lower redirectors used.

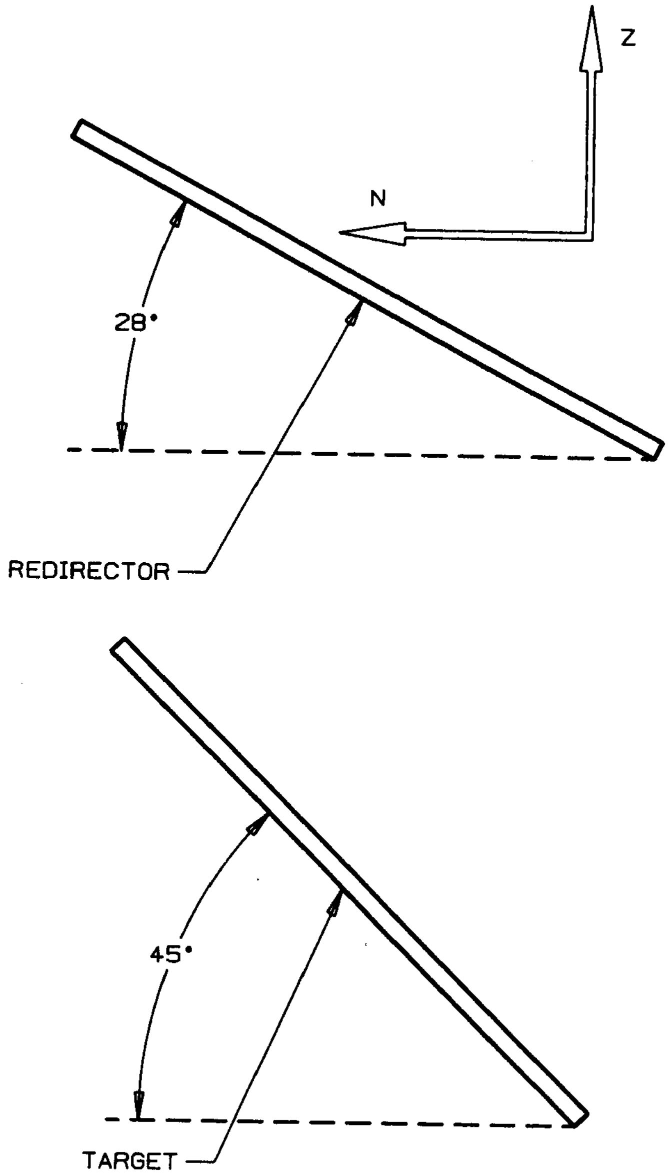

Figure 14. Redirector/Target Geometry: Orientation #2

1 W/SQ CM ON TARGET SURFACE FOR DAY 180. AND TIME 0.0000 HOURS.

TOTAL POWER DENSITY UPON RECEIVER

Z METERS	X(I)= -.5000	-.4000	-.3000	-.2000	-.1000	0.0000	.1000	.2000	.3000	.4000	.5000 M
.5000	.182E+01	.213E+01	.249E+01	.317E+01	.367E+01	.406E+01	.401E+01	.335E+01	.255E+01	.274E+01	.295E+01
.4000	.199E+01	.252E+01	.333E+01	.471E+01	.617E+01	.669E+01	.708E+01	.558E+01	.398E+01	.339E+01	.353E+01
.3000	.242E+01	.315E+01	.398E+01	.702E+01	.987E+01	.107E+02	.101E+02	.877E+01	.538E+01	.434E+01	.397E+01
.2000	.285E+01	.351E+01	.636E+01	.103E+02	.121E+02	.132E+02	.136E+02	.114E+02	.725E+01	.516E+01	.482E+01
.1000	.351E+01	.442E+01	.779E+01	.111E+02	.140E+02	.153E+02	.148E+02	.128E+02	.955E+01	.556E+01	.550E+01
0.0000	.421E+01	.499E+01	.880E+01	.129E+02	.154E+02	.164E+02	.153E+02	.128E+02	.943E+01	.554E+01	.476E+01
-.1000	.464E+01	.590E+01	.940E+01	.134E+02	.152E+02	.158E+02	.145E+02	.124E+02	.826E+01	.478E+01	.394E+01
-.2000	.463E+01	.532E+01	.797E+01	.117E+02	.136E+02	.147E+02	.138E+02	.114E+02	.656E+01	.355E+01	.263E+01
-.3000	.404E+01	.505E+01	.597E+01	.834E+01	.111E+02	.129E+02	.115E+02	.882E+01	.518E+01	.288E+01	.162E+01
-.4000	.375E+01	.406E+01	.436E+01	.618E+01	.827E+01	.848E+01	.813E+01	.640E+01	.429E+01	.323E+01	.189E+01
-.5000	.317E+01	.294E+01	.300E+01	.477E+01	.596E+01	.587E+01	.585E+01	.471E+01	.348E+01	.329E+01	.262E+01

TOWER COORDINATES OF TARGET POINTS 1, 11, 111, AND 121

-.500E+00	.807E+01	.514E+02	UPPER LEFT CORNER
.500E+00	.807E+01	.514E+02	UPPER RIGHT CORNER
-.500E+00	.737E+01	.507E+02	LOWER LEFT CORNER
.500E+00	.737E+01	.507E+02	LOWER RIGHT CORNER

INTEGRAL OF POWER DENSITY IS 77170.591 WATTS

TIME FOR C IS 150.855000

Figure 15. Flux Profile on Upper Surface of Flat Plate at 45° Angle. Single upper redirector used.

```
L W/SQ CM ON TARGET SURFACE FOR DAY 180.  AND TIME  0.0000  HOURS.

        TOTAL POWER DENSITY UPON RECEIVER
```

Z METERS	X(I)= -.5000	-.4000	-.3000	-.2000	-.1000	0.0000	.1000	.2000	.3000	.4000	.5000 M
-.5000	.245E+01	.262E+01	.364E+01	.534E+01	.575E+01	.566E+01	.556E+01	.493E+01	.329E+01	.245E+01	.208E+01
-.4000	.375E+01	.534E+01	.682E+01	.764E+01	.809E+01	.879E+01	.841E+01	.696E+01	.603E+01	.512E+01	.454E+01
-.3000	.440E+01	.667E+01	.861E+01	.907E+01	.122E+02	.149E+02	.134E+02	.900E+01	.740E+01	.674E+01	.584E+01
-.2000	.498E+01	.679E+01	.928E+01	.143E+02	.184E+02	.202E+02	.186E+02	.138E+02	.981E+01	.729E+01	.621E+01
-.1000	.544E+01	.766E+01	.121E+02	.169E+02	.197E+02	.223E+02	.215E+02	.189E+02	.134E+02	.844E+01	.603E+01
0.0000	.604E+01	.708E+01	.122E+02	.161E+02	.199E+02	.218E+02	.207E+02	.181E+02	.130E+02	.787E+01	.556E+01
.1000	.647E+01	.647E+01	.107E+02	.161E+02	.187E+02	.183E+02	.173E+02	.151E+02	.105E+02	.552E+01	.450E+01
.2000	.543E+01	.578E+01	.736E+01	.125E+02	.170E+02	.167E+02	.148E+02	.108E+02	.622E+01	.412E+01	.378E+01
.3000	.419E+01	.469E+01	.490E+01	.741E+01	.114E+02	.126E+02	.983E+01	.645E+01	.479E+01	.380E+01	.298E+01
.4000	.303E+01	.261E+01	.336E+01	.429E+01	.550E+01	.588E+01	.525E+01	.475E+01	.402E+01	.345E+01	.166E+01
.5000	.140E+01	.167E+01	.262E+01	.331E+01	.332E+01	.338E+01	.287E+01	.202E+01	.191E+01	.131E+01	.359E+00

```
    TOWER COORDINATES OF TARGET POINTS 1, 11, 111, AND 121
        -.500E+00  .722E+01  .511E+02  UPPER LEFT CORNER
        -.500E+00  .822E+01  .511E+02  UPPER RIGHT CORNER
         .500E+00  .722E+01  .511E+02  LOWER LEFT CORNER
         .500E+00  .822E+01  .511E+02  LOWER RIGHT CORNER

        INTEGRAL OF POWER DENSITY IS       94517.065  WATTS

 TIME FOR C IS      145.262000
```

Figure 16. Flux Profile on Upper Surface of Horizontal Flat Plate. Single upper redirector used.

W/SQ CM ON TARGET SURFACE FOR DAY 180. AND TIME 0.0000 HOURS.

TOTAL POWER DENSITY UPON RECEIVER

Z METERS	X(I)= 0.0000	.0576	.1152	.1729	.2305	.2881	.3457	.4033	.4610	.5186	.5762 M
0.0000	.754E+01	.113E+02	.122E+02	.110E+02	.108E+02	.110E+02	.856E+01	.799E+01	.676E+01	.678E+01	.627E+01
.6283	.117E+02	.222E+02	.232E+02	.215E+02	.202E+02	.169E+02	.126E+02	.986E+01	.703E+01	.521E+01	.237E+01
1.2566	.164E+02	.367E+02	.330E+02	.313E+02	.287E+02	.224E+02	.177E+02	.107E+02	.817E+01	.243E+01	.490E+00
1.8850	.179E+02	.361E+02	.326E+02	.332E+02	.286E+02	.221E+02	.142E+02	.127E+02	.633E+01	.283E+01	.104E+00
2.5133	.115E+02	.244E+02	.253E+02	.208E+02	.193E+02	.154E+02	.119E+02	.784E+01	.697E+01	.431E+01	.246E+01
3.1416	.772E+01	.111E+02	.102E+02	.107E+02	.106E+02	.825E+01	.750E+01	.717E+01	.649E+01	.596E+01	.584E+01
3.7699	.576E+01	.715E+01	.672E+01	.689E+01	.708E+01	.699E+01	.739E+01	.793E+01	.852E+01	.904E+01	.962E+01
4.3982	.646E+01	.678E+01	.715E+01	.759E+01	.811E+01	.873E+01	.945E+01	.103E+02	.111E+02	.121E+02	.130E+02
5.0265	.646E+01	.679E+01	.719E+01	.765E+01	.820E+01	.885E+01	.959E+01	.104E+02	.113E+02	.123E+02	.132E+02
5.6549	.556E+01	.567E+01	.659E+01	.733E+01	.750E+01	.784E+01	.780E+01	.874E+01	.906E+01	.960E+01	.102E+02
6.2832	.754E+01	.113E+02	.122E+02	.110E+02	.108E+02	.110E+02	.856E+01	.799E+01	.676E+01	.678E+01	.627E+01

TOWER COORDINATES OF TARGET POINTS 1, 11, 111, AND 121

.102E+00	.743E+01	.511E+02	UPPER LEFT CORNER
.666E-14	.801E+01	.511E+02	UPPER RIGHT CORNER
.102E+00	.743E+01	.511E+02	LOWER LEFT CORNER
.666E-14	.801E+01	.511E+02	LOWER RIGHT CORNER

INTEGRAL OF POWER DENSITY IS 19511.740 WATTS

TIME FOR C IS 472.847000

Figure 17. Flux Profile on Surface of APL Nose Cone

4. Summary

A method for designing a redirector/ reconcentrator has been presented. Although the particular application discussed is a nose cone to be tested at the CRTF, the method can be applied to any central receiver type facility or to any shaped target that can be described by a mathematical model. All computer codes discussed are available by contacting the authors and are very useful for determining the size, shape, and location of a reconcentrator/redirector with respect to a target.

References

[1]F. Biggs and C. N. Vittitoe, *The HELIOS Model for the Optical Behavior of Reflecting Solar Concentrators*, SAND76-0347 (Albuquerque, NM: Sandia National Laboratories, 1979).

[2]D. E. Arvizu and G. P. Mulholland, *Redirector Design Methodology for Horizontal Target Plane Applications at the Central Receiver Test Facility*, SAND82-2682 (Albuquerque, NM: Sandia National Laboratories, 1984).

[3]F. Biggs and C. N. Vittitoe, *A User's Guide to HELIOS: Part 1, Introduction and Code Input*, SAND81-1180 (Albuquerque, NM: Sandia National Laboratories, 1981).

APPENDIX A

Computer Code REDIR

File - REDIR:

Program to Predict

Unit Normals from

Redirector Facets

```
C
C       PROGRAM REDIR
C
C       DEVELOPED BY
C
C       GEORGE P. MULHOLLAND
C       NEW MEXICO STATE UNIVERSITY
C
C       CHERYL MAXWELL GHANBARI
C       TECHNADYNE ENGINEERING CONSULTANTS
C
C
C       THE PURPOSE OF THIS CODE IS TO AID IN THE DESIGN OF A REDIRECTOR
C       FOR THE CENTRAL RECEIVER TEST FACILITY (CRTF).
C
C       THIS CODE CALCULATES THE CENTER OF EACH FACET ON A REDIRECTOR
C       AND THE UNIT NORMAL TO THAT FACET.  EACH FACET CENTER IS
C       CONTAINED IN A PLANE WHICH IS DEFINED BY AN ANGLE OF ROTATION
C       ABOUT X-TOWER COORD. AND A Z TARGET VALUE FOR A REF. HELIOSTAT
C
C
C       INPUT:
C
C       - TITLE OF THE SPECIFIC INPUT
C       - NUMBER OF HLSTS TO BE ANALYZED, NUMBER OF HLSTS AIMED AT UPPER REDIR
C       - NUMBER OF AIMPOINTS AND TARGET POINTS
C       - COORDINATES OF AIMPOINTS AND TARGET POINTS
C       - ANGLE THAT UPPER AND LOWER REDIRECTORS MAKE WITH THE HORIZONTAL
C       - DAY OF YEAR, TIME OF DAY (SOLAR NOON = 0.0 HRS)
C       - HELIOSTAT NUMBER (AS REFRNCED IN HELIOS PRGM), ALGNMNT AND AIMPT
C
C
C
C       OUTPUT:
C
C       - HELIOSTAT NUMBER AS REFERENCED IN THE HELIOS PROGRAM
C       - POSITION OF THE CENTER OF THE CENTER FACET OF EACH HELIOSTAT
C         IN TOWER COORDINATES
C       - PIERCE POINT ON REDIRECTOR OF RAY FROM CENTER FACET OF EACH
C         HELIOSTAT IN TOWER COORDINATES
C       - ANGLE BETWEEN THE REDIRECTOR NORMAL AND THE RAY COMING FROM
C         THE HELIOSTAT
C
C
C       INPUT FORMAT:
C
C       CARD 1: TITLE OF PROGRAM RUN--FORMAT (18A4)
C       CARD 2: TOTAL # OF HLSTS, # HLSTS AIMED AT UPPER REDIR. (2I5)
C       CARD 3: NUMBER OF AIMPOINTS, NUMBER OF TARGET POINTS--FORMAT(2I5)
C       CARD 4: AIMPOINT(S) COORDINATES--FORMAT(3F7.2)
C       CARD 5: TARGET(S) COORDINATES--FORMAT(3F7.2)
C       CARD 6: HELIOSTAT NUMBER, TARGET PT. REF. #, AIM PT. REF. #,
C               FORMAT (3I5)
C       CARD 8: ANGLE PHE FOR UPPER AND LOWER REDIR. --FORMAT (F7.2)
C       CARD 9: DAY,HOUR--FORMAT (F4.0,F5.2)
C
```

```
C
C       THE MAIN VARIABLES USED IN THIS PROGRAM:
C
C       ANGLE----ARRAY OF THE ARCCOSINE OF THE VARIABLE (IDOTN)
C       AP-------ARRAY OF THE DISTANCE FROM THE AIM POINT TO THE POSITION
C                OF THE CENTER FACET OF EACH HELIOSTAT
C       AZ-------AZIMITH OF THE SUN'S POSITION WITH THE TOWER AS REFERENCE
C       C--------ARRAY OF THE COLUMN POSITION OF EACH HELIOSTAT
C       C1-------REFERENCE COLUMN BY WHICH THE PROPER ZH CAN BE CALCULATED
C       DELZU----Z-DISTANCE BETWEEN A REDIRECTOR ABOVE TARGET AND THE TARGET
C       DELZL----Z-DISTANCE BETWEEN A REDIRECTOR BELOW TARGET AND THE TARGET
C       EL-------ELEVATION OF THE SUN'S POSITION WITH THE TOWER AS REFERENCE
C       FX-------ARRAY OF THE X-COORDINATES OF THE FOUNDATION OF HELIOSTAT
C       FY-------ARRAY OF THE Y-COORDINATES OF THE FOUNDATION OF HELIOSTAT
C       FZ-------ARRAY OF THE Z-COORDINATES OF THE FOUNDATION OF HELIOSTAT
C       H1H2-----ARRAY OF DISTANCE BETWEEN PIERCE POINTS AND THE REFERENCE
C                PIERCE POINT
C       HN-------ARRAY OF THE HELIOSTAT NUMBER AS NUMBERED BY THE HELIOS
C                PROGRAM
C       HP-------ARRAY OF THE HELIOSTAT NUMBER AS NUMBERED BY THE HELIOS
C                PROGRAM--INPUT BY USER
C       HP(1)----REFERENCE HELIOSTAT FOR UPPER REDIRECTOR
C       HP(NU+1)-REFERENCE HELIOSTAT FOR LOWER REDIRECTOR
C       IDOTN----ARRAY OF THE NEGATIVE DOT PRODUCT OF THE I AND NORMAL
C                VECTORS
C       L--------ARRAY OF THE I COMPONENT OF THE I-VECTOR
C       M--------ARRAY OF THE J COMPONENT OF THE I-VECTOR
C       N--------ARRAY OF THE K COMPONENT OF THE I-VECTOR
C       NP-------NUMBER OF HELIOSTATS TO BE ANALYZED
C       NU-------NUMBER OF HELIOSTATS AIMED AT THE UPPER REDIRECTOR
C       PHE------ANGLE WHICH PIERCE PLANE MAKES WITH HORIZONTAL
C       PI-------CONSTANT OF PI
C       R--------ARRAY OF THE ROW POSITION OF EACH HELIOSTAT
C       XA-------ARRAY OF X-COORDINATES OF AIM POINT
C       XF-------ARRAY OF X-COORDINATES OF THE TARGET POINT
C       XH-------ARRAY OF X-COORDINATES OF THE PIERCE POINT
C       XN-------ARRAY OF THE I COMPONENT OF THE NORMAL VECTOR
C       XP-------ARRAY OF X-COORDINATES OF THE CENTER FACET OF HELIOSTAT
C       XT-------ARRAY OF X-COORD. OF THE PIERCE POINT IN TARGET COORD.
C       YA-------ARRAY OF Y-COORDINATES OF AIM POINT
C       YF-------ARRAY OF Y-COORDINATES OF THE TARGET POINT
C       YH-------ARRAY OF Y-COORDINATES OF THE PIERCE POINT
C       YN-------ARRAY OF J COMPONENT OF THE NORMAL VECTOR
C       YP-------ARRAY OF Y-COORDINATES OF THE CENTER FACET OF HELIOSTAT
C       YT-------ARRAY OF Y-COORD. OF THE PIERCE POINT IN TARGET COORD.
C       ZA-------ARRAY OF Z-COORDINATES OF AIM POINT
C       ZF-------ARRAY OF Z-COORDINATES OF THE TARGET POINT
C       ZH-------ARRAY OF Z-COORDINATES OF THE PIERCE POINT
C       ZN-------ARRAY OF THE K COMPONENT OF THE NORMAL VECTOR
C       ZP-------ARRAY OF THE Z-COORDINATES OF THE CENTER FACET OF HELIOSTAT
C       ZT-------ARRAY OF THE Z-COORD. OF THE PIERCE POINT IN TARGET COORD.
C
```

```
C
C     *****************************************************************
      PROGRAM REDIR(TAPE1,TAPE2)
C
C
C     THE PURPOSE OF THE MAIN PROGRAM IS TO READ THE INPUT,CALL ADJOIN-
C     ING SUBROUTINES TO PERFORM THE APPROPRIATE CALCULATIONS, AND
C     PRINT THE RESULTANT OUTPUT.
C
C
C     COMMON THE MAIN VARIABLES BY BLOCKS
C
      COMMON/BLOCK1/XA(222),YA(222),ZA(222)
      COMMON/BLOCK2/XP(222),YP(222),ZP(222)
      COMMON/BLOCK3/XH(222),YH(222),ZH(222)
      COMMON/BLOCK5/PI,H1H2(222)
      COMMON/BLOCK6/XF(222),YF(222),ZF(222)
      COMMON/BLOCK7/XN(222),YN(222),ZN(222),ANGLE(222)
      COMMON/BLOCK8/AZ,EL
      COMMON/BLOCK9/FX(222),FY(222),FZ(222)
      COMMON/BLOCK10/DELZU,DELZL,DELYL
      COMMON/BLOCK11/HN,HP
      COMMON/BLOCK4/L,M,N,AP(222)
      COMMON/BLOCK12/XT(222),YT(222),ZT(222)
      COMMON/BLOCK13/AL1,AL2,EU3X(222),EU3Y(222),EU3Z(222)
      COMMON/BLOCK14/EU1X(222),EU1Y(222),EU2X(222),EU2Y(222),EU2Z(222)
      COMMON/BLOCK15/P1X(222),P1Y(222),P1Z(222),P2X(222)
     1,P2Y(222),P2Z(222)
      COMMON/BLOCK16/P3X(222),P3Y(222),P3Z(222),PX(4,222)
     1,PY(4,222),PZ(4,222)
      COMMON/BLOCK17/XHA(12,4,222),YHA(12,4,222),ZHA(12,4,222)
      REAL L(222),N(222),M(222),IDOTN(222)
      INTEGER HN(222),HP(222)
      DIMENSION TITLE(18),XTT(222),ZTT(222)
      DIMENSION CXA(222),CYA(222),CZA(222),CXF(222),CYF(222),CZF(222)
C
C     INTIALIZE THE VARIABLE HN
C==================================================
      DATA (HN(I),I=1,222)/
     1211,212,213,214,215, 28, 29, 30, 31, 32,222,223,
     1224,225,226,227, 39, 40, 41, 42, 43, 44,232,233,
     1234,235,236,237,238, 49, 50, 51, 52, 53, 54, 55,
     1241,242,243,244,245,246,247,248, 58, 59, 60, 61,
     162, 63, 64, 65,250,251,252,253,254,255, 67, 68,
     169, 70, 71, 72,260,261,262,263, 77, 78, 79, 80,
     1249, 66,256,257,258,259, 73, 74, 75, 76,264,265,
     1266,267,268,269,270, 81, 82, 83, 84, 85, 86, 87,
     1271,272,273,274,275,276,277,278,279,280,281,282,
     188, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99,
     1283,284,285,286,287,288,289,290,291,292,293,294,
     1295,296,100,101,102,103,104,105,106,107,108,109,
     1110,111,112,113,297,298,299,300,301,302,303,304,
     1305,306,307,308,309,310,114,115,116,117,118,119,
     1120,121,122,123,124,125,126,127,311,312,313,314,
     1315,316,317,318,319,320,321,322,323,324,128,129,
     1130,131,132,133,134,135,136,137,138,139,140,141,
     1325,326,327,328,329,330,142,143,144,145,146,147,
     156, 46, 45,239,229,228/
```

```
C      INTIALIZE THE VARIABLES FX,FY,FZ
C
      DATA (FX(I),I=1,50)/
     116.043,  48.039,   79.910,  111.952,  143.938,
     1-15.986,  -52.045,  -79.907, -111.928, -143.945,
     116.042,  48.068,   79.940,  111.947,  143.873,
     1175.908,  -15.892,  -47.901,  -79.913, -111.916,
     1-143.905, -175.898,  16.003,   48.009,   79.922,
     1111.908,  143.865,  175.901,  207.951,  -15.926,
     1-47.970,  -79.879, -111.883, -144.007, -175.952,
     1-207.943,  16.143,   48.122,   79.926,  111.982,
     1143.989,  175.949,  207.970,  239.987,  -15.932,
     1-47.960,  -79.800, -111.963, -143.912, -175.719/
C===================================================
      DATA (FX(I),I=51,100)/
     1-207.892, -239.788,  16.051,   48.015,   80.005,
     1111.905,  143.954,  175.916,  -16.001,  -47.994,
     1-79.993, -111.954, -143.758, -175.865,   16.040,
     147.979,   80.019,  111.985,  -16.010,  -48.025,
     1-79.965, -111.975,  271.592, -271.843,  207.938,
     1239.918,  271.888,  303.853, -207.711, -239.819,
     1-271.815, -303.800,  143.957,  175.955,  207.966,
     1239.916,  271.903,  303.811,  335.868, -143.908,
     1-175.874, -207.914, -239.876, -271.893, -303.841,
     1-335.903,  15.958,   47.982,   80.015,  111.943/
C===================================================
      DATA (FX(I),I=101,150)/
     1143.903,  175.969,  207.980,  239.940,  271.967,
     1303.810,  335.846,  368.028,  -15.960,  -47.996,
     1-79.900, -111.914, -143.931, -175.860, -207.806,
     1-239.972, -271.803, -303.875, -335.793, -367.854,
     115.996,   48.011,   80.003,  111.974,  143.929,
     1175.965,  207.933,  239.916,  271.923,  303.857,
     1335.795,  367.936,  399.853,  431.905,  -15.973,
     1-47.987,  -79.981, -111.961, -143.978, -175.925,
     1-207.953, -239.908, -271.831, -303.907, -335.838,
     1-367.881, -399.862, -431.818,   15.976,   47.981/
C===================================================
      DATA (FX(I),I=151,200)/
     180.008,  111.971,  143.920,  175.875,  207.977,
     1239.918,  271.882,  303.850,  335.888,  367.904,
     1399.901,  431.862,  -16.054,  -48.011,  -79.988,
     1-111.947, -143.976, -175.903, -207.939, -239.900,
     1-271.945, -303.887, -335.846, -367.870, -399.939,
     1-431.883,  15.867,   47.982,   80.013,  111.907,
     1143.909,  175.947,  207.949,  239.932,  271.934,
     1303.867,  335.902,  367.850,  399.934,  431.903,
     1-16.059,  -47.946,  -79.936, -111.934, -143.864,
     1-175.964, -207.944, -239.830, -271.925, -304.029/
C===================================================
      DATA (FX(I),I=201,222)/
     1-335.894, -367.838, -399.874, -431.816,   16.093,
     147.977,   80.036,  111.874,  143.929,  175.962,
     1-16.019,  -48.054,  -80.074, -111.960, -143.977,
     1-175.949, -239.928, -239.830, -207.865,  239.844,
     1239.890,  207.874/
C===================================================
      DATA (FY(I),I=1,50)/
     1150.075,  150.095,  150.092,  150.085,  150.061,
     1150.052,  150.034,  150.086,  150.054,  150.042,
     1190.061,  190.101,  190.043,  190.085,  190.070,
     1190.089,  190.073,  190.072,  189.996,  190.018,
     1190.051,  189.981,  229.955,  229.971,  230.020,
     1229.985,  229.960,  229.978,  230.043,  229.997,
     1229.992,  229.995,  230.007,  229.953,  230.006,
     1230.011,  269.938,  269.946,  270.006,  270.011,
     1269.981,  270.049,  269.956,  269.995,  270.046,
     1270.003,  270.002,  269.959,  270.031,  269.991/
```

```
C=====================================================
      DATA (FY(I),I=51,100)/
     1270.019,  269.983,  309.997,  310.000,  310.050,
     1310.034,  309.986,  309.990,  310.038,  310.013,
     1309.965,  310.011,  309.988,  309.972,  352.018,
     1351.960,  351.988,  352.019,  352.048,  352.087,
     1351.989,  351.998,  269.995,  270.033,  309.979,
     1309.970,  309.986,  309.979,  309.966,  310.026,
     1310.003,  310.010,  352.017,  352.001,  351.989,
     1352.023,  351.980,  352.003,  351.999,  351.988,
     1352.023,  352.019,  352.032,  352.011,  351.990,
     1351.963,  398.985,  398.953,  399.033,  398.911/
C=====================================================
      DATA (FY(I),I=101,150)/
     1398.942,  399.003,  398.962,  398.919,  398.973,
     1399.055,  399.027,  398.816,  399.000,  398.950,
     1398.969,  398.970,  398.919,  398.914,  398.935,
     1399.021,  399.037,  399.040,  399.035,  398.971,
     1448.944,  448.981,  448.948,  448.960,  448.988,
     1448.936,  448.982,  448.937,  448.954,  448.952,
     1448.858,  448.868,  448.970,  448.897,  448.978,
     1448.969,  448.956,  448.897,  448.994,  448.976,
     1449.001,  449.081,  449.056,  449.019,  449.041,
     1448.985,  449.027,  449.033,  506.958,  506.910/
C=====================================================
      DATA (FY(I),I=151,200)/
     1506.946,  506.922,  506.981,  506.947,  506.971,
     1506.917,  506.940,  507.014,  506.966,  506.917,
     1507.012,  506.946,  506.962,  506.957,  506.984,
     1506.912,  506.962,  506.929,  506.919,  506.920,
     1506.944,  506.961,  506.988,  507.014,  507.018,
     1507.009,  569.936,  569.938,  569.976,  569.929,
     1569.924,  569.941,  569.924,  569.919,  569.949,
     1569.873,  569.893,  569.935,  569.951,  569.903,
     1569.954,  569.890,  569.995,  570.047,  570.001,
     1569.919,  570.047,  570.081,  569.969,  569.951/
C=====================================================
      DATA (FY(I),I=201,222)/
     1569.987,  569.950,  569.994,  569.939,  638.975,
     1638.973,  638.891,  638.921,  638.872,  638.865,
     1638.826,  638.919,  638.797,  638.996,  638.947,
     1638.952,  230.024,  190.109,  190.084,  230.058,
     1190.091,  190.101/
C=====================================================
      DATA (FZ(I),I=1,90)/
     1-.401,     .059,     .399,     .859,    1.329,    -.761,
     1-1.191,  -1.651,   -2.081,   -2.581,    -.131,     .269,
     1.709,    1.229,    1.909,    2.559,    -.581,    -.991,
     1-1.491,  -2.041,   -2.531,   -3.231,     .189,     .599,
     11.159,   1.699,    2.409,    3.049,    3.679,    -.311,
     1-.781,   -1.311,   -1.891,   -2.531,   -3.161,   -3.891,
     1.579,    1.059,    1.639,    2.339,    2.959,    3.579,
     14.259,   4.879,     .019,    -.561,   -1.111,   -1.661,
     1-2.451,  -3.161,   -3.761,   -4.511,     .919,    1.539,
     12.269,   2.939,    3.519,    4.139,     .429,    -.151,
     1-.701,   -1.451,   -2.181,   -2.921,    1.359,    2.169,
     12.799,   3.439,     .799,     .119,    -.531,   -1.391,
     15.659,  -5.351,    4.779,    5.439,    6.099,    6.839,
     1-3.661,  -4.491,   -5.221,   -6.041,    4.039,    4.719,
     15.399,   6.019,    6.599,    7.339,    8.059,   -2.161/
C-----------------------------------------------------
```

```
C------------------------------------------------------------
      DATA (FZ(I),I=91,180)/
     1-2.911,  -3.581,  -4.371,  -5.071,  -5.961,  -6.711,
     11.699,   2.529,   3.259,   4.009,   4.579,   5.289,
     15.919,   6.589,   7.189,   7.839,   8.589,   9.599,
     1.969,    .339,   -.471,  -1.161,  -1.971,  -2.631,
     1-3.441,  -4.191,  -4.951,  -5.691,  -6.431,  -7.141,
     11.719,   2.559,   3.239,   3.969,   4.729,   5.489,
     16.149,   6.899,   7.629,   8.429,   9.069,   9.819,
     110.549,  11.049,   1.089,    .399,   -.471,  -1.231,
     1-1.831,  -2.751,  -3.461,  -4.121,  -4.991,  -5.851,
     1-6.561,  -7.241,  -7.721,  -8.371,   1.909,   2.589,
     13.359,   4.099,   4.849,   5.579,   6.279,   7.039,
     17.879,   8.659,   9.379,  10.149,  10.829,  11.689,
     11.239,    .429,   -.361,  -1.081,  -1.921,  -2.701,
     1-3.421,  -4.121,  -4.961,  -5.611,  -6.421,  -7.251,
     1-7.721,  -8.281,   2.079,   2.709,   3.459,   4.219/
C============================================================
      DATA (FZ(I),I=181,222)/
     14.959,   5.679,   6.359,   7.179,   7.919,   8.719,
     19.419,  10.209,  11.029,  11.899,   1.279,    .569,
     1-.141,   -.891,  -1.681,  -2.401,  -3.261,  -3.961,
     1-4.741,  -5.581,  -6.311,  -7.041,  -7.631,  -8.191,
     12.209,   2.879,   3.629,   4.429,   5.139,   5.899,
     11.559,    .819,    .219,   -.771,  -1.541,  -2.381,
     1-4.671,  -4.731,  -4.031,   4.309,   3.769,   3.129/
C
C     CHANGE FX, FY & FZ FROM FEET TO METERS
C
       DO 90102 JJ=1,222
       FX(JJ)=FX(JJ)*0.3048
       FY(JJ)=FY(JJ)*0.3048
       FZ(JJ)=FZ(JJ)*0.3048
90102  CONTINUE
C
C     CALCULATE THE CONSTANT PI
C
      PI=ATAN(1.)*4.
C
C     READ IN THE TITLE, NUMBER OF HELIOSTATS TO BE EVALUATED (NP),
C     NUMBER OF HELIOSTATS AIMED AT THE UPPER REDIRECTOR (NU)
C      NUMBER OF AIMPTS (IAIMP) AND TARGET POINTS (ITAR)
C     READ COORDINATES OF THE AIMPTS AND THE TARGET POINTS
C
      READ (1,100) (TITLE(I),I=1,18)
      READ (1,101) NP,NU
      READ (1,116) IAIMP,ITAR
      READ (1,111) (CXA(I),CYA(I),CZA(I),I=1,IAIMP)
      READ (1,111) (CXF(I),CYF(I),CZF(I),I=1,ITAR)

C
C     READ IN VALUES FOR AIM POINT AND TARGET POINT
C     NOTE THAT THE FIRST HELIOSTAT READ IS THE REFERENCE HELIOSTAT
C     THIS APPLIES TO THE UPPER AND LOWER REDIRECTORS.  EACH MUST
C     HAVE A REFERENCE HELIOSTAT.
C
C
      DO 85 I=1,NP
      READ (1,114)HP(I),NTAR,NAIM
      XA(I) = CXA(NAIM)
      YA(I) = CYA(NAIM)
      ZA(I) = CZA(NAIM)
      XF(I) = CXF(NTAR)
      YF(I) = CYF(NTAR)
      ZF(I) = CZF(NTAR)
   85 CONTINUE
```

```
C
C      READ IN REMAINING INPUT
C
       READ (1,104)PHEU,PHEL
       READ (1,105)DAY,HOUR
   100 FORMAT (18A4)
   101 FORMAT (2I5)
   102 FORMAT (I5,6F7.2)
   104 FORMAT (2F7.2)
   105 FORMAT (F4.0,F5.2)
   109 FORMAT (6F7.2)
   111 FORMAT (3F10.2)
   113 FORMAT (I5,3F7.2)
   114 FORMAT (3I3)
   116 FORMAT (2I5)
       PHEU = PI * PHEU/180.
       PHEL = PI * PHEL/180.
       NLOW = 1
       NHIGH = NU
C
C
C      CALL SUBROUTINE TO ASSOCIATE THE HELIOSTAT NUMBER WITH
C      THE FOUNDATION POINTS
C
       CALL SORTPT(NLOW,NHIGH)
C
C      CALL SUBROUTINE TO CALCULATE THE AZIMITH AND ELEVATION
C      OF THE SUN
C
       CALL SUN(DAY,HOUR,AZ,EL)
C
C      CALL SUBROUTINE TO CALCULATE THE THE POSITION OF THE
C      CENTER FACET OF EACH HELIOSTAT IN TOWER COORDINATES
C
       CALL POINTS(NLOW,NHIGH)
C
       AL1=0.318
       AL2 = 3.987
       AL3 = 3.048
       DO 999 I = NLOW,NHIGH
C
C      THE FOLLOWING SECTION LOCATES THE FOUR CORNERS OF THE
C      HELIOSTAT
C
C      EU3 IS NORMAL TO HELIOSTAT
C
       EU3X(I) = (XP(I)-FX(I))/AL1
       EU3Y(I) = (YP(I)-FY(I))/AL1
       EU3Z(I) = (ZP(I)-FZ(I)-AL2)/AL1
       EU3 = SQRT(EU3X(I)**2+EU3Y(I)**2+EU3Z(I)**2)
       EU3X(I) = EU3X(I)/EU3
       EU3Y(I) = EU3Y(I)/EU3
       EU3Z(I) = EU3Z(I)/EU3
       EU1 = SQRT(EU3X(I)**2+EU3Y(I)**2)
       EU1X(I) =-EU3Y(I)/EU1
       EU1Y(I) = EU3X(I)/EU1
       EU2X(I) = -EU3Z(I)*EU1Y(I)
       EU2Y(I) = EU3Z(I)*EU1X(I)
       EU2Z(I) = EU3X(I)*EU1Y(I)-EU3Y(I)*EU1X(I)
         DO 899 JJ=1,4
         ALB =AL3
         IF (JJ.GT.2) ALB=-AL3
         AA = ((-1)**JJ)*AL3
         PX(JJ,I) = XP(I)+AA*EU1X(I)+ALB*EU2X(I)
         PY(JJ,I) = YP(I)+AA*EU1Y(I)+ALB*EU2Y(I)
899      PZ(JJ,I) = ZP(I)+AL3*EU2Z(I)
999    CONTINUE
```

```
C
C     CALL SUBROUTINE TO CALCULATE THE COMPONENTS OF THE I-
C     VECTOR
C
      CALL IVECTOR(NLOW,NHIGH)
C
      NCOUNT = 1.
C
C     CALL SUBROUTINE TO CALCULATE THE PIERCE POINTS
C
      CALL PIERCE(NLOW,NHIGH,NCOUNT, PHEU,PHEL)
C
C     CALL SUBROUTINE TO LOCATE PIERCE POINTS IN TARGET COORDINATE SYSTEM
C
      CALL CORPIUP(NLOW, NHIGH, PHEU)
C
C     CALL SUBROUTINE TO CALCULATE THE NORMAL VECTOR TO THE
C     REDIRECTING SURFACE AND THE ANGLE BETWEEN THIS NORMAL
C     AND THE INCIDENT HELIOSTAT RAY
C
      CALL NVECTOR(NLOW, NHIGH)
C
      A = COS(EL)*COS(AZ)
      B = COS(EL)*SIN(AZ)
      CA= SIN(EL)
      U1 = 9.167*0.3048
      U2 = 8.417*0.3048
      U3 = 0.208*0.3048
C
C     LOCATE CENTER OF FACETS 1,5,21,25
C
      DO 998 J = NLOW,NHIGH
      NN=1
996   IF(NN.GT.4) GO TO 998
      GO TO (990,990,980,980) NN
990   X = XP(J)+U1*(-1)**NN*EU1X(J)+U2*EU2X(J)
      Y = YP(J)+U1*(-1)**NN*EU1Y(J)+U2*EU2Y(J)
      Z = ZP(J)+U3*EU2Z(J)
      GO TO 997
980   X = XP(J)+U1*(-1)**NN*EU1X(J)-U2*EU2X(J)
      Y = YP(J)+U1*(-1)**NN*EU1Y(J)-U2*EU2Y(J)
      Z = ZP(J)-U3*EU2Z(J)
997   RSQ = SQRT((XA(J)-X)**2+(YA(J)-Y)**2+(ZA(J)-Z)**2)
C
C     COMPONENTS OF THE REFLECTED RAY
C
      RX = (XA(J)-X)/RSQ
      RY = (YA(J)-Y)/RSQ
      RZ = (ZA(J)-Z)/RSQ
      AA = SQRT((A+RX)**2+(B+RY)**2+(CA+RZ)**2)
C
C     COMPONENTS OF THE NORMAL
C
      ANX = (A+RX)/AA
      ANY = (B+RY)/AA
      ANZ = (CA+RZ)/AA
C
C     HERE FACET IS ASSUMED FLAT.IF FACET IS CONTOURED .
C     THEN ANX,ANY,ANZ MUCT BE MODIFIED TO ACCOUNT FOR
C     THE CONTOUR.  REMEMBER THAT ANX,ANY,AND ANZ ARE NORMAL
C     AT FACET CENTER
```

```
C
C     DETERMINE VECTOR I-PRIMED.  ALPH IS
C     HALF-ANGLE FOR SOLAR DISK WHILE PHII IS
C     AZIMUTHAL ANGLE ON DISK
      ALPH=16./60.
      ALPH = ALPH *PI/180.
      ACOF  = TAN(ALPH)/SQRT(A**2+B**2)
      APMAG = SQRT(1.+TAN(ALPH)**2)
      DO 799 K= 1,12
      PHII  = FLOAT(K-1)*(2.*PI)/12.
      CPHI  = COS(PHII)
      SPHI  = SIN(PHII)
      DP  = (ACOF*(-B*CPHI-A*CA*SPHI)+A)/APMAG
      BP  = (ACOF*(A*CPHI-B*CA*SPHI)+B)/APMAG
      CP  = (ACOF*(A**2+B**2)*SPHI+CA)/APMAG
C
C     DETERMINE VECTOR B : B = (BX,BY,BZ)
C
      DOT  = DP*ANX+BP*ANY+CP*ANZ
      BX  = -DP+2.*DOT*ANX
      BY  = -BP+2.*DOT*ANY
      BZ  = -CP+2.*DOT*ANZ
C
C     DETERMINE DISTANCE FROM FACET TO REDIRECTOR,
C     AL; NORMAL TO REDIRECTOR IS (XN,YN,ZN)
C
      AL=(XH(J)-PX(NN,J))*XN(J)+(YH(J)-PY(NN,J))*YN(J)+(ZH(J)
     1-PZ(NN,J))*ZN(J)
      AL  = AL/(BX*XN(J)+BY*YN(J)+BZ*ZN(J))
      XHA(K,NN,J)  =  PX(NN,J)+AL*BX
      YHA(K,NN,J)  =  PY(NN,J)+AL*BY
      ZHA(K,NN,J)  =  PZ(NN,J)+AL*BZ
799   CONTINUE
      NN  = NN+1
      GO TO 996
998   CONTINUE
C
  4    FORMAT(5X,3F16.5)
C
      IF(NP.EQ.NU) GO TO 9999
      NLOW = NU + 1
      NHIGH = NP
C
      CALL SORTPT(NLOW, NHIGH)
      CALL POINTS(NLOW,NHIGH)
      DO 9909 I = NLOW,NHIGH
C
C     EU3 IS NORMAL TO HELIOSTAT
C
      EU3X(I)  =  (XP(I)-FX(I))/AL1
      EU3Y(I)  =  (YP(I)-FY(I))/AL1
      EU3Z(I)  =  (ZP(I)-FZ(I)-AL2)/AL1
      EU3  = SQRT(EU3X(I)**2+EU3Y(I)**2+EU3Z(I)**2)
      EU3X(I)  =  EU3X(I)/EU3
      EU3Y(I)  =  EU3Y(I)/EU3
      EU3Z(I)  =  EU3Z(I)/EU3
      EU1  = SQRT(EU3X(I)**2+EU3Y(I)**2)
      EU1X(I)  =-EU3Y(I)/EU1
      EU1Y(I)  =  EU3X(I)/EU1
      EU2X(I)  =  -EU3Z(I)*EU1Y(I)
      EU2Y(I)  =  EU3Z(I)*EU1X(I)
      EU2Z(I)  =  EU3X(I)*EU1Y(I)-EU3Y(I)*EU1X(I)
        DO 8909 JJ=1,4
        ALB =AL3
        IF (JJ.GT.2) ALB=-AL3
        AA = ((-1)**JJ)*AL3
        PX(JJ,I)  = XP(I)+AA*EU1X(I)+ALB*EU2X(I)
        PY(JJ,I)  = YP(I)+AA*EU1Y(I)+ALB*EU2Y(I)
8909     PZ(JJ,I)  = ZP(I)+AL3*EU2Z(I)
9909   CONTINUE
```

```
      CALL IVECTOR(NLOW, NHIGH)
      NCOUNT = NCOUNT + 1
      CALL PIERCE(NLOW,NHIGH,NCOUNT,PHEU,PHEL)
      CALL CORPIDN(NLOW, NHIGH. PHEL)
      CALL NVECTOR(NLOW, NHIGH)
C
C     LOCATE CENTER OF FACETS 1,5,21,25
C
      DO 9908 J = NLOW,NHIGH
      NN=1
9906  IF(NN.GT.4) GO TO 9908
      GO TO (9900,9900,9800,9800) NN
9900  X = XP(J)+U1*(-1)**NN*EU1X(J)+U2*EU2X(J)
      Y = YP(J)+U1*(-1)**NN*EU1Y(J)+U2*EU2Y(J)
      Z = ZP(J)+U3*EU2Z(J)
      GO TO 9907
9800  X = XP(J)+U1*(-1)**NN*EU1X(J)-U2*EU2X(J)
      Y = YP(J)+U1*(-1)**NN*EU1Y(J)-U2*EU2Y(J)
      Z = ZP(J)-U3*EU2Z(J)
9907  RSQ = SQRT((XA(J)-X)**2+(YA(J)-Y)**2+(ZA(J)-Z)**2)
      RX = (XA(J)-X)/RSQ
      RY = (YA(J)-Y)/RSQ
      RZ = (ZA(J)-Z)/RSQ
      AA = SQRT((A+RX)**2+(B+RY)**2+(CA+RZ)**2)
      ANX = (A+RX)/AA
      ANY = (B+RY)/AA
      ANZ = (CA+RZ)/AA
C
C     HERE FACET IS ASSUMED FLAT.IF FACET IS CONTOURED ,
C     THEN ANX,ANY,ANZ MUCT BE MODIFIED TO ACCOUNT FOR
C     THE CONTOUR.  REMEMBER THAT ANX,ANY,AND ANZ ARE NORMAL
C     AT FACET CENTER
C
C     DETERMINE VECTOR I-PRIMED.  ALPH IS
C     HALF-ANGLE FOR SOLAR DISK WHILE PHII IS
C     AZIMUTHAL ANGLE ON DISK
      ALPH=16./60.
      ALPH = ALPH *PI/180.
      ACOF = TAN(ALPH)/SQRT(A**2+B**2)
      APMAG = SQRT(1.+TAN(ALPH)**2)
      DO 7909 K= 1,12
      PHII = FLOAT(K-1)*(2.*PI)/12.
      CPHI = COS(PHII)
      SPHI = SIN(PHII)
      DP = (ACOF*(-B*CPHI-A*CA*SPHI)+A)/APMAG
      BP = (ACOF*(A*CPHI-B*CA*SPHI)+B)/APMAG
      CP = (ACOF*(A**2+B**2)*SPHI+CA)/APMAG
C
C     DETERMINE VECTOR B : B = (BX,BY,BZ)
C
      DOT = DP*ANX+BP*ANY+CP*ANZ
      BX = -DP+2.*DOT*ANX
      BY = -BP+2.*DOT*ANY
      BZ = -CP+2.*DOT*ANZ
C
C     DETERMINE DISTANCE FROM FACET TO REDIRECTOR.
C     AL; NORMAL TO REDIRECTOR IS (XN,YN,ZN)
C
      AL=(XH(J)-PX(NN,J))*XN(J)+(YH(J)-PY(NN,J))*YN(J)+(ZH(J)
     1-PZ(NN,J))*ZN(J)
      AL = AL/(BX*XN(J)+BY*YN(J)+BZ*ZN(J))
      XHA(K,NN,J) = PX(NN,J)+AL*BX
      YHA(K,NN,J) = PY(NN,J)+AL*BY
      ZHA(K,NN,J) = PZ(NN,J)+AL*BZ
7909  CONTINUE
      NN = NN+1
      GO TO 9906
```

```
C
C      PRINT THE OUTPUT
C
9999  WRITE (2,1100) (TITLE(I),I=1,18)
      WRITE (2,80)
   80 FORMAT(1X,72("*"),/)
      WRITE (2,50)
   50 FORMAT(6X,"HELIOSTAT",15X,"PIERCE",16X," FACET",7X,"ANGLE")
      WRITE (2,51)
   51 FORMAT(7X,"NUMBER",17X,"POINT",18X,"NORMAL",)
      WRITE (2,52)
   52 FORMAT(1X,72("*"))
      DO 61  I=1,NP
      WRITE (2,53) HP(I),XH(I),YH(I),ZH(I),XN(I),YN(I),
     1ZN(I),ANGLE(I)
   53 FORMAT(7X,I4,5X,3(F7.2),4X,3(F7.2),1X,F6.1)
   61 CONTINUE
   54 FORMAT(10X,I4,9X,3(F7.4),1X,3(F7.2))
 1100 FORMAT (//18A4)
      DO 98765 J=1,NP
      WRITE(2,92345) HP(J)
      WRITE(2,92346) XH(J),YH(J),ZH(J)
      DO 98764 NN=1,4
      WRITE(2,92348)
      DO 98766 K=1,12
      THET=FLOAT(K-1)*30.
      WRITE(2,92347) XHA(K,NN,J),YHA(K,NN,J),ZHA(K,NN,J),THET,NN
98766 CONTINUE
98764 CONTINUE
98765 CONTINUE
92345 FORMAT(///,5X,"PIERCE POINTS FOR CENTER FACET OF",
     1" HELIOSTAT #",I4)
92346 FORMAT(5X,"(",F8.5,",",F8.5,",",F8.5,")",/)
92348 FORMAT(//,24X,13HPIERCE POINTS,22X,5HTHETA,5X,15HHELIOSTAT
     1/70X,7H POINTS)
92347 FORMAT(1X,4F16.5,I9)
92349 FORMAT(//)
      STOP
      END
CMG1
```

```
C=================================================================
      SUBROUTINE CORPIDN(NLOW,NHIGH,PHEL)
C
C     THIS SUBROUTINE REFINES THE PIERCE POINT CALCULATION FROM
C     PIERCE SO THAT ALL PIERCE POINTS FALL IN A PLANE
C
      COMMON/BLOCK2/XP(222),YP(222),ZP(222)
      COMMON/BLOCK3/XH(222),YH(222),ZH(222)
      COMMON/BLOCK4/L,M,N,AP(222)
      COMMON/BLOCK5/PI,H1H2(222)
      COMMON/BLOCK7/XN(222),YN(222),ZN(222),ANGLE(222)
      COMMON/BLOCK11/HN,HP
      COMMON/BLOCK12/XT(222),YT(222),ZT(222)
      REAL L(222),M(222),N(222),PH(222)
      INTEGER HN(222),HP(222)
C
C
      YREF = YH(NLOW)
      ZREF = ZH(NLOW)
C
C     CONVERT TOWER COORDINATES TO TARGET COORDINATES
C
      DO 10 I=NLOW,NHIGH
      XT(I)=-XH(I)
      YT(I)=(YH(I)-YREF) * SIN(PHEL) + (ZH(I)-ZREF) * COS(PHEL)
      ZT(I)=-(YH(I)-YREF) * COS(PHEL) + (ZH(I)-ZREF) * SIN(PHEL)
   10 CONTINUE
C
C     RETURN TO MAIN PROGRAM
C
      RETURN
      END
CMG1
C=================================================================
      SUBROUTINE CORPIUP(NLOW,NHIGH,PHEU)
C
C     THIS SUBROUTINE REFINES THE PIERCE POINT CALCULATION FROM
C     PIERCE SO THAT ALL PIERCE POINTS FALL IN A PLANE
C
      COMMON/BLOCK2/XP(222),YP(222),ZP(222)
      COMMON/BLOCK3/XH(222),YH(222),ZH(222)
      COMMON/BLOCK4/L,M,N,AP(222)
      COMMON/BLOCK5/PI,H1H2(222)
      COMMON/BLOCK7/XN(222),YN(222),ZN(222),ANGLE(222)
      COMMON/BLOCK11/HN,HP
      COMMON/BLOCK12/XT(222),YT(222),ZT(222)
      REAL L(222),M(222),N(222),PH(222)
      INTEGER HN(222),HP(222)
C
C
      YREF = YH(NLOW)
      ZREF = ZH(NLOW)
C
C     CONVERT TOWER COORDINATES TO TARGET COORDINATES
C
      DO 10 I=NLOW,NHIGH
      XT(I)=-XH(I)
      YT(I)=(YH(I)-YREF) * SIN(PHEU) - (ZH(I)-ZREF) * COS(PHEU)
      ZT(I)=(YH(I)-YREF) * COS(PHEU) + (ZH(I)-ZREF) * SIN(PHEU)
   10 CONTINUE
C
C     RETURN TO MAIN PROGRAM
C
      RETURN
      END
CMG1
```

```
C=============================================================
      SUBROUTINE IVECTOR(NLOW, NHIGH)
C
C     THIS SUBROUTINE CALCULATES THE I.J.AND K COMPONENTS OF THE
C     VECTOR FROM THE CENTER FACET OF EACH HELIOSTAT TO ITS SPECIFIC
C     AIM POINT.
C
C     VARIABLES SPECIFIC TO THIS SUBROUTINE:
C     AP1--DUMMY VARIABLE USED TO CONTINUE THE CALCULATION OF
C          AP(1)
C     APN--DUMMY VARIABLE USED TO CONTINUE THE CALCULATION OF
C          AP(I)
C
C
C     COMMON THE MAIN VARIABLES IN BLOCKS
C
      COMMON/BLOCK1/XA(222),YA(222),ZA(222)
      COMMON/BLOCK2/XP(222),YP(222),ZP(222)
      COMMON/BLOCK4/L,M,N,AP(222)
      REAL L(222),M(222),N(222)
C
C     INITIALIZE THE DUMMY VARIABLES TO EQUAL 0.
C
      AP1=0.
      APN=0.
C
C     CHECK IF ONLY ONE HELIOSTAT HAS BEEN ENTERED
C
      IF(NHIGH-NLOW.EQ.0)GO TO 22
      GO TO 23
C
C     CALCULATE THE DISTANCE FROM CENTER FACET TO AIM POINT FOR
C     ONLY ONE HELIOSTAT
C
   22 AP1=(XA(1)-XP(1))**2.+(YA(1)-YP(1))**2.
      AP(1)=(AP1+(ZA(1)-ZP(1))**2.)**.5
C
C     CALCULATE THE I,J,K COMPONENTS OF THE I-VECTOR
C
      L(NLOW)=(XA(1)-XP(1))/AP(1)
      M(NLOW)=(YA(1)-YP(1))/AP(1)
      N(NLOW)=(ZA(1)-ZP(1))/AP(1)
      GO TO 30
C
C     USE DO LOOP TO CALCULATE THE DISTANCE FROM THE CENTER FACET
C     TO AIM POINT AND THE I,J,K COMPONENTS OF THE I-VECTOR FOR
C     MORE THAN ONE HELIOSTAT
C
   23 DO 14 I=NLOW,NHIGH
      APN=((XA(I)-XP(I))**2.+(YA(I)-YP(I))**2.+(ZA(I)-ZP(I))**2.)
      AP(I)=APN**.5
      L(I)=(XA(I)-XP(I))/AP(I)
      M(I)=(YA(I)-YP(I))/AP(I)
      N(I)=(ZA(I)-ZP(I))/AP(I)
   14 CONTINUE
C
C     RETURN TO THE MAIN PROGRAM
C
   30 RETURN
      END
CMG1
```

```
C=================================================================
      SUBROUTINE NVECTOR(NLOW,NHIGH)
C
C     THIS SUBROUTINE CALCULATES THE NORMAL TO THE REDIRECTING SURFACE
C     AT THE PIERCE POINT OF THE HELIOSTAT CENTRAL RAY WITH THE
C     REDIRECTOR PLANE AND THE ANGLE BETWEEN THE REDIRECTOR NORMAL AND
C     THE INCOMING RAY FROM THE CENTER OF THE HELIOSTAT CENTER FACET.
C     THIS ANGLE SHOULD BE MINIMIZED IN ORDER TO MAXIMIZE THE
C     EFFICIENCY OF THE REDIRECTOR-CONCENTRATOR.
C
C     VARIABLES SPECIFIC TO THE SUBROUTINE:
C
C     IDOTR--DOT PRODUCT OF THE I AND R VECTORS
C     RDIS---DISTANCE BETWEEN THE TARGET POINT AND THE PIERCE POINT
C     XIR----I COMPONENT OF THE VECTOR SUM OF THE I AND R VECTORS
C     XR-----ARRAY OF THE I COMPONENT OF THE VECTOR FROM THE PIERCE
C            POINT TO THE TARGET POINT
C     YIR----J COMPONENT OF THE VECTOR SUM OF THE I AND R VECTORS
C     YR-----ARRAY OF THE J COMPONENT OF THE VECTOR FROM THE PIERCE
C            POINT TO THE TARGET POINT
C     ZIR----K COMPONENT OF THE VECTOR SUM OF THE I AND R VECTORS
C     ZR-----ARRAY OF THE K COMPONENT OF THE VECTOR FROM THE PIERCE
C            POINT TO THE TARGET POINT
C     ANGLE--ANGLE BETWEEN REDIRECTOR NORMAL AND THE INCOMING
C            HELIOSTAT CENTRAL RAY
C
C
C     COMMON AND DIMENSION THE VARIABLES
C
      COMMON/BLOCK3/XH(222),YH(222),ZH(222)
      COMMON/BLOCK7/XN(222),YN(222),ZN(222),ANGLE(222)
      COMMON/BLOCK6/XF(222),YF(222),ZF(222)
      COMMON/BLOCK4/L,M,N,AP(222)
      COMMON/BLOCK5/PI,H1H2(222)
      REAL L(222),N(222),M(222),IDOTN(222),IDOTR
      DIMENSION XR(222),YR(222),ZR(222)
C
C     CHECK IF ONLY ONE HELIOSTAT IS TO BE ANALYZED
C
      IF(NHIGH - NLOW.EQ.0) GO TO 36
C
C     USE DO LOOP TO CALCULATE THE COMPONENETS OF THE R VECTOR
C     AND TO CALCULATE THE NORMAL VECTOR
      DO 19 I=NLOW,NHIGH
      RDIS=((XF(I)-XH(I))**2.+(YF(I)-YH(I))**2.+(ZF(I)-ZH(I))**2.)
     1**.5
      XR(I)=(XF(I)-XH(I))/RDIS
      YR(I)=(YF(I)-YH(I))/RDIS
      ZR(I)=(ZF(I)-ZH(I))/RDIS
      XIR=-1.*L(I)+XR(I)
      YIR=-1.*M(I)+YR(I)
      ZIR=-1.*N(I)+ZR(I)
      IDOTR=L(I)*XR(I)+M(I)*YR(I)+N(I)*ZR(I)
      XN(I)=XIR/(2.-2.*IDOTR)**.5
      YN(I)=YIR/(2.-2.*IDOTR)**.5
      ZN(I)=ZIR/(2.-2.*IDOTR)**.5
      IDOTN(I)=-1.*L(I)*XN(I)-M(I)*YN(I)-N(I)*ZN(I)
      ANGLE(I)=ACOS(IDOTN(I))
C
C     CONVERT ANGLE TO DEGREES FROM RADIANS
      ANGLE(I)=180.*ANGLE(I)/PI
   19 CONTINUE
C
C     RETURN TO MAIN PROGRAM
```

```
C
      GO TO 37
C
C     CALCULATE THE NORMAL VECTOR FOR ONLY ONE HELIOSTAT
C
   36 R1DIS=(XF(NLOW)-XH(NLOW))**2.+(YF(NLOW)-YH(NLOW))**2.
     1 +(ZF(NLOW)-ZH(NLOW))**2.
      RDIS=R1DIS**.5
      XR(NLOW)=(XF(NLOW)-XH(NLOW))/RDIS
      YR(NLOW)=(YF(NLOW)-YH(NLOW))/RDIS
      ZR(NLOW)=(ZF(NLOW)-ZH(NLOW))/RDIS
      XIR=-1.*L(NLOW)+XR(NLOW)
      YIR=-1.*M(NLOW)+YR(NLOW)
      ZIR=-1.*N(NLOW)+ZR(NLOW)
      IDOTR=L(NLOW)*XR(NLOW)+M(NLOW)*YR(NLOW)+N(NLOW)*ZR(NLOW)
      XN(NLOW)=XIR/(2.-2.*IDOTR)**.5
      YN(NLOW)=YIR/(2.-2.*IDOTR)**.5
      ZN(NLOW)=ZIR/(2.-2.*IDOTR)**.5
      IDOTN(NLOW)=-1.*L(NLOW)*XN(NLOW)-M(NLOW)*YN(NLOW)-N(NLOW)*ZN(NLOW)
      ANGLE(NLOW)=ACOS(IDOTN(NLOW))
C
C     CONVERT ANGLE TO DEGREES FROM RADIANS
      ANGLE(NLOW)=180.*ANGLE(NLOW)/PI
C
C     RETURN TO MAIN PROGRAM
C
   37 RETURN
      END
CMG1
```

```
C=================================================================
      SUBROUTINE PIERCE(NLOW,NHIGH,NCOUNT,PHEU,PHEL)
C
C     THIS SUBROUTINE CALCULATES THE COORDINATES FOR THE PIERCE POINT
C     GIVEN THE INTIAL Z-COORDINATE.  THIS SUBROUTINE ALSO CALCULATES
C     THE APPROXIMATE Z-COORDINATE OF EACH PIERCE POINT BY THE LAW OF
C     SINES.
C
C     VARIABLES SPECIFIC TO THIS SUBROUTINE:
C
C     AH-----DISTANCE FROM AIM POINT TO THE PIERCE POINT
C     DOTI---DOT PRODUCT OF THE I-VECTOR OF THE REFERENCE HELIOSTAT
C            AND THE I-VECTOR OF THE OTHER HELIOSTATS
C     PH-----DISTANCE FROM THE CENTER FACET TO THE PIERCE POINT
C     PSI----ANGLE BETWEEN THE I-VECTOR AND THE HORIZONTAL
C     THETA--ANGLE BETWEEN THE I-VECTOR OF THE REFERENCE HELIOSTAT
C            AND THE I-VECTOR OF THE OTHER HELIOSTATS WITH THE
C            AIM POINT AS THE VERTEX
C
C     COMMON AND DIMENSION THE VARIABLES
C
      COMMON/BLOCK1/XA(222),YA(222),ZA(222)
      COMMON/BLOCK6/XF(222),YF(222),ZF(222)
      COMMON/BLOCK10/DELZU,DELZL,DELYL
      COMMON/BLOCK2/XP(222),YP(222),ZP(222)
      COMMON/BLOCK5/PI,H1H2(222)
      COMMON/BLOCK3/XH(222),YH(222),ZH(222)
      COMMON/BLOCK11/HN,HP
      COMMON/BLOCK4/L,M,N,AP(222)
      REAL L(222),M(222),N(222)
      INTEGER HN(222),HP(222)
      DIMENSION PH(222),PSI(222),AH(222)
C
C     GIVEN THE INITIAL Z-COORDINATE CALCULATE THE X- AND
C     Y-COORDINATE OF THE PIERCE POINT FOR THE REFERENCE
C     HELIOSTAT
C
      IF(NCOUNT.GT.1) GO TO 975
      R1MXA = XA(1) - XP(1)
      R1MYA = YA(1) - YP(1)
      R1MZA = ZA(1) - ZP(1)
      RAMAG = SQRT(R1MXA**2. + R1MYA**2. + R1MZA**2.)
C
      R1MXA = R1MXA/RAMAG
      R1MYA = R1MYA/RAMAG
      R1MZA = R1MZA/RAMAG
      P1 = ((YF(1) - YP(1))*RAMAG)/ (YA(1)- YP(1))
      DELZU = ZP(1) - ZF(1) + P1 * (ZA(1) - ZP(1))/RAMAG
      WRITE(2,801) DELZU
801   FORMAT(5X,17HTARGET IS LOCATED, F10.5,'  METERS BELOW',
     1'  ZH(1) ON REDIRECTOR PLANE')
      ZH(1) = ZF(1) +DELZU
C
      PH(1)=(ZH(1)-ZP(1))/N(1)
      XH(1)=XP(1)+L(1)*PH(1)
      YH(1)=YP(1)+M(1)*PH(1)
C
C     INITIALIZE THE VARIABLE H1H2
C
      H1H2(1)=0.
C
C     CHECK IF ONLY ONE HELIOSTAT TO BE ANALYZED
C
      IF(NHIGH-NLOW.EQ.0) GO TO 35
C
```

```
C
      PSI(1)=ACOS(-1*M(1))
      AH(1)=AP(1)-PH(1)
C
C     USE DO LOOP TO CALCULATE THE PIERCE POINTS FOR THE REST
C     OF THE HELIOSTATS
C
      DO 16 I=NLOW+1, NHIGH
C
C
C
      R1MX = XA(I) - XP(I)
      R1MY = YA(I) - YP(I)
      R1MZ = ZA(I) - ZP(I)
C     R1MAG = SQRT(R1MX**2. + R1MY**2. + R1MZ**2.)
C     R1MZ = R1MZ/R1MAG
C
      R2MX = XF(I) - XP(I)
      R2MY = YF(I) - YP(I)
      R2MZ = ZF(I) - ZP(I)
C     R2MAG = SQRT(R2MX**2. + R2MY**2. + R2MZ**2.)
C     R2MZ = R2MZ/R2MAG
C
      RTEST = R1MZ - R2MZ
C     IF(RTEST.LT.0.0) GO TO 976
C     GO TO 977
C76   WRITE(2,978) I
C78   FORMAT(2X,17HTROUBLE IN PIERCE,//,10X,19HHELIOSTAT NUMBER = ,
C    1I5)
C     RTEST=-RTEST
C     WRITE(2,9788) I,RTEST
C788  FORMAT(2X,'ZA(',I4,') MUST BE INCREASED BY AT LEAST',F10.4,
C    1'METERS')
C     STOP
C
977   YH(I) = N(I)*YP(I)/M(I) - YF(1) * TAN(PHEU) + ZF(1) +
     1DELZU - ZP(I)
      YH(I) = YH(I)/((N(I)/M(I)) - TAN(PHEU))
      ZH(I) = ZP(I) + N(I) * (YH(I) - YP(I))/M(I)
      XH(I) = XP(I) + L(I) * (YH(I) - YP(I))/M(I)
      H1H2(I) = SQRT((XH(I) - XH(1))**2 + (YH(I) - YH(1))**2.
     *+ (ZH(I) - ZH(1))**2.)
C
  16  CONTINUE
      GO TO 35
C
 975  R1MXB = XA(NLOW) - XP(NLOW)
      R1MYB = YA(NLOW) - YP(NLOW)
      R1MZB = ZA(NLOW) - ZP(NLOW)
      PIOVR2 = PI/2.
      RBMAG = SQRT(R1MXB**2. + R1MYB**2. + R1MZB**2.)
      IF(PHEL.GT.PIOVR2) GO TO 579
C
      R1MXB = R1MXB/RBMAG
      R1MYB = R1MYB/RBMAG
      R1MZB = R1MZB/RBMAG
      P2 = (YF(NLOW) - YP(NLOW))*RBMAG / (YA(NLOW)- YP(NLOW))
      DELZL = ZF(NLOW) - ZP(NLOW) - P2 * (ZA(NLOW)- ZP(NLOW))
     1/RBMAG
      WRITE(2,802) DELZL, NLOW
802   FORMAT(5X,17HTARGET IS LOCATED, F10.5,'  METERS ABOVE',
     1'  ZH(',I3,') ON REDIRECTOR PLANE')
C
C
C
C
      ZH(NLOW) = ZP(NLOW) + (ZA(NLOW)-ZP(NLOW))*P2/RBMAG
      PH(NLOW)=(ZH(NLOW)-ZP(NLOW))/N(NLOW)
```

```
 579  P2=(ZF(NLOW) - ZP(NLOW))*RBMAG/(ZA(NLOW) - ZP(NLOW))
      DELYL = YF(NLOW)- YP(NLOW)-P2*(YA(NLOW)-YP(NLOW))/RBMAG
      WRITE(2,803) DELYL,NLOW
803   FORMAT(5X,17HTARGET IS LOCATED,F10.5," METERS NORTH OF ",
     1" YH(",I4,") ON REDIRECTOR PLANE")
      ZH(NLOW) = ZF(NLOW)
      YH(NLOW) = YF(NLOW) -DELYL
      XH(NLOW) = XP(NLOW) + (XA(NLOW)-XP(NLOW))*P2/RBMAG
      PH(NLOW) = (ZH(NLOW) - ZP(NLOW))/N(NLOW)
C
C     INITIALIZE THE VARIABLE H1H2
C
 578  H1H2(NLOW)=0.
C
C     CHECK IF ONLY ONE HELIOSTAT TO BE ANALYZED
C
      IF(NHIGH-NLOW.EQ.0) GO TO 35
C
C     CALCULATE PSI AND AH FOR THE REFERENCE HELIOSTAT
C
      PSI(NLOW)=ACOS(-1*M(NLOW))
      AH(NLOW)=AP(NLOW)-PH(NLOW)
C
C     USE DO LOOP TO CALCULATE THE PIERCE POINTS FOR THE REST
C     OF THE HELIOSTATS
C
      DO 166 II=NLOW+1, NHIGH
C
C
C
      R1MX = XA(II) - XP(II)
      R1MY = YA(II) - YP(II)
      R1MZ = ZA(II) - ZP(II)
C     R1MAG = SQRT(R1MX**2. + R1MY**2. + R1MZ**2.)
C     R1MZ = R1MZ/R1MAG
C
      R2MX = XF(II) - XP(II)
      R2MY = YF(II) - YP(II)
      R2MZ = ZF(II) - ZP(II)
C     R2MAG = SQRT(R2MX**2. + R2MY**2. + R2MZ**2.)
C     R2MZ = R2MZ/R2MAG
C
      RTEST = R2MZ - R1MZ
C     IF(RTEST.LT.0.0) GO TO 967
C     GO TO 968
C67   WRITE(2,969) II
C69   FORMAT(2X,17HTROUBLE IN PIERCE,//,10X,19HHELIOSTAT NUMBER = ,
C    1I5)
C     RTEST=-RTEST
C     WRITE(2,9699) II,RTEST
C699  FORMAT(2X,'ZA(',I4,') MUST BE DECREASED BY AT LEAST',F10.4,
C    1'METERS')
C     STOP
C
C
 968  IF(PHEL.GT.PIOVR2) GO TO 869
      YH(II) = N(II)*YP(II)/M(II) + YF(NLOW) * TAN(PHEL) + ZF(NLOW)
     1- DELZL - ZP(II)
      GO TO 868
 869  YH(II) = N(II)*YP(II)/M(II) + ZH(NLOW) + YH(NLOW)*TAN(PHEL)
     1- ZP(II)
 868  YH(II) = YH(II)/((N(II)/M(II)) + TAN(PHEL))
      ZH(II) = ZP(II) + N(II) * (YH(II) - YP(II))/M(II)
      XH(II) = XP(II) + L(II) * (YH(II) - YP(II))/M(II)
      H1H2(II) = SQRT((XH(II)-XH(NLOW))**2 + (YH(II)-YH(NLOW))**2
     1 + (ZH(II) - ZH(NLOW))**2)
C
 166  CONTINUE
```

```
      SUBROUTINE POINTS(NLOW,NHIGH)
C
C     THIS SUBROUTINE CALCULATES THE X,Y,Z COORDINATES OF THE CENTER
C     OF THE CENTER FACET OF EACH HELIOSTAT GIVEN THE AZIMUTH AND ELE-
C     VATION OF THE SUN; THE AIM POINT; AND THE FOUNDATION POINT OF
C     EACH HELIOSTAT.
C
C     VARIABLES SPECIFIC TO THE SUBROUTINE:
C
C     A--------DIRECTION COSINE IN THE I DIRECTION OF THE CENTRAL RAY
C              FROM HELIOSTAT TO THE SUN
C     1/ALPHA--MAGNITUDE OF NORMAL VECTOR FROM HELIOSTAT
C     B--------DIRECTION COSINE IN THE J DIRECTION OF THE CENTRAL RAY
C              FROM HELIOSTAT TO THE SUN
C     C--------DIRECTION COSINE IN THE K DIRECTION OF THE CENTRAL RAY
C              FROM HELIOSTAT TO THE SUN
C     DELTA----ERROR CRITERIA
C     ERRTOL---ERROR TOLERANCE
C     PHET-----AZIMUTH ANGLE OF THE HELIOSTAT
C     THE------ELEVATION ANGLE OF THE HELIOSTAT
C
C     COMMON AND DIMENSION THE VARIABLES
C
      COMMON/BLOCK1/XA(222),YA(222),ZA(222)
      COMMON/BLOCK2/XP(222),YP(222),ZP(222)
      COMMON/BLOCK9/FX(222),FY(222),FZ(222)
      COMMON/BLOCK8/AZ,EL
      COMMON/BLOCK5/PI,H1H2(222)
      DIMENSION X(222,20),Y(222,20),Z(222,20)
C
C     INITIALIZE THE ERROR TOLERANCE
C
      DATA ERRTOL/1.0E-4/
C
C     CALCULATE THE DIRECTION COSINES OF THE CENTRAL RAY
C
      A=COS(EL)*COS(AZ)
      B=COS(EL)*SIN(AZ)
      C=SIN(EL)
C
C     USE DO LOOP TO ASSIGN THE FIRST APPROXIMATION OF THE
C     COORDINATES TO THE CENTER FACET
C
      DO 90 I=NLOW,NHIGH
      X(I,1)=FX(I)
      Y(I,1)=FY(I)
      Z(I,1)=FZ(I)+3.987
C
C     USE DO LOOP TO CALCULATE THE ITH APPROXIMATION OF THE
C     COORDINATES TO THE CENTER FACET AND CHECK IF NEW
C     APPROXIMATIONS MEET THE ERROR TOLERANCE
C
      DO 95 J=2,20
      THE=(ZA(I)-Z(I,J-1))
      THE=THE/(((X(I,J-1)-XA(I))**2.+(Y(I,J-1)-YA(I))**2.)**.5)
      THE=ATAN(THE)
      PHETA = YA(I) - Y(I,J-1)
      PHET1 = ABS(PHETA)
      PHETB = XA(I) - X(I,J-1)
      PHET2 = ABS(PHETB)
      IF(PHET2.LT.1.E-30) GO TO 9677
      PHET = ATAN(PHET1/PHET2)
      IF(PHETA.LE.0.0.AND.PHETB.GT.0.0) PHET = 2.*PI -PHET
      IF(PHETA.LE.0.0.AND.PHETB.LT.0.0) PHET = PHET +PI
      IF(PHETA.GT.0.0) GO TO 9666
      GO TO 9678
9677  PHET = 3. * PI/2.
9678  CONTINUE
```

```
C
      ALPHA=A*COS(THE)*COS(PHET)+B*COS(THE)*SIN(PHET)+C*SIN(THE)
      ALPHA=2.+2.*ALPHA
      ALPHA=(1/ALPHA)**0.5
      X(I,J)=(A+COS(THE)*COS(PHET))*ALPHA*0.318+FX(I)
      Y(I,J)=(B+COS(THE)*SIN(PHET))*ALPHA*0.318+FY(I)
      Z(I,J)=(C+SIN(THE))*ALPHA*0.318+FZ(I)+3.987
      DELTA=(X(I,J)-X(I,J-1))**2.+(Y(I,J)-Y(I,J-1))**2.
      DELTA=(DELTA+(Z(I,J)-Z(I,J-1))**2.)**.5
      NO=J
      IF(DELTA.LE.ERRTOL)GO TO 96
   95 CONTINUE
C
C     ASSIGN THE COORDINATES OF THE CENTER FACET THE FINAL
C     APPROXIMATION
C
   96 XP(I)=X(I,NO)
      YP(I)=Y(I,NO)
      ZP(I)=Z(I,NO)
C     WRITE(2,960) DELTA,I
C 960 FORMAT(5X,F10.7,2X,I5)
      GO TO 90
9666  WRITE(2,9667)
9667  FORMAT(10X,17HTROUBLE IN POINTS)
      STOP
   90 CONTINUE
C
C     RETURN TO MAIN PROGRAM
C
      RETURN
      END
CMG1
```

```
C=================================================================
      SUBROUTINE SORTPT(NLOW,NHIGH)
C
C     THIS SUBROUTINE SORTS THE INPUT IN ORDER THAT THE INDEPENDENT
C     VARIABLES ARE IN THE PROPER SEQUENTIAL ORDER SO THAT THE
C     POSITION-DEPENDENT VARIABLES CAN BE PROPERLY CALCULATED.
C
C     VARIABLES SPECIFIC TO THIS SUBROUTINE:
C
C     CTEMP---TEMPORARY STORAGE IN ORDER TO SWITCH THE ORDER OF THE
C             VALUES IN THE C ARRAY
C     FXTEMP--TEMPORARY STORAGE IN ORDER TO SWITCH THE ORDER OF THE
C             VALUES IN THE FX ARRAY
C     FYTEMP--TEMPORARY STORAGE IN ORDER TO SWITCH THE ORDER OF THE
C             VALUES IN THE FY ARRAY
C     FZTEMP--TEMPORARY STORAGE IN ORDER TO SWITCH THE ORDER OF THE
C             VALUES IN THE FZ ARRAY
C     ITEMP---TEMPORARY STORAGE IN ORDER TO SWITCH THE ORDER OF THE
C             VALUES IN THE HN ARRAY
C     NR------ARRAY OF THE NUMBER OF HELIOSTATS INPUTTED IN EACH ROW
C     NR1-----COUNTER OF THE NUMBER OF HELIOSTATS INPUTTED
C     RIC-----DUMMY VARIABLE TO REPRESENT THE ROW NUMBER FOR THE SORT-
C             ING BY ROWS
C     R1TEMP--DUMMY VARIABLE TO INCREMENT THE VARIABLE RIC TO CHECK
C             EVERY ROW
C     RTEMP---TEMPORARY STORAGE IN ORDER TO SWITCH THE ORDER OF THE
C             VALUES IN THE R ARRAY
C     XATEMP--TEMPORARY STORAGE IN ORDER TO SWITCH THE ORDER OF THE
C             VALUES IN THE XA ARRAY
C     XFTEMP--TEMPORARY STORAGE IN ORDER TO SWITCH THE ORDER OF THE
C             VALUES IN THE XF ARRAY
C     YATEMP--TEMPORARY STORAGE IN ORDER TO SWITCH THE ORDER OF THE
C             VALUES IN THE YA ARRAY
C     YFTEMP--TEMPORARY STORAGE IN ORDER TO SWITCH THE ORDER OF THE
C             VALUES IN THE YF ARRAY
C     ZATEMP--TEMPORARY STORAGE IN ORDER TO SWITCH THE ORDER OF THE
C             VALUES IN THE ZA ARRAY
C     ZFTEMP--TEMPORARY STORAGE IN ORDER TO SWITCH THE ORDER OF THE
C             VALUES IN THE ZF ARRAY
C
C     COMMON AND DIMENSION THE VARIABLES
C
      COMMON/BLOCK1/XA(222),YA(222),ZA(222)
      COMMON/BLOCK6/XF(222),YF(222),ZF(222)
      COMMON/BLOCK9/FX(222),FY(222),FZ(222)
      COMMON/BLOCK11/HN,HP
      INTEGER HN(222),HP(222)
      INTEGER TEMP
      DIMENSION NR(222)
C
C     USE DO LOOP TO SEARCH THE HN ARRAY FOR THE HELIOSTAT
C     NUMBERS INPUTTED IN THE HP ARRAY, THEN ALSO TRANSFER THE
C     R,C,FX,FY,FZ ARRAYS SO THAT THE ARRAYS ARE IN THE ORDER
C     OF THE USER INPUT VALUES IN THE DATA FILE
C
```

```
      DO 60 I=NLOW,NHIGH
      TEMP=HP(I)
      DO 61 N=1,222
      IF(TEMP.EQ.HN(N))GO TO 62
      GO TO 61
   62 ITEMP=HN(I)
      HN(I)=HN(N)
      HN(N)=ITEMP
      FXTEMP=FX(I)
      FX(I)=FX(N)
      FX(N)=FXTEMP
      FYTEMP=FY(I)
      FY(I)=FY(N)
      FY(N)=FYTEMP
      FZTEMP=FZ(I)
      FZ(I)=FZ(N)
      FZ(N)=FZTEMP
      GO TO 60
   61 CONTINUE
   60 CONTINUE
      RETURN
      END
CMG1
```

```
C=====================================================================
      SUBROUTINE SUN(DAY,HOUR,AZ,EL)
C
C     THIS SUBROUTINE WAS TAKEN FROM THE HELIOS CODE.  IT CONTAINS
C     THE CRTF LATITUDE AND LONGITUDE IN THE CALCULATION. ANY QUESTIONS
C     SHOULD BE REFERRED TO THE DOCUMENTATION OF THE HELIOS PROGRAM.
C     THIS SUBROUTINE RETURNS THE AZIMUTH AZ AND ELEVTION EL OF THE
C     SUN IN RADIANS.  THE AZIMUTH IS MEASURED COUNTER-CLOCKWIZE FROM
C     THE EAST.  INPUT IS THE DAY OF YEAR (DAY=80 FOR MARCH 21) AND
C     TIME OF DAY.  HOUR=0. FOR SOLAR NOON WITH NEGATIVE BEING
C     MORNING AND POSITIVE BEING EVENING.  HOUR IS IN HOURS.
C
      PI=ATAN(1.)*4.
      CON=PI/180.
      PHIL=35.0517*CON
      DELS=23.45229*SIN(2.*PI*(DAY-80.)/365.)*CON
      HS=15.*HOUR*CON
      EL=SIN(PHIL)*SIN(DELS)+COS(DELS)*COS(PHIL)*COS(HS)
      EL=PI/2.-ACOS(EL)
      AZ=SIN(DELS)*COS(PHIL)-COS(DELS)*SIN(PHIL)*COS(HS)
      AZ=ATAN2(AZ,-COS(DELS)*SIN(HS))
      RETURN
      END
```

APPENDIX B

Computer Code CONE

File - CONE:

Modifications to HELIOS Code

to

Predict Flux on a Nose Cone

```
*D,BASKET.4,42
C**************************************************************************
C                                                                         *
C                 DATA FILE IS  CONED                                     *
C                                                                         *
C       ROUTINE DETERMINES WHICH BASKET THE REDIRECTOR DIRECTS            *
C       ENERGY INTO. THE RECEIVER IS A CONE DESIGNED BY                   *
C       APPLIED PHYSICS LAB                                               *
C                                                                         *
C       FOR THIS UPDATE ITARSH = 7,IAPT = 0,KORD=1, AND IOPT = 4 OR 5     *
C                                                                         *
C       IF BLOCKING IS TO BE INCLUDED , APERT AND APERTV MUST             *
C                           BE MODIFIED                                   *
C                                                                         *
C       REDIRECTOR FACETS ARE ASSUMED FLAT. IF FACETS HAVE CURVATURE      *
C                                                                         *
C                      POWREC SHOULD BE MODIFIED                          *
C                                                                         *
C                                                                         *
C**************************************************************************
C
C
C
       IF(ABS(XI).GT.100.0) GO TO 10
       PI=4.*ATAN(1.)
C*****************************************************************************
C                             INPUT HERE                                     *
C                                                                            *
C       BASKETS MADE LARGER THAN RECEIVER SO BASKET MIDPOINTS                *
C       CORRESPOND TO THE 121 TARGET POINTS IN THE RECEIVER.                 *
C                                                                            *
C       READ POSITIONS FOR FRONT (XF,YF,ZF) AND BACK (XB,YB,ZB)              *
C                                                                            *
C                   OF CONE IN TOWER COORDINATES                             *
C                                                                            *
C                                                                            *
C*****************************************************************************
        XF=0.0
        YF=7.335
        ZF=50.939
        XB=0.0
        YB=7.025
        ZB=50.461
C
C       END OF INPUT
C
```

```
          ALEN=SQRT((XF-XB)**2+(YF-YB)**2+(ZF-ZB)**2)
             XCONE=XI-XB
             YCONE=YI-YB
             ZCONE=ZI-ZB
          ALL=SQRT((XF-XB)**2+(YF-YB)**2)
          AL=ALEN
              V1XU=(XF-XB)/AL
              V1YU=(YF-YB)/AL
              V1ZU=(ZF-ZB)/AL
              V1MAG=SQRT(V1XU**2+V1YU**2+V1ZU**2)
              V1XU=V1XU/V1MAG
              V1YU=V1YU/V1MAG
              V1ZU=V1ZU/V1MAG
          V2XU=(YF-YB)/ALL
          V2YU=-(XF-XB)/ALL
          V2ZU=0.
          V2MAG=SQRT(V2XU**2+V2YU**2)
          V2XU=V2XU/V2MAG
          V2YU=V2YU/V2MAG
             V3XU=V2YU*V1ZU-V2ZU*V1YU
             V3YU=V2ZU*V1XU-V2XU*V1ZU
             V3ZU=V2XU*V1YU-V2YU*V1XU
             V3MAG=SQRT(V3XU**2+V3YU**2+V3ZU**2)
             V3XU=V3XU/V3MAG
             V3YU=V3YU/V3MAG
             V3ZU=V3ZU/V3MAG
             AXPOS=XCONE*V2XU+YCONE*V2YU+ZCONE*V2ZU
             AYPOS=XCONE*V3XU+YCONE*V3YU+ZCONE*V3ZU
             AZPOS=XCONE*V1XU+YCONE*V1YU+ZCONE*V1ZU
          IF(AZPOS.LT.(-ALEN/20.)) GO TO 10
          A1=ABS(AXPOS)
          A2=ABS(AYPOS)
             IF(A1.LT.1.E-30.AND.AYPOS.GT.0.0) GO TO 28
             IF(A1.LT.1.E-30.AND.AYPOS.LT.0.0) GO TO 27
          ANGLE=ATAN(A2/A1)
          GO TO 299
C
28        ANGLE=PI/2.
          GO TO 29
27        ANGLE=1.5*PI
          GO TO 29
299       IF(AXPOS.GE.1.E-30.AND.AYPOS.LT.0.0) ANGLE=2.*PI-ANGLE
          IF(AXPOS.LE.(-1.E-30).AND.AYPOS.GE.0.0) ANGLE=PI-ANGLE
          IF(AXPOS.LE.(-1.E-30).AND.AYPOS.LT.0.0)ANGLE=PI+ANGLE
29        IBASX=0
          X=-ALEN/20.
30        IBASX=IBASX+1
          X=X+ALEN/10.
          IF(AZPOS.LT.X) GO TO 40
          GO TO 30
40        IBASY=0
          Y=-PI/10.
50        Y=Y+2.*PI/10.
          IBASY=IBASY+1
          IF(ANGLE.LT.Y) GO TO 60
          GO TO 50
60        IF(IBASX.GT.11.OR.IBASY.GT.11) GO TO 10
          RETURN
10        IBASX=-1
         IBASY=-1
         RETURN
         END
```

```
C
C
*D,USTG1.31,143
C***********************************************************************
C                        INPUT HERE                                    *
C                                                                      *
C                                                                      *
C                       REDIRECTOR PANELS                              *
C                                                                      *
C      THE CENTER POINT (XTA,YTA,ZTA) AND NORMAL (ANX,ANY,ANZ) FOR EACH *
C               FACET ON THE REDIRECTOR IS ENTERED HERE                *
C                                                                      *
C        THE X AND Z DIMENSIONS FOR THE REDIRECTOR ARE                 *
C                        ENTERED HERE                                  *
C                                                                      *
C        AXEXT IS X-DIMENSION FOR ONE REDIRECTOR FACET                 *
C                                                                      *
C        AZEXT IS Z-DIMENSION FOR ONE REDIRECTOR FACET                 *
C                                                                      *
C                                                                      *
C                                                                      *
C***********************************************************************
       AXEXT=0.3048
       AZEXT=0.3048
       IF(ISECT.LE.0.OR.ISECT.GT.IRECP) GO TO 155
      NR=(NTAG-1)/IXPTS+1
      NTU=(NR-1)*IXPTS
      NCOL=NTAG-NTU
      GO TO (10,20,30,40,50,60,70,80,90,100,110,120,130,140,
     *150,160),ISECT
C
C
C     DIMENSIONS GIVEN BELOW HAVE UNITS OF METERS  } The number of statement
C                                                  } numbers must be equal to
C                                                  } the number of facets
C
10    XTA= 0.381      }
      YTA= 6.363      }
      ZTA=51.195      }    Data for
      ANX=-0.3216     }    Redirector
      ANY= 0.8449     }    Facet #1
      ANZ=-0.4275     }
      GO TO 11
C
20    XTA= 0.381      }
      YTA= 8.14861    }
      ZTA=50.6758     }    Data for
      ANX=-0.3470     }    Redirector
      ANY= 0.4047     }    Facet #2
      ANZ=-0.8437     }
      GO TO 11
C
30    XTA=-0.381
      YTA= 8.14861
      ZTA=50.6758
      ANX= 0.4076
      ANY= 0.3832
      ANZ=-0.8289
      GO TO 11
C
40    XTA=-1.143
      YTA= 8.14861
      ZTA=50.6758
      ANX= 0.7290
      ANY= 0.3139
      ANZ=-0.6083
      GO TO 11
```

```
C
50    XTA= 1.143
      YTA= 7.95139
      ZTA=49.93976
      ANX=-0.8467
      ANY= 0.3636
      ANZ=-0.3883
      GO TO 11
C
60    XTA= 0.381
      YTA= 7.95139
      ZTA=49.93976
      ANX=-0.5634
      ANY= 0.5412
      ANZ=-0.6243
      GO TO 11
C
70    XTA=-0.381
      YTA= 7.95139
      ZTA=49.93976
      ANX= 0.5889
      ANY= 0.5129
      ANZ=-0.6252
      GO TO 11
C
80    XTA=-1.143
      YTA= 7.95139
      ZTA=49.93976
      ANX= 0.8483
      ANY= 0.3656
      ANZ=-0.3830
      GO TO 11
C
90    XTA= 1.41
      YTA= 7.75
      ZTA=49.27
      ANX= 0.2678
      ANY= 0.7205
      ANZ= 0.6396
      GO TO 11
C
100   XTA= 0.38
      YTA= 7.75
      ZTA=49.27
      ANX= 0.0845
      ANY= 0.8043
      ANZ= 0.5882
      GO TO 11
C
110   XTA=-0.38
      YTA= 7.75
      ZTA=49.27
      ANX= 0.1735
      ANY= 0.8068
      ANZ= 0.5648
      GO TO 11
C
120   XTA=-1.14
      YTA= 7.75
      ZTA=49.27
      ANX= 0.1735
      ANY= 0.8068
      ANZ= 0.5648
      GO TO 11
```

```
C
130    XTA= 1.14
       YTA= 7.95
       ZTA=48.54
       ANX= 0.2678
       ANY= 0.7205
       ANZ= 0.6396
       GO TO 11
C
140    XTA= 0.38
       YTA= 7.95
       ZTA=48.54
       ANX= 0.1658
       ANY= 0.7509
       ANZ= 0.6392
       GO TO 11
C
150    XTA=-0.38
       YTA= 7.95
       ZTA=48.54
       ANX=-0.2273
       ANY= 0.7375
       ANZ= 0.6359
       GO TO 11
C
160    XTA=-1.14
       YTA= 7.95
       ZTA=48.54
       ANX=-0.2756
       ANY= 0.6803
       ANZ= 0.6791
       GO TO 11
C

11     ASQ=(ANX*ANX+ANY*ANY)**0.5
       E1X=ANY/ASQ
       E1Y=-ANX/ASQ
       E2X=E1Y*ANZ
       E2Y=-E1X*ANZ
       E2Z=-ANX*E1Y+E1X*ANY
       DX=AXEXT/FLOAT(IXPTS-1)
       DZ=AZEXT/FLOAT(IYPTS-1)
       AFLX=FLOAT(IXPTS-1)*(DX/2.)
       AFLY=FLOAT(IYPTS-1)*(DZ/2.)
       XA=XTA+AFLX*E1X+AFLY*E2X
       YA=YTA+AFLX*E1Y+AFLY*E2Y
       ZA=ZTA+AFLY*E2Z
        AFCOL=FLOAT(NCOL-1)*DX
       AFRO=FLOAT(NR-1)*DZ
       XTA=(XA+AFCOL*(-E1X)+AFRO*(-E2X))
       YTA=(YA+AFCOL*(-E1Y)+AFRO*(-E2Y))
       ZTA=(ZA+AFRO*(-E2Z))
135    VMT(1)=ANX
       VMT(2)=ANY
       VMT(3)=ANZ
       RETURN
155    WRITE(NOUT,99999)
       STOP 111
C
99999 FORMAT(2X,50HSTOP IN USERTG, USER DEFINED TARGET SURFACE ERROR.)
       END
```

```
*D,RAREC.20,59
C***********************************************************************
C                               INPUT HERE                             *
C      READ POSITIONS FOR FRONT (XF,YF,ZF) AND BACK (XB,YB,ZB)          *
C                                                                      *
C                   OF CONE IN TOWER COORDINATES                       *
C                                                                      *
C             RADIUS OF CYLINDER BASE IS RB                            *
C             LENGTH OF CYLINDER IS ALCYL                              *
C             RA IS SURFACE AREA OF CYLINDER                           *
C             SL IS SLOPE                                              *
C                                                                      *
C        THE X AND Z DIMENSIONS FOR THE REDIRECTOR ARE                 *
C                      ENTERED HERE                                    *
C                                                                      *
C        AXEXT IS X-DIMENSION FOR ONE REDIRECTOR FACET                 *
C                                                                      *
C        AZEXT IS Z-DIMENSION FOR ONE REDIRECTOR FACET                 *
C                                                                      *
C                                                                      *
C                                                                      *
C***********************************************************************
      RB=0.1143
      SL=-0.1763
      AXEXT=0.3048
      AZEXT=0.3048
C  COMMENTS FOR SL
C
        XF=0.0
        YF=7.335
        ZF=50.939
        XB=0.0
        YB=7.025
        ZB=50.461
C
C       END OF INPUT
C
       ALCYL=SQRT((XF-XB)**2+(YF-YB)**2+(ZF-ZB)**2)
      THET=ATAN(SL)
      PI=4.*ATAN(1.)
C
C     RAREA IS THE TOTAL SURFACE AREA OF EACH REDIRECTOR FACET
C     RA IS THE TOTAL SURFACE AREA OF CONE
C
      RAREA=AXEXT* A * AZEXT
      RA=2.*PI*(RB+SL*ALCYL*0.5)*(ALCYL+ALCYL/10.)/COS(THET)
      RAREA=RAREA/RA
      RETURN
      END
```

```
*D,POWREC.9,35
C***********************************************************************
C                             INPUT HERE                                *
C                                                                       *
C        THE X AND Z DIMENSIONS FOR THE REDIRECTOR ARE                  *
C                      ENTERED HERE                                     *
C                                                                       *
C        AXEXT IS X-DIMENSION FOR ONE REDIRECTOR FACET                  *
C                                                                       *
C        AZEXT IS Z-DIMENSION FOR ONE REDIRECTOR FACET                  *
C                                                                       *
C                                                                       *
C***********************************************************************
      DIMENSION RECOP(121,16),HITE(11,11)
       DO 120 ISECT=1,IRECP
C
C      ENTER INPUT HERE
C
       AXEXT=0.3048
       AZEXT=0.3048
C
C      END OF INPUT
C
       DX=AXEXT/FLOAT(IXPTS-1)
       DZ=AZEXT/FLOAT(IYPTS-1)
*D,FACETC.16
     *YTA,ZTA,NTAG1,XT0,YT0,ZT0,BASK(11,11,16),RECN(3),BASKM
*D,FACETC.13
      COMMON/NWRAYS/NWRC(16,121),NWRE(16,11,11),IBASX,IBASY,RAREA,
*D,PHIC.27
     *YTA,ZTA,NTAG1,XT0,YT0,ZT0,BASK(11,11,16),RECN(3),BASKM
*D,C.45
     *YTA,ZTA,NTAG1,XT0,YT0,ZT0,BASK(11,11,16),RECN(3),BASKM
*D,C.56
     *RECD(3),RECOP(121,16),PDT(121),TPDT(3,121),HITE(11,11),
*D,C.38
      COMMON/NWRAYS/NWRC(16,121),NWRE(16,11,11),IBASX,IBASY,RAREA,
*D,C.74
         DO 30 K=1,IRECP
*D,C.79
      DO 70 I1=1,IRECP
*D,C.85
      DO 100 I1=1,IRECP
*D,COORD.21,25
10    PI=4.*ATAN(1.)
C******************************************************************
C                                                                 *
C                          INPUT HERE                             *
C                                                                 *
C                 ALEN IS LENGTH OF CYLINDER                      *
C                                                                 *
C                                                                 *
C******************************************************************
        XF=0.0
        YF=7.335
        ZF=50.939
        XB=0.0
        YB=7.025
        ZB=50.461
C
C       END OF INPUT
C
```

```
          ALEN=SQRT((XF-XB)**2+(YF-YB)**2+(ZF-ZB)**2)
       DO 20 IAB=1,IXPTS
       XM(IAB)=ALEN*FLOAT(IAB-1)/10.
 20    CONTINUE
       DO 30 JAB=1,IYPTS
       YM(JAB)=FLOAT(JAB-1)*2.*PI/10.
*D,FACETC.160
       IF(IBASY.NE.1) GO TO 101
       BASK(IBASX,11,ISECT)=BASK(IBASX,11,ISECT)+
      *AXZ*CRE*RAREA*AER*BASKM
       NWRE(ISECT,IBASX,11)=NWRE(ISECT,IBASX,11)+1
       GO TO 100
101    IF(IBASY.NE.11) GO TO 100
       BASK(IBASX,1,ISECT)=BASK(IBASX,1,ISECT)+
      *AXZ*CRE*RAREA*AER*BASKM
       NWRE(ISECT,IBASX,1)=NWRE(ISECT,IBASX,1)+1
100    CONTINUE
*D,FACETC.150
C
*D,FACETC.275
C
*D,FACETC.281
        IF(IBASY.NE.1) GO TO 231
        BASK(IBASX,11,ISECT)=BASK(IBASX,11,ISECT)+
      * CRE*RAREA*BASKM*FACET
        NWRE(ISECT,IBASX,11)=NWRE(ISECT,IBASX,11)+1
        RETURN
231     IF(IBASY.NE.11) RETURN
        BASK(IBASX,1,ISECT)=BASK(IBASX,1,ISECT)+
      * CRE*RAREA*BASKM*FACET
        NWRE(ISECT,IBASX,1)=NWRE(ISECT,IBASX,1)+1
        RETURN
*D,TCIRPC.7,41
        DIMENSION VFE(3),TV(3),UTV(3),NWRC(16,121),VMT(3),B(3),
      * RECN(3)
C***********************************************************************
C                                                                     *
C                            INPUT HERE                               *
C                                                                     *
C        ENTER POSITION FOR THE FRONT OF CONE (XF,YF,ZF) AND          *
C                    BACK OF CONE (XB,YB,ZB)                          *
C                                                                     *
C        RB IS RADIUS OF BASE OF CONE                                 *
C                                                                     *
C        SL IS SLOPE FOR CONE                                         *
C                                                                     *
C***********************************************************************
        RB=0.1143
        SL=-0.1763
        XF=0.0
        YF=7.335
        ZF=50.939
        XB=0.0
        YB=7.025
        ZB=50.461
C
C       END OF INPUT
C
```

```
      PI=4.*ATAN(1.)
      ALL=SQRT((XF-XB)**2+(YF-YB)**2)
      AL=SQRT((XF-XB)**2+(YF-YB)**2+(ZF-ZB)**2)
      DISTB=SQRT((XB-XTA)**2+(YB-YTA)**2+(ZB-ZTA)**2)
      DISTF=SQRT((XF-XTA)**2+(YF-YTA)**2+(ZF-ZTA)**2)
C
C
      RTEST1=DISTB
      IF(DISTF.GT.DISTB) RTEST1=DISTF
      RTEST1=2.0*RTEST1
      RTEST=RTEST1/20.
      DELRA=RB/5.0
      IF (RTEST.GT.0.05) RTEST=0.05
C
C
      TV(1)=XTA-VFE(1)
      TV(2)=YTA-VFE(2)
      TV(3)=ZTA-VFE(3)
      TVMAG=ABSA(TV)
      DO 10 K=1,3
       UTV(K)=-TV(K)/TVMAG
10    CONTINUE
      CO=ADOTB(UTV,VMT)
      NWRC(ISECT,NTAG1)=NWRC(ISECT,NTAG1)+1
      CDM=2.*CO
      DO 20 K=1,3
       B(K)=CDM*VMT(K)-UTV(K)
20    CONTINUE
      V1XU=(XF-XB)/AL
      V1YU=(YF-YB)/AL
      V1ZU=(ZF-ZB)/AL
      V1MAG=SQRT(V1XU**2+V1YU**2+V1ZU**2)
      V1XU=V1XU/V1MAG
      V1YU=V1YU/V1MAG
      V1ZU=V1ZU/V1MAG
      V2XU=(YF-YB)/ALL
      V2YU=-(XF-XB)/ALL
      V2ZU=0.0
      V2MAG=SQRT(V2XU**2+V2YU**2+V2ZU**2)
      V2XU=V2XU/V2MAG
      V2YU=V2YU/V2MAG
      V3XU=V2YU*V1ZU-V2ZU*V1YU
      V3YU=V2ZU*V1XU-V2XU*V1ZU
      V3ZU=V2XU*V1YU-V2YU*V1XU
      V3MAG=SQRT(V3XU**2+V3YU**2+V3ZU**2)
      V3XU=V3XU/V3MAG
      V3YU=V3YU/V3MAG
      V3ZU=V3ZU/V3MAG
      XCONE=XTA-XB
      YCONE=YTA-YB
      ZCONE=ZTA-ZB
```

```
C
C        ROUTINE TO DETERMINE IF RAY INTERSECTS FRONT OR REAR
C
C                          PLANE OF CONE
C
C
      RF=RB+SL*AL
      ADISTF=(XTA-XF)*V1XU+(YTA-YF)*V1YU+(ZTA-ZF)*V1ZU
      ADISTB=(XTA-XB)*V1XU+(YTA-YB)*V1YU+(ZTA-ZB)*V1ZU
      BDOT=B(1)*V1XU+B(2)*V1YU+B(3)*V1ZU
      IF(ABS(ADISTB).LE.1.E-30.AND.BDOT.LE.1.E-30) GO TO 98764
      IF(ABS(ADISTF).LE.1.E-30.AND.BDOT.LE.1.E-30) GO TO 98763
      IF(ADISTB.GT.0.0) GO TO 98765
      ADISTB=-ADISTB/BDOT
      XII=XTA+B(1)*ADISTB
      YII=YTA+B(2)*ADISTB
      ZII=ZTA+B(3)*ADISTB
      RBASX=XII-XB
      RBASY=YII-YB
      RBASZ=ZII-ZB
      RBAS=SQRT(RBASX**2+RBASY**2+RBASZ**2)
      IF(RBAS.GT.RB) GO TO 10007
C     WRITE(6,56789)
C     WRITE(6,10005) XII,YII,ZII
      GO TO 10006
98765 CONTINUE
      IF(ADISTF.LT.0.0) GO TO 10007
      ADISTF=ADISTF/(-BDOT)
      XII=XTA+ADISTF*B(1)
      YII=YTA+ADISTF*B(2)
      ZII=ZTA+ADISTF*B(3)
      RFRTX=XII-XF
      RFRTY=YII-YF
      RFRTZ=ZII-ZF
      RFRT=SQRT(RFRTX**2+RFRTY**2+RFRTZ**2)
      IF(RFRT.GT.RF) GO TO 10007
C     WRITE(6,56788)
C     WRITE(6,10005) XII,YII,ZII
      GO TO 10006
98764 XI=XB-B(1)*RB
      YI=YB-B(2)*RB
      ZI=ZB-B(3)*RB
       WRITE(6,78912) XTA,YTA,ZTA,XI,YI,ZI,B(1),B(2),B(3)
78912  FORMAT(2X,9F10.5)
      RETURN
98763 XI=XF-B(1)*RF
      YI=YF-B(2)*RF
      ZI=ZF-B(3)*RF
       WRITE(6,78912) XTA,YTA,ZTA,XI,YI,ZI,B(1),B(2),B(3)
      RETURN
```

```
56788 FORMAT(//,10X,34HRAY INTERSECTS FRONT PLANE OF CONE,//)
56789 FORMAT(//,10X,33HRAY INTERSECTS BACK PLANE OF CONE,//)
10007  NN=0
2      NN=NN+1
       IF(NN.GT.8) GO TO 3
       DELR=((-1.)**(NN+1))*(DELRA/(2.**NN))
1      RTESTA=RTEST
       RTEST=RTEST+DELR
       IF(ABS(RTEST).GT.RTEST1) GO TO 7
       CCX1=XCONE+RTEST*B(1)
       CCY1=YCONE+RTEST*B(2)
       CCZ1=ZCONE+RTEST*B(3)
       CCX2=XCONE+RTESTA*B(1)
       CCY2=YCONE+RTESTA*B(2)
       CCZ2=ZCONE+RTESTA*B(3)
       ZLEN1=CCX1*V1XU+CCY1*V1YU+CCZ1*V1ZU
       ZLEN2=CCX2*V1XU+CCY2*V1YU+CCZ2*V1ZU
       IF(ZLEN1.LT.0.0.AND.ZLEN2.LT.0.0) GO TO 1
       IF(ZLEN1.GT.AL.AND.ZLEN2.GT.AL) GO TO 1
       CCV21=CCX1*V2XU+CCY1*V2YU+CCZ1*V2ZU
       CCV31=CCX1*V3XU+CCY1*V3YU+CCZ1*V3ZU
       RAD1=SQRT(CCV21**2+CCV31**2)
       CCV22=CCX2*V2XU+CCY2*V2YU+CCZ2*V2ZU
       CCV32=CCX2*V3XU+CCY2*V3YU+CCZ2*V3ZU
       RAD2=SQRT(CCV22**2+CCV32**2)
       R1=RB+SL*ZLEN1
       R2=RB+SL*ZLEN2
       FUN1=RAD1-R1
       FUN2=RAD2-R2
       IF(((FUN1.GT.0.0).AND.(FUN2.GT.0.0)).OR.((FUN1.LT.0.0).AND.
     * (FUN2.LT.0.0))) GO TO 1
       IF(((FUN1.GE.0.0).AND.(FUN2.LE.0.0)).OR.((FUN1.LE.0.0).AND.
     * (FUN2.GE.0.0))) GO TO 2
3      RTEST=(RTEST+RTESTA)/2.
       XI=XTA+RTEST*B(1)
       YI=YTA+RTEST*B(2)
       ZI=ZTA+RTEST*B(3)
       WRITE(6,78912) XTA,YTA,ZTA,XI,YI,ZI,B(1),B(2),B(3)
       RETURN
7      XI=XTA+RTEST*B(1)
       YI=YTA+RTEST*B(2)
       ZI=ZTA+RTEST*B(3)
C       WRITE(6,10093)
C       WRITE(6,10001) XTA,YTA,ZTA,NTAG1
C       WRITE(6,10002) VMT(1),VMT(2),VMT(3)
C       WRITE(6,10003) B(1),B(2),B(3)
C       WRITE(6,10004) RECN(1),RECN(2),RECN(3)
C       WRITE(6,10005) XI,YI,ZI
10093 FORMAT(/,10X,48HRAY DOES NOT INTERSECT TARGET FOR XI,YI,ZI EQUAL)
10001   FORMAT(2X,15HPOINT ON REDIR.,3F12.5,I7)
10002   FORMAT(2X,16HNORMAL TO REDIR.,3F12.5)
10003   FORMAT(2X,8HB-VECTOR,3F12.5)
10004   FORMAT(2X,16HNORMAL TO TARGET,3F12.5)
10005   FORMAT(2X,18HINTERSECTION POINT,3F12.5,/)
10006  XI=-200.0
       YI=0.0
       ZI=0.0
       WRITE(6,78912) XTA,YTA,ZTA,XI,YI,ZI,B(1),B(2),B(3)
       RETURN
       END
```

```
*D,C.191
C***************************************************************************
C                              INPUT HERE                                  *
C                                                                          *
C       READ POSITIONS FOR FRONT (XF,YF,ZF) AND BACK (XB,YB,ZB)            *
C                                                                          *
C                   OF CONE IN TOWER COORDINATES                           *
C                                                                          *
C                                                                          *
C***************************************************************************
        XF=0.0
        YF=7.335
        ZF=50.939
        XB=0.0
        YB=7.025
        ZB=50.461
C
C       END OF INPUT
C
        AL=SQRT((XF-XB)**2+(YF-YB)**2+(ZF-ZB)**2)
        ALL=SQRT((XF-XB)**2+(YF-YB)**2)
        V1XU=(XF-XB)/AL
        V1YU=(YF-YB)/AL
        V1ZU=(ZF-ZB)/AL
        V1MAG=SQRT(V1XU**2+V1YU**2+V1ZU**2)
        V1XU=V1XU/V1MAG
        V1YU=V1YU/V1MAG
        V1ZU=V1ZU/V1MAG
        V2XU=(YF-YB)/ALL
        V2YU=-(XF-XB)/ALL
        V2ZU=0.0
        V2MAG=SQRT(V2XU**2+V2YU**2)
        V2XU=V2XU/V2MAG
        V2YU=V2YU/V2MAG
        V3XU=V2YU*V1ZU-V2ZU*V1YU
        V3YU=V2ZU*V1XU-V2XU*V1ZU
        V3ZU=V2XU*V1YU-V2YU*V1XU
        V3MAG=SQRT(V3XU**2+V3YU**2+V3ZU**2)
        V3XU=V3XU/V3MAG
        V3YU=V3YU/V3MAG
        V3ZU=V3ZU/V3MAG
*D,C.431,433
        XT0=XB+AL*V1XU/2.
        YT0=YB+AL*V1YU/2.
        ZT0=ZB+AL*V1ZU/2.
        RECD(1)=V2XU
        RECD(2)=V2YU
        RECD(3)=V2ZU
        ITARSH=2
```

```
*D,TARGE1.42,95
C*************************************************************************
C                          INPUT HERE                                    *
C                                                                        *
C      READ POSITIONS FOR FRONT (XF,YF,ZF) AND BACK (XB,YB,ZB)           *
C                                                                        *
C                   OF CONE IN TOWER COORDINATES                         *
C                                                                        *
C          RB IS RADIUS OF BASE OF CONE                                  *
C                                                                        *
C          SL IS SLOPE (R=RB+SL*Z OR R=RB-SL*Z)                          *
C                                                                        *
C         WHERE R IS CONE RADIUS AT AXIAL POSITION Z                     *
C                                                                        *
C                                                                        *
C*************************************************************************
40      RB=0.1143
        SL=-0.1763
        XB=0.0
        YB=7.025
        ZB=50.461
        XF=0.0
        YF=7.335
        ZF=50.939
C
C       END OF INPUT
C
        PI=4.*ATAN(1.)
        ALEN=SQRT((XF-XB)**2+(YF-YB)**2+(ZF-ZB)**2)
          V1XU=(XF-XB)/ALEN
          V1YU=(YF-YB)/ALEN
          V1ZU=(ZF-ZB)/ALEN
       VVV=V1XU*V1XU+V1YU*V1YU+V1ZU*V1ZU
       VVS=SQRT(VVV)
          V1XU=V1XU/VVS
          V1YU=V1YU/VVS
          V1ZU=V1ZU/VVS
        ALL=SQRT((XF-XB)**2+(YF-YB)**2)
           V2XU=(YF-YB)/ALL
           V2YU=-(XF-XB)/ALL
           V2ZU=0.0
        V2MAG=SQRT(V2XU**2+V2YU**2)
        V2XU=V2XU/V2MAG
        V2YU=V2YU/V2MAG
           V3XU=V2YU*V1ZU-V2ZU*V1YU
           V3YU=V2ZU*V1XU-V2XU*V1ZU
           V3ZU=V2XU*V1YU-V2YU*V1XU
        V3MAG=SQRT(V3XU**2+V3YU**2+V3ZU**2)
        V3XU=V3XU/V3MAG
        V3YU=V3YU/V3MAG
        V3ZU=V3ZU/V3MAG
           DX=ALEN/XDIV
           DZ=2.*PI/ZDIV
           XT=FLOAT(NCOL-1)*DX
           ZT=FLOAT(NR-1)*DZ
        CZT=COS(ZT)
        SZT=SIN(ZT)
        RAD=RB+SL*XT
           XTA=XB+XT*V1XU+(CZT*V2XU+SZT*V3XU)*RAD
           YTA=YB+XT*V1YU+(CZT*V2YU+SZT*V3YU)*RAD
           ZTA=ZB+XT*V1ZU+(CZT*V2ZU+SZT*V3ZU)*RAD
```

```
      THET=ATAN(SL)
      VHNEWX=CZT*V2XU+SZT*V3XU
      VHNEWY=CZT*V2YU+SZT*V3YU
      VHNEWZ=CZT*V2ZU+SZT*V3ZU
           CT=COS(THET)
           ST=SIN(THET)
      VSX=CT*V1XU+ST*VHNEWX
      VSY=CT*V1YU+ST*VHNEWY
      VSZ=CT*V1ZU+ST*VHNEWZ
          VOX=VSY*VHNEWZ-VSZ*VHNEWY
          VOY=VSZ*VHNEWX-VSX*VHNEWZ
          VOZ=VSX*VHNEWY-VSY*VHNEWX
      VMT(1)=VOY*VSZ-VOZ*VSY
      VMT(2)=VOZ*VSX-VOX*VSZ
      VMT(3)=VOX*VSY-VOY*VSX
      VMAGT=SQRT((VMT(1))**2+(VMT(2))**2+(VMT(3))**2)
C
      DO 11080 I=1,3
      VMT(I)=VMT(I)/VMAGT
11080   CONTINUE
      RETURN
C==========================================================
*D,C.490,493
430   CONTINUE
C==========================================================
*D,POWER.44
C***************************************************************************
C                            INPUT HERE                                    *
C                                                                          *
C      READ POSITIONS FOR FRONT (XF,YF,ZF) AND BACK (XB,YB,ZB)             *
C                                                                          *
C                    OF CONE IN TOWER COORDINATES                          *
C                                                                          *
C        RB IS RADIUS OF CONE BASE. SL IS SLOPE                            *
C                                                                          *
C        R=RB+SL*Z OR R=RB-SL*Z                                            *
C                                                                          *
C        WHERE R IS CONE RADIUS AT AXIAL POSITION Z                        *
C                                                                          *
C                                                                          *
C***************************************************************************
       XF=0.0
       YF=7.335
       ZF=50.939
       XB=0.0
       YB=7.025
       ZB=50.461
       RB=0.1143
       SL=-0.1763
C
C      END OF INPUT
C
```

```
      ALEN=SQRT((XF-XB)**2+(YF-YB)**2+(ZF-ZB)**2)
      AL=ALEN
      PI=4.*ATAN(1.)
      DX=AL/FLOAT(IXPTS-1)
      DZ=2.*PI/FLOAT(IYPTS-1)
      JP=JT+1
         AIM=RB+SL*FLOAT(IM-1)*DX
         AIP=RB+SL*FLOAT(IP-1)*DX
         AIT=RB+SL*FLOAT(IT-1)*DX
      HITE(IM,JM)=HITE(IM,JM)*AIM
      HITE(IP,JM)=HITE(IP,JM)*AIP
      HITE(IP,JP)=HITE(IP,JP)*AIP
      HITE(IM,JP)=HITE(IM,JP)*AIM
      HITE(IT,JM)=HITE(IT,JM)*AIT
      HITE(IP,JT)=HITE(IP,JT)*AIP
      HITE(IT,JP)=HITE(IT,JP)*AIT
      HITE(IM,JT)=HITE(IM,JT)*AIM
      HITE(IT,JT)=HITE(IT,JT)*AIT
*D,C.770
C**************************************************************************
C                              INPUT HERE                                *
C                                                                        *
C      READ POSITIONS FOR FRONT (XF,YF,ZF) AND BACK (XB,YB,ZB)           *
C                                                                        *
C                   OF CONE IN TOWER COORDINATES                         *
C                                                                        *
C        RB IS RADIUS OF CONE BASE. SL IS SLOPE                          *
C                                                                        *
C        R=RB+SL*Z OR R=RB-SL*Z                                          *
C                                                                        *
C        WHERE R IS CONE RADIUS AT AXIAL POSITION Z                      *
C                                                                        *
C                                                                        *
C**************************************************************************
       XF=0.0
       YF=7.335
       ZF=50.939
       XB=0.0
       YB=7.025
       ZB=50.461
       RB=0.1143
       SL=-0.1763
C
C      END OF INPUT
C
      PI=4.*ATAN(1.)
         ALEN=SQRT((XF-XB)**2+(YF-YB)**2+(ZF-ZB)**2)
         AL=ALEN
      DX=AL/FLOAT(IXPTS-1)
      DZ=2.*PI/FLOAT(IYPTS-1)
         JP=JT+1
      AIM=RB+SL*FLOAT(IM-1)*DX
      AIP=RB+SL*FLOAT(IP-1)*DX
      AIT=RB+SL*FLOAT(IT-1)*DX
         HITE(IM,JM)=HITE(IM,JM)*AIM
         HITE(IP,JM)=HITE(IP,JM)*AIP
         HITE(IP,JP)=HITE(IP,JP)*AIP
         HITE(IM,JP)=HITE(IM,JP)*AIM
         HITE(IT,JM)=HITE(IT,JM)*AIT
         HITE(IP,JT)=HITE(IP,JT)*AIP
         HITE(IT,JP)=HITE(IT,JP)*AIT
         HITE(IM,JT)=HITE(IM,JT)*AIM
         HITE(IT,JT)=HITE(IT,JT)*AIT
```

```
*D,C.782
         DO 9300 II=1,5
          IIT=2*II
          IIM=IIT-1
          IIP=IIT+1
         DO 9200 JJ=1,5
          JJT=2*JJ
          JJM=JJT-1
          JJP=JJT+1
        AIM=RB+SL*FLOAT(IIM-1)*DX
        AIP=RB+SL*FLOAT(IIP-1)*DX
        AIT=RB+SL*FLOAT(IIT-1)*DX
           HITE(IIM,JJM)=HITE(IIM,JJM)/AIM
           HITE(IIP,JJM)=HITE(IIP,JJM)/AIP
           HITE(IIP,JJP)=HITE(IIP,JJP)/AIP
           HITE(IIM,JJP)=HITE(IIM,JJP)/AIM
           HITE(IIT,JJM)=HITE(IIT,JJM)/AIT
           HITE(IIP,JJT)=HITE(IIP,JJT)/AIP
           HITE(IIT,JJP)=HITE(IIT,JJP)/AIT
           HITE(IIM,JJT)=HITE(IIM,JJT)/AIM
           HITE(IIT,JJT)=HITE(IIT,JJT)/AIT
9200    CONTINUE
9300    CONTINUE
          WRITE(NOUT,99956)
```

File - CONED:

Data File Submitted with CONE

```
GR1       *CRTF FULL* FIELD    * DATA    *FILE FOR * APL CONE*          *         *
          1         0          0         1         1         1          0         1
GR2      PARAMETROS DEL SOL
          2         0          7         6         1         1          1         6
   18
   0.00000 202.40000
    .00022 202.40000
    .00065 202.40000
    .00109 200.28000
    .00153 197.10000
    .00196 192.86000
    .00240 188.63000
    .00284 182.27000
    .00327 172.73000
    .00371 155.78000
    .00415 105.97000
    .00458 7.5030000
    .00502 .28300000
    .00545 .17600000
    .00589 .12100000
    .00633 .08800000
    .00676 .07400000
    .00720 .06600000
          1         1          2         0
0.00        .00120     .00120
.00085      .00080
GR3       *         *TARGET    *         *         *         *          *         *
          3        121         59        2         1         0         [10]       1
          2        [13]        0
-0.38      5.54       59.19                 # of aimpoints        IVMD-General
-0.38      5.54       59.19                                       direction of the
 0.000     7.720      52.320                                      normal to the
 0.91      7.980      52.460                                      target
 0.3       7.980      52.460
-0.3       7.980      52.460
-0.91      7.980      52.460   } Aimpoint Coordinates
 0.91      7.440      52.170
 0.3       7.440      52.170
-0.3       7.440      52.170
-0.91      7.440      52.170
 0.0       7.86       51.07
 0.0       7.58       51.07            Number of
-0.05      7.72       51.07        Redirector Facets
 0.05      7.72       51.07
65.33      34.96      1.00       1.00       0.00      8.050      49.704     60.96
 6.60      7.80
0.00     8.05     49.704  0.00     7.05     49.704  1.00       8.05       49.704
         11         11          7         [8]
GR4       *FACET    * DATA     *         *         *         *          *         *
          4         25         1         5         5         1          -1        0
REFLECT       0.79
GR5       *HELIOSTAT*DATA      *         *         *         *          *         *
          5        [242]      [22]       -2        0         8          0         1
  2  1      First heliostat     Total # of
              to evaluate      heliostats to evaluate
GR6       *TIME DATA*          *         *         *         *          *         *
          6         1          1         1
       [180.] Day of year
  [0.] Time of day
GR7       *ATMOSPH  *DATA      *         *         *         *          *
          7         1          1         3
```

```
MM HOH=     10.9
DATA TERMINATION
           -1
  40   1   7
  44   2   6
  59   1   3
  62   2   2
  65   2   2
 212   1   8
 227   2   9
 245   1   4
 248   2   5
 283   2  10
  85   2  12
 122   2  12
 126   2  12
 132   2  11
 268   2  13
 275   2  10
 304   2  13
 308   2  13
 314   2  11
  91   2  10
 144   2  11
```

Heliostat number;
prealignment number;
aimpoint number

APPENDIX C

Computer Code PLATE

File - PLATE:
Modifications to the HELIOS Code
to Predict Flux on a Flat
PLATE from Redirectors

```
*D,HELIOS.113
      COMMON/CMAX/ AXEXT, AZEXT
C*************************************************************************
C                                                                        *
C                                                                        *
C      THIS UPDATE IS FOR A FLAT PLATE BEING IRRADIATED                  *
C      BY ENERGY FROM THE HELIOSTAT FIELD WHICH IS REDIRECTED            *
C      ONTO THE RECEIVER BY A SERIES OF FLAT PANELS (IN THIS CASE        *
C      8 REDIRECTORS FACETS ARE USED)  IF MORE THAN 16 REDIRECTOR       *
C      FACETS ARE USED ALL DIMENSION STATEMENTS MUST BE CHANGED.         *
C                                                                        *
C                     DATA FILE IS BCRTFVD                               *
C                                                                        *
C       INPUT REQUIRED IN ROUTINES USTG1,INDATA,AND BASKET               *
C                                                                        *
C      THE ARRAYS BASK(11,11,IRECP),NWRC(IRECP,121),NWRE(IRECP,11,11).   *
C      RECOP(121,IRECP) MUST BE DIMENSIONED PROPERLY IN ALL COMMON       *
C      STATEMENTS                                                        *
C                                                                        *
C       THE PARAMETER IVMD IN GROUP 3 DATA MUST BE CORRECT. THIS         *
C       INPUT INDICATES THE GENERAL DIRECTION OF THE NORMAL TO           *
C       THE TARGET SURFACE                                               *
C                                                                        *
C                                                                        *
C*************************************************************************
*D,USTG1.16
      COMMON/CMAX/ AXEXT, AZEXT
*D,USTG1.31,143
     NR=(NTAG-1)/IXPTS+1
     NTU=(NR-1)*IXPTS
     NCOL=NTAG-NTU
C*************************************************************************
C                                                                        *
C                            INPUT                                       *
C                                                                        *
C        ISECT IS THE REDIRECTOR FACET BEING CONSIDERED                  *
C        IRECP IS THE NUMBER OF REDIRECTOR FACETS, VALUE                 *
C        READ IN DATA FILE (GROUP 3)                                     *
C        (NOTE THAT A NUMBERED STATEMENT IS REQUIRED FOR EACH FACET)     *
C                                                                        *
C        XTA IS THE X-COORDINATE OF THE CENTER OF EACH                   *
C        REDIRECTOR FACET (TOWER COORDINATE SYSTEM)                      *
C                                                                        *
C        YTA IS THE Y-COORDINATE OF THE CENTER OF EACH                   *
C        REDIRECTOR FACET                                                *
C                                                                        *
C        ZTA IS THE Z-COORDINATE OF THE CENTER OF EACH                   *
C        REDIRECTOR FACET                                                *
C                                                                        *
C        ANX, ANY AND ANZ ARE THE RESPECTIVE COMPONENTS OF THE           *
C        UNIT NORMAL (TOWER COORDINATE SYSTEM)                           *
C                                                                        *
C*************************************************************************
C
```

```
      IF(ISECT.LE.0.OR.ISECT.GT.IRECP) GO TO 1501
      GO TO (10,20,30,40,50,60,70,80),ISECT
C    1121,122,123,124),ISECT
C
10    XTA=0.91
      YTA=7.98
      ZTA=52.46
      ANX=-0.60
      ANY= 0.38
      ANZ=-0.71
      GO TO 1101
C
20    XTA=0.3
      YTA=7.98
      ZTA=52.46
      ANX=-0.22
      ANY= 0.38
      ANZ=-0.90
      GO TO 1101
C
30    XTA=-0.3
      YTA=7.98
      ZTA=52.46
      ANX= 0.39
      ANY= 0.34
      ANZ=-0.86
      GO TO 1101
C
40    XTA=-0.91
      YTA=7.98
      ZTA=52.46
      ANX= 0.650
      ANY= 0.35
      ANZ=-0.68
      GO TO 1101
C
50    XTA=0.91
      YTA=7.44
      ZTA=52.17
      ANX=-0.65
      ANY= 0.31
      ANZ=-0.69
      GO TO 1101
C
60    XTA=0.3
      YTA=7.44
      ZTA=52.17
      ANX=-0.24
      ANY= 0.49
      ANZ=-0.84
      GO TO 1101
C
70    XTA=-0.3
      YTA=7.44
      ZTA=52.17
      ANX= 0.25
      ANY= 0.43
      ANZ=-0.87
      GO TO 1101
```

The number of statement numbers must be the same as the number of redirector facets

Data for Redirector Facet #1

Data for Redirector Facet #2

*Note that the values for ANX, ANY and ANZ are calculated in REDIR

```
80      XTA=-0.91
        YTA=7.44
        ZTA=52.17
        ANX= 0.66
        ANY= 0.31
        ANZ=-0.68
        GO TO 1101
C
C0      XTA=0.91
C       YTA=6.97
C       ZTA=51.82
C       ANX=-0.6800
C       ANY=0.620
C       ANZ=-.400
C       GO TO 1101
C
C00     XTA=0.3
C       YTA=6.97
C       ZTA=51.82
C       ANX=-0.27
C       ANY=0.810
C       ANZ=-0.5600
C        GO TO 1101
C
C10     XTA=-0.3
CC      YTA=6.97
C       ZTA=51.82
C       ANX=0.350
C       ANY=0.780
C       ANZ=-0.5200
C        GO TO 1101
C
C20     XTA=-0.91
C       YTA=6.97
C       ZTA=51.82
C       ANX=0.70
C       ANY=0.61
C       ANZ=-0.3800
C        GO TO 1101
C
C21     XTA=0.91
C       YTA=6.54
C       ZTA=51.39
C       ANX=-0.650
C       ANY=0.72
C       ANZ=-0.2500
C        GO TO 1101
C
C22     XTA=0.3
C       YTA=6.54
C       ZTA=51.39
C       ANX=-0.290
C       ANY=0.92
C       ANZ=-0.2800
C        GO TO 1101
C
CC3     XTA=-0.3
C       YTA=6.54
C       ZTA=51.39
C       ANX=0.46
C       ANY=0.85
C       ANZ=-0.26
C        GO TO 1101
C
```

```
C24   XTA=-0.91
C     YTA=6.54
C     ZTA=51.39
C     ANX=0.53
C     ANY=0.81
C     ANZ=-0.25
C
1101  ASQ=(ANX*ANX+ANY*ANY)**0.5
       DX=AXEXT
       DZ=AZEXT
C***********************************************************************
C                                                                      *
C                   END OF INPUT                                       *
C                                                                      *
C                                                                      *
C                                                                      *
C***********************************************************************
      E1X=ANY/ASQ
      E1Y=-ANX/ASQ
      E2X=E1Y*ANZ
      E2Y=-E1X*ANZ
      E2Z=-ANX*E1Y+E1X*ANY
      DX=DX/FLOAT(IXPTS-1)
      DZ=DZ/FLOAT(IYPTS-1)
      AFLX=FLOAT(IXPTS-1)*(DX/2.)
      AFLY=FLOAT(IYPTS-1)*(DZ/2.)
      XA=XTA+AFLX*E1X+AFLY*E2X
      YA=YTA+AFLX*E1Y+AFLY*E2Y
      ZA=ZTA+AFLY*E2Z
       AFCOL=FLOAT(NCOL-1)*DX
      AFRO=FLOAT(NR-1)*DZ
      XTA=(XA+AFCOL*(-E1X)+AFRO*(-E2X))
      YTA=(YA+AFCOL*(-E1Y)+AFRO*(-E2Y))
      ZTA=(ZA+AFRO*(-E2Z))
135   VMT(1)=ANX
      VMT(2)=ANY
      VMT(3)=ANZ
      RETURN
1501  WRITE(NOUT,99999)
      STOP 111
C
99999 FORMAT(2X,50HSTOP IN USERTG, USER DEFINED TARGET SURFACE ERROR.)
      END
*D,A.29
       COMMON/CMAX/ AXEXT, AZEXT
        INTEGER HNM
*D,INDATA.60
       COMMON/CMAX/ AXEXT, AZEXT
        INTEGER HNM
*D,INDATA.820
C*******************************************************************
C                                                                  *
C          VTAR(I,J) ARE DEFINED IN GROUP 3                        *
C                                                                  *
C           XEXT AND ZEXT ARE DEFINED IN GROUP 3                   *
C                                                                  *
C     AXEXT AND AZEXT ARE THE HORIZONTAL AND VERTICAL EXTENTS FOR  *
C     EACH REDIRECTOR PANEL (UNITS ARE IN METERS)                  *
C                                                                  *
C                       INPUTS REQUIRED ARE                        *
C        1. TARGET CENTER ; VTAR(1,J),J=1,3                        *
C        2. TARGET NORMAL ; ANX,ANY,ANZ                            *
C        3. TARGET EXTENTS ; XEXT,ZEXT                             *
C        4. REDIRECTOR EXTENTS ; AXEXT,AZEXT                       *
C                                                                  *
C*******************************************************************
```

```
      VTAR(1,1)=0.000
      VTAR(1,2)=7.72
      VTAR(1,3)=51.070
      ANX=0.0 )
      ANY=0.0 } ------------------  *Note that the values used for
      ANZ=1.0 )                      ANX, ANY and ANZ here are for
      XEXT=1.0                       a horizontal flat plate facing
      ZEXT=1.0                       upward
      AXEXT=0.6096
      AZEXT=0.6096
C
C
C                END OF INPUT
C
C
      ANNOR=SQRT(ANX**2+ANY**2)
      IF(ANNOR.EQ.0.0) GO TO 10101
      E1X=-ANY/ANNOR
      E1Y=ANX/ANNOR
      E1Z=0.
      E2X=-ANZ*E1Y
      E2Y=ANZ*E1X
      E2Z=ANX*E1Y-ANY*E1X
      GO TO 10102
10101 E1X=-1.0
      E1Y=0.0
      E1Z=0.0
      E2X=0.0
      E2Y=-1.0
      E2Z=0.0
10102 VTAR(2,1)=VTAR(1,1)+(XEXT/2.)*E1X
      VTAR(2,2)=VTAR(1,2)+(XEXT/2.)*E1Y
      VTAR(2,3)=VTAR(1,3)+(XEXT/2.)*E1Z
      VTAR(3,1)=VTAR(1,1)+(ZEXT/2.)*E2X
      VTAR(3,2)=VTAR(1,2)+(ZEXT/2.)*E2Y
      VTAR(3,3)=VTAR(1,3)+(ZEXT/2.)*E2Z
        XTAR=VTAR(1,1)
*D,C.38
      COMMON/NWRAYS/NWRC(16,121),NWRE(16,11,11),IBASX,IBASY,RAREA,
*D,C.45
     *YTA,ZTA,NTAG1,XT0,YT0,ZT0,BASK(11,11,16),RECN(3),BASKM
*D,C.56
     *RECD(3),RECOP(121,16),PDT(121),TPDT(3,121),HITE(11,11),
*D,C.74
         DO 30 K=1,IRECP
*D,C.79
      DO 70 I1=1,IRECP
*D,C.85
      DO 100 I1=1.IRECP
```

```
*D,BASKET.3,42
      COMMON/TARGT/ XEXT, ZEXT, XTAR, YTAR, ZTAR, ITAR, IGEO,
     * VTAR(3,3), IVMD
C***************************************************************************
C                                                                          *
C                           INPUT                                          *
C                                                                          *
C                                                                          *
C      BASKETS MADE LARGER THAN RECEIVER SO BASKET MIDPOINTS               *
C      CORRESPOND TO THE 121 TARGET POINTS IN THE RECEIVER.                *
C                                                                          *
C                                                                          *
C               FRONT VIEW OF PLATE                                        *
C          TOP AND BOTTOM SURFACES ARE PARALLEL TO EAST-NORTH PLANE        *
C                                                                          *
C                                                                          *
C                                                                          *
C                                                          (SOUTH)         *
C                                                           (E2)           *
C                                                            *             *
C            PL *********************************PR          *             *
C               *                               *            *             *
C               *                               *            *             *
C               *             PC                *            ********(E1)  *
C               *                               *                   (WEST) *
C               *                               *                          *
C            PB *********************************                          *
C                                                                          *
C                                                                          *
C           NOTE: FOR A HORIZONTAL PLATE THE TOP IS TOWARD SOUTH           *
C             TOP AND BOTTOM SURFACES ARE IN EAST-WEST DIRECTION           *
C                                                                          *
C                                                                          *
C            ANX,ANY,ANZ ARE COMPONENTS OF THE UNIT NORMAL TO PLATE        *
C                                                                          *
C            PCX,PCY,PCZ ARE TOWER COORDINATES FOR PLATE CENTER            *
C                                                                          *
C***************************************************************************
      ANX=0.0
      ANY=0.0
      ANZ=1.0
      PCX=0.000
      PCY=7.72
      PCZ=51.070
C**************************************************************************
C                                                                         *
C                                                                         *
C                                                                         *
C                       END OF INPUT                                      *
C                                                                         *
C                                                                         *
C                                                                         *
C**************************************************************************
       DEX = XEXT/10.
       DEY = ZEXT/10.
      ANNOR=SQRT(ANX**2+ANY**2)
      IF(ANNOR.EQ.0.0) GO TO 10101
      E1X=-ANY/ANNOR
      E1Y=ANX/ANNOR
      E1Z=0.
      E2X=-ANZ*E1Y
      E2Y=ANZ*E1X
      E2Z=ANX*E1Y-ANY*E1X
      GO TO 10102
```

```
10101 E1X=-1.0
      E1Y=0.0
      E1Z=0.0
      E2X=0.0
      E2Y=-1.0
      E2Z=0.0
10102 PLX=PCX-(XEXT/2.)*E1X+(ZEXT/2.)*E2X
      PLY=PCY-(XEXT/2.)*E1Y+(ZEXT/2.)*E2Y
      PLZ=PCZ-(XEXT/2.)*E1Z+(ZEXT/2.)*E2Z
      PRX=PLX+XEXT*E1X
      PRY=PLY+XEXT*E1Y
      PRZ=PLZ+XEXT*E1Z
      PBX=PLX-ZEXT*E2X
      PBY=PLY-ZEXT*E2Y
      PBZ=PLZ-ZEXT*E2Z
      RX=XI-PLX
      RY=YI-PLY
      RZ=ZI-PLZ
      XDIST=RX*E1X+RY*E1Y+RZ*E1Z
      YDIST=RX*(-E2X)+RY*(-E2Y)+RZ*(-E2Z)
      XDMAX=XEXT*(1.05)
      XDMIN=-XEXT/20.
      YDMAX=ZEXT*(1.05)
      YDMIN=-ZEXT/20.
      IF(XDIST.GT.XDMAX) GO TO 10
      IF(XDIST.LT.XDMIN) GO TO 10
      IF(YDIST.GT.YDMAX) GO TO 10
      IF(YDIST.LT.YDMIN) GO TO 10
C
C
C       CHECK TO INSURE THAT R-VECTOR IS IN THE TARGET PLANE
C
C          R DOT (E1 X E2) = 0
C
C
       RCK1=RX*(E1Y*E2Z-E1Z*E2Y)
       RCK2=RY*(E1Z*E2X-E1X*E2Z)
       RCK3=RZ*(E1X*E2Y-E1Y*E2X)
       RCK=RCK1+RCK2+RCK3
       IF(ABS(RCK).LT.1.E-4) GO TO 20
       WRITE (6,99999) XI,YI,ZI
       STOP 222
   10   IBASX=-1
       IBASY=-1
       RETURN
   20  IBASY=0
       Y=YDMIN
   30  IBASY=IBASY+1
       Y=Y+DEY
       IF(YDIST.LT.Y) GO TO 40
       GO TO 30
   40  X=XDMIN
       IBASX=0
   50  X=X+DEX
       IBASX=IBASX+1
       IF(XDIST.LT.X) GO TO 60
       GO TO 50
   60  IF (IBASX.GT.11.OR.IBASY.GT.11) GO TO 10
       RETURN
C
99999  FORMAT (1X,6HBASKET.3E15.5)
C
       END
```

```
*D,FACETC.13
       COMMON/NWRAYS/NWRC(16,121),NWRE(16,11,11),IBASX,IBASY,RAREA,
*D,FACETC.16
      *YTA,ZTA,NTAG1,XT0,YT0,ZT0,BASK(11,11,16),RECN(3),BASKM
*D,PHIC.27
      *YTA,ZTA,NTAG1,XT0,YT0,ZT0,BASK(11,11,16),RECN(3),BASKM
*D,POWREC.9,35
       DIMENSION RECOP(121,16),HITE(11,11)
        COMMON/CMAX/ AXEXT, AZEXT
        DO 120 ISECT=1,IRECP
        DX=AXEXT/FLOAT(IXPTS-1)
        DZ=AZEXT/FLOAT(IYPTS-1)
*D,RAREC.10
        COMMON/CMAX/ AXEXT, AZEXT
        COMMON/TARGT/ XEXT, ZEXT, XTAR, YTAR, ZTAR, ITAR, IGEO,
      * VTAR(3,3), IVMD
*D,RAREC.20,59
       RAREA=AXEXT * A * AZEXT
       RA= (XEXT + XEXT/10.) * (ZEXT + ZEXT/10.)
       RAREA=RAREA/RA
       RETURN
       END
*D,TCIRPC.7
       DIMENSION VFE(3),TV(3),UTV(3),NWRC(16,121),VMT(3),B(3),
```

File - PLATED: Data File to be Submitted with PLATE

```
GR1       *CRTF FULL* FIELD   *UPDATE   * FILE IS * BCRTFV  *       *       *
          1         1         0         1         1         1       0       1
GR2      PARAMETROS DEL SOL
          2         0         7         6         1         1       1       6
   18
   0.00000 202.40000
    .00022 202.40000
    .00065 202.40000
    .00109 200.28000
    .00153 197.10000
    .00196 192.86000
    .00240 188.63000
    .00284 182.27000
    .00327 172.73000
    .00371 155.78000
    .00415 105.97000
    .00458 7.5030000
    .00502 .28300000
    .00545 .17600000
    .00589 .12100000
    .00633 .08800000
    .00676 .07400000
    .00720 .06600000
          1         1         2         0
0.00      .00120    .00120
.00085    .00080
GR3       *         *TARGET   *         *         *         *       *       *
          3        121        59        2         1         0       10      1
          2         9         0
-0.38     5.54      59.19
-0.38     5.54      59.19
  0.00     7.72      52.32
  0.91     7.98      52.46
  0.30     7.98      52.46
  -.30     7.98      52.46
  -.91     7.98      52.46
  0.91     7.44      52.17
  0.30     7.44      52.17
  -.30     7.44      52.17
  -.91     7.44      52.17
65.33     34.96     1.00      1.00      0.000     7.450     50.43     60.96
 6.60      7.80
0.000     7.45      50.430    0.000     7.1632    50.8396 0.500   7.45    50.430
          11        11        7         8
GR4       *FACET    * DATA    *         *         *         *       *       *
          4         25        1         5         5         1       -1      0
REFLECT       0.79
GR5       *HELIOSTAT*DATA     *         *         *         *       *       *
          5         242       10        -2        0         8       0       1
  2  1
GR6       *TIME DATA*         *         *         *         *       *       *
          6         1         1         1
     180
  0
```

General Direction of the normal to the target

Number of Aimpoints

Coordinates of the Aimpoints

Extents of the target (in meters)

Number of Redirector Facets

Number of First Heliostat to Evaluate

Total number of Heliostats to Evaluate

Aimpoint number of first Heliostat Evaluated

Day of the year to make predictions for

Time of day to make predictions for

```
GR7      *ATMOSPH  *DATA     *         *         *         *         *
          7          1          1         3
MM HOH=    10.9
DATA TERMINATION
          -1
 40  1  7
 44  2  6
 59  1  3
 62  2  2
 65  2  2
212  1  8
227  2  9
245  1  4
248  2  5
283  2 10
122  2 11
126  2 11
132  2 12
142  2 12
304  2 13
314  2 13
308  2 14
 85  2 15
 91  2 16
268  2 17
275  2 18
```

Heliostat number, alignment number and aimpoint number of heliostat to be evaluated

APPENDIX D
Optics Theory

The optics code (REDIR) takes the central ray from the sun and determines the location in space where the ray intersects the redirector plane. Five points on the heliostat are evaluated—the center and the four corners. The output gives the intersection point and the normal vectors (between the redirector plane and the target) for each ray. In this manner, the size and contour of each redirector panel can be estimated. Further design refinements of the panels can be made with the HELIOS code.

For this analysis, the tower coordinate system is used, and the following parameters are assumed to be known (Figure D-1).

(X_O,Y_O,Z_O)	heliostat foundation position
ρ_S, ϕ_S	elevation and azimuth angle of the sun
(X_F,Y_F,Z_F)	position of target center
(X_A,Y_A,Z_A)	aim point for heliostat (note that this point can be at the redirector surface)
L_1,L_2	heliostat dimensions.

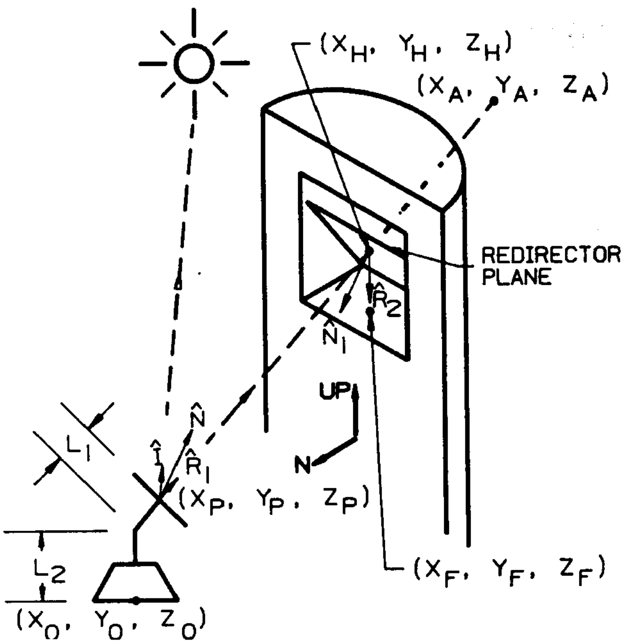

Figure D-1. Geometric Description of Redirector Plane

The incident central ray from the sun with unit vector

$$\hat{I} = A_S\,\hat{i} + B_S\,\hat{j} + C_S\,\hat{k} \qquad \text{(D-1)}$$

where

$$A_S = \cos\rho_S \cos\phi_S$$
$$B_S = \cos\rho_S \sin\phi_S$$
$$C_S = \sin\rho_S$$

will intersect the center of the central facet at (X_p,Y_p,Z_p) and will be reflected toward the aim point (X_A,Y_A,Z_A). The unit vectors describing the reflected ray, $\hat{R}_1$, and the normal, $\hat{N}$, to the heliostat are

$$\hat{R}_1 = \cos\rho_t \cos\phi_t\,\hat{i} + \cos\rho_t \sin\phi_t\,\hat{j} + \sin\rho_t\,\hat{k} \qquad \text{(D-2)}$$

and

$$\hat{N} = N_X\,\hat{i} + N_Y\,\hat{j} + N_Z\,\hat{k} \ , \qquad \text{(D-3)}$$

where

$$\cos\rho_t \cos\phi_t = \frac{X_A - X_P}{\ell} \ ,$$

$$\cos\rho_t \sin\phi_t = \frac{Y_A - Y_P}{\ell} \ ,$$

and

$$\sin\rho_t = \frac{Z_A - Z_P}{\ell} \ ;$$

ρ_t elevation angle of reflected ray from heliostat,

$0 \leq \rho_t \leq \pi/2$,

ϕ_t azimuth angle of reflected ray from heliostat,

$$\ell = [(X_A - X_P)^2 + (Y_A - Y_P)^2 + (Z_A - Z_P)^2]^{1/2} \ ,$$

$$N_X = \alpha\,(\cos\rho_S \cos\phi_S + \cos\rho_t \cos\phi_t) \ ,$$

$$N_Y = \alpha\,(\cos\rho_S \sin\phi_S + \cos\rho_t \sin\phi_t) \ ,$$

$$N_Z = \alpha\,(\sin\rho_S + \sin\rho_t) \ ,$$

and

$$\alpha^{-2} = 2 + 2\,(\cos\rho_S \cos\phi_S \cos\rho_t \cos\phi_t + \cos\rho_S \sin\phi_S \cos\rho_t \sin\phi_t + \sin\rho_s \sin\rho_t) \ .$$

To determine the midpoint of the center facet on the heliostat (X_P,Y_P,Z_P), we write the normal vector of Equation (D-3) in the alternate form

$$\hat{N} = \frac{(X_P - X_O)}{L_1}\hat{i} + \frac{(Y_P - Y_O)}{L_1}\hat{j} + \frac{(Z_P - Z_O - L_2)}{L_1}\hat{k} \ , \quad \text{(D-4)}$$

where L_1 and L_2 are defined in Figure 1. Comparing Equations (D-3) and (D-4), we obtain the following relations for determining the point (X_P,Y_P,Z_P) on the heliostat:

$$X_P = X_O + \alpha L_1 (\cos\rho_S \cos\phi_S + \cos\rho_t \cos\phi_t) \ , \quad \text{(D-5)}$$

$$Y_P = Y_O + \alpha L_1 (\cos\rho_S \sin\phi_S + \cos\rho_t \sin\phi_t) \ , \quad \text{(D-6)}$$

and

$$Z_P + Z_O + L_2 + \alpha L_1 (\sin\rho_S + \sin\rho_t) \ . \quad \text{(D-7)}$$

The unit vector $\hat{R}_1$ is given by Equation (D-2), and $\hat{R}_2$ can be written as

$$\hat{R}_2 = \frac{(X_F - X_H)\hat{i} + (Y_F - Y_H)\hat{j} + (Z_F - Z_H)\hat{k}}{[(X_F - X_H)^2 + (Y_F - Y_H)^2 + (Z_F - Z_H)^2]^{1/2}} \ . \quad \text{(D-8)}$$

The problem is now reduced to finding the intersection of the incident ray $\hat{R}_1$ with the plane. The unit vector $\hat{R}_1$ has been given by Equation (D-2) and can also be written as

$$\hat{R}_1 = \frac{(X_H - X_P)}{P}\hat{i} + \frac{(Y_H - Y_P)}{P}\hat{j} + \frac{(Z_H - Z_P)}{P}\hat{k} \quad \text{(D-9a)}$$

or

$$\hat{R}_1 = \frac{(X_A - X_P)}{\ell}\hat{i} + \frac{(Y_A - Y_P)}{\ell}\hat{j} + \frac{(Z_A - Z_P)}{\ell}\hat{k} \ , \quad \text{(D-9b)}$$

where

$$P^2 = (X_H - X_P)^2 + (Y_H - Y_P)^2 + (Z_H - Z_P)^2 \ .$$

Comparing Equations (D-2) and (D-9), we obtain the following set of equations for determining the intersection point (X_H,Y_H,Z_H):

$$\frac{X_A - X_P}{\ell} = \frac{X_H - X_P}{P} = \cos\rho_t \cos\phi_t \ , \quad \text{(D-10)}$$

$$\frac{Y_A - Y_P}{\ell} = \frac{Y_H - Y_P}{P} = \cos\rho_t \sin\phi_t \ , \quad \text{(D-11)}$$

$$\frac{Z_A - Z_P}{\ell} = \frac{Z_H - Z_P}{P} = \sin\rho_t \ . \quad \text{(D-12)}$$

For the redirector plane above the target, Figure D-2, the equation describing the surface is

$$Z_H = (Y_H - Y_{F_{RU}}) \tan\psi_U + Z_{F_{RU}} + \Delta Z_U \ , \quad \text{(D-13)}$$

where $(X_{F_{RU}}, Y_{F_{RU}}, Z_{F_{RU}})$ defines the intersection point on the target surface for the reference heliostat, ΔZ_U is the distance from this point on the target surface to a reference point on the redirector plane, and (X_H, Y_H, Y_H) defines the intersection point on the redirector surface for heliostats other than the reference heliostat. This reference heliostat, which is chosen arbitrarily, enables us to locate the redirector plane in space.

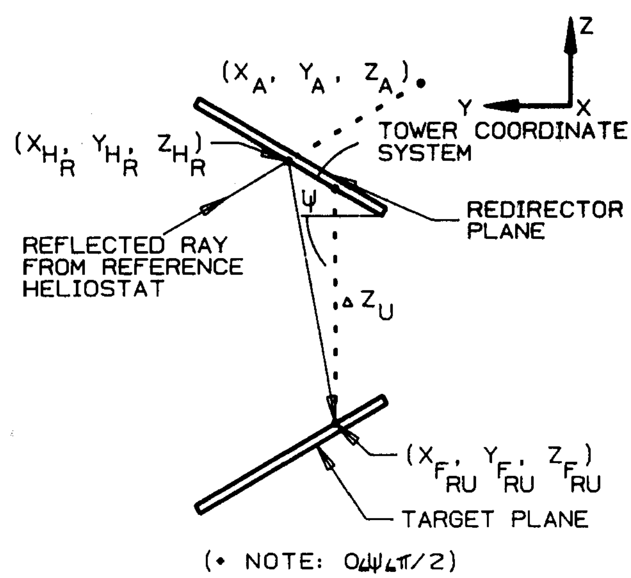

Figure D-2. Redirector/Target Geometry With Redirector Above the Target

The point where the ray from the center facet of the reference heliostat pierces the redirector plane is labeled as $(X_{H_R},Y_{H_R},Z_{H_R})$. Using Equations (D-10) through (D-13), we can write a general expression containing ΔZ_U and Y_{H_R};

$$(Y_{H_R} - Y_{F_{RU}}) \tan\psi_U + Z_{F_{RU}} + \Delta Z_U$$

$$= Z_{PR} + \left(\frac{Y_{H_R} - Y_{PR}}{Y_{AR} - Y_{PR}}\right)(Z_{AR} - Z_{PR}) \ . \qquad \text{(D-14)}$$

For the initial calculations, we position the redirector so that

$$Y_{H_R} = Y_{F_{RU}} \qquad \text{(D-15)}$$

and solve Equation (D-14) for ΔZ_U ;

$$\Delta Z_U = Z_{PR} - Z_{F_{RU}} + \left(\frac{Y_{H_R} - Y_{PR}}{Y_{AR} - Y_{PR}}\right)(Z_{AR} - Z_{PR}) \ . \qquad \text{(D-16)}$$

We use this value for ΔZ_U to initially position the redirector with respect to the target. The actual location of this point can now be determined from Equations (D-10), (D-11), (D-13), and (D-16);

$$Y_{H_R} = Y_{F_{RU}} \ , \qquad \text{(D-15)}$$

$$Z_{H_R} = Z_{F_{RU}} + \Delta Z_U \ , \qquad \text{(D-17)}$$

and

$$X_{H_R} = X_{PR} + \left(\frac{Y_{H_R} - Y_{PR}}{Y_{AR} - Y_{PR}}\right)(X_{AR} - X_{PR}) \ . \qquad \text{(D-18)}$$

Further refinements can be made by modifying ΔZ_U, solving for Y_{H_R} from Equation (D-14), using Equation (D-13) to determine Z_{H_R} , and Equations (D-10) and (D-11) to obtain X_{H_R}. With this point determined, the pierce points for the remaining heliostats can be obtained from Equations (D-10) through (D-14);

$$Y_H = \frac{Y_P \tan\rho_t - Y_{F_{RU}} \tan\psi_U \sin\phi_t + (Z_{F_{RU}} + \Delta Z_U - Z_\rho)\sin\phi_t}{\tan\rho_t - \tan\psi_U \sin\rho_t} \ , \qquad \text{(D-19)}$$

$$Z_H = (Y_H - Y_{F_{RU}}) \tan\psi_U + Z_{F_{RU}} + \Delta Z_U \ , \qquad \text{(D-20)}$$

and

$$X_H = X_P + (Z_H Z_P) \frac{\cos\phi_t}{\tan\rho_t} \ . \qquad \text{(D-21)}$$

In Equations (D-19), (D-20), and (D-21) the angles ϕ_t and ρ_t are defined by

$$\phi_t = \tan^{-1}\left(\frac{Y_A - Y_P}{X_A - X_P}\right) \qquad \text{(D-22)}$$

and

$$\rho_t = \tan^{-1}\frac{(Z_A - Z_P)}{\sqrt{(X_A - X_P)^2 + (Y_A - Y_P)^2}} \ . \qquad \text{(D-23)}$$

For the redirector located below the target plane, there are two possible orientations; see Figures D-3 and D-4. For the first case, $0<\psi_L<\pi/2$, the equation describing the surface is given by

$$Z_H = (Y_{F_{RL}} - Y_H) \tan\psi_L + Z_{F_{RL}} - \Delta Z_L \ , \qquad \text{(D-24)}$$

where $Y_{F_{RL}}$ and $Z_{F_{RL}}$ are the Y- and Z-coordinates for the target point of the reference heliostat. Proceeding as before, we write the general expression containing Y_{H_R} and ΔZ_L ;

$$(Y_{F_{RL}} - Y_{H_R})\tan\psi_L + Z_{F_{RL}} - \Delta Z_L - Z_{PR}$$

$$= \frac{(Y_{H_{RL}} - Y_{PR})}{Y_{AR} - Y_{PR}}(Z_{AR} - Z_{PR}) \ . \qquad \text{(D-25)}$$

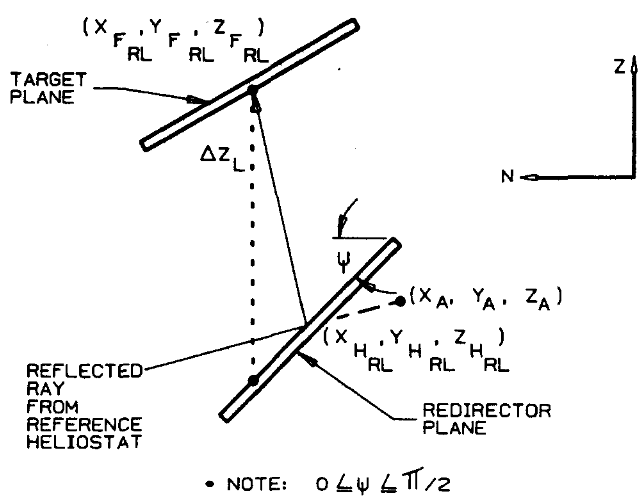

Figure D-3. Redirector/Target Geometry: Redirector Below the Target

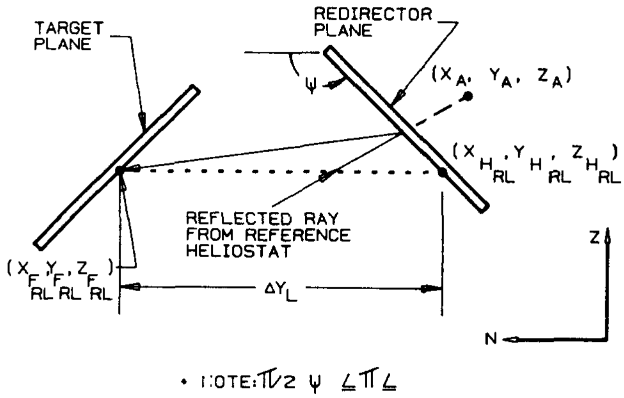

Figure D-4. Redirector/Target Geometry: Redirector Below the Target

We first position the redirector so that

$$Y_{H_{RL}} = Y_{F_{RL}} \qquad \text{(D-26)}$$

and solve Equation (D-25) for ΔZ_L;

$$\Delta Z_L = Z_{F_{RL}} - Z_{PR} - \frac{(Y_{H_{RL}} - Y_{PR})}{Y_{AR} - Y_{PR}} (Z_{AR} - Z_{PR}) \; . \qquad \text{(D-27)}$$

The pierce point on the redirector is then determined from the following relations:

$$Y_{H_{RL}} = Y_{F_{RL}} \; , \qquad \text{(D-28)}$$

$$Z_{H_{RL}} = Z_{F_{RL}} - \Delta Z_L \; ,$$

and

$$X_{H_{RL}} = X_{PR} + \frac{(Y_{H_{RL}} - Y_{PR})}{Y_{AR} - Y_{PR}} (X_{AR} - X_{PR}) \; . \qquad \text{(D-18)}$$

Further refinements can be made by using the same procedure recommended for the upper redirector. Once the final value for ΔZ_L is decided upon, the pierce points on the redirector plane can be determined by using Equations (D-10) through (D-13) and (D-24):

$$Y_H = \frac{Y_P \tan \rho_t + Y_{F_{RL}} \tan \psi_L \sin \phi_t + (Z_{F_{RL}} - \Delta Z_{L_p}) \sin \phi_t}{\tan \rho_t + \sin \phi_t \tan \psi_L} \; , \qquad \text{(D-28)}$$

$$Z_H = (Y_{F_{RL}} - Y_H) \tan \psi_L + Z_{F_{RL}} - \Delta Z_L \; , \qquad \text{(D-24)}$$

and

$$X_H = X_P + (Z_H - Z_P) \frac{\cos \phi_t}{\tan \rho} \; . \qquad \text{(D-21)}$$

where ϕ_t and ρ_t are given by Equations (D-22) and (D-23).

The second possibility for a redirector located below the target plane occurs when $\pi/2 < \psi_L < \pi$. For this case the equation describing the surface is given by (see Figure D-2a)

$$Y_H = Y_{F_{RL}} - \Delta Y_L - \frac{(Z_H - Z_{F_{RL}})}{\tan \psi_L} \; . \qquad \text{(D-29)}$$

The general expression containing Z_{H_R} and ΔY_L is obtained from Equations (D-11), (D-12), and (D-29);

$$Y_{F_{RL}} - \Delta Y_L - \frac{(Z_{H_{RL}} - Z_{F_{RL}})}{\tan \psi_L}$$

$$= Y_{PR} + \frac{(Z_{H_{RL}} - Z_{PR})}{Z_{AR} - Z_{PR}} (Y_{AR} - Y_{PR}) \; . \qquad \text{(D-30)}$$

We next position the redirector so that

$$Z_{H_{RL}} = Z_{F_{RL}} \qquad \text{(D-31)}$$

and solve Equation (D-30) for ΔY_L;

$$\Delta Y_L = Y_{F_{RL}} - Y_{PR} - \frac{(Z_{H_{RL}} - Z_{PR})}{Z_{AR} - Z_{PR}} (Y_{AR} - Y_{PR}) \; . \qquad \text{(D-32)}$$

The pierce points on the redirector are then given by

$$Z_{H_{RL}} = Z_{F_{RL}} \; , \qquad \text{(D-33)}$$

$$Y_{H_{RL}} = Y_{F_{RL}} - \Delta Y_L \; , \qquad \text{(D-34)}$$

and Equation (D-18).

Further refinements for positioning the redirector can be made by modifying the value for ΔY_L, solving for Z_{H_R} from Equation (D-30), and proceeding in the same manner as discussed previously. The final step is to determine the relations for the pierce points of the remaining heliostats:

$$Z_H = \frac{Z_p \sin \phi_t \tan \psi_L + Z_{F_{RL}} \tan \rho r_t + (Y_{F_{RL}} - \Delta Y_L - Y_P) \tan \rho_t \tan \psi_L}{\tan \rho_t + \sin \phi_t \tan \psi_L} \; , \qquad \text{(D-35)}$$

Equation (D-29) and Equation (D-21),

where ϕ_t and ρ_t are given by Equations (D-22) and (D-23).

The above development has located the pierce point (X_H, Y_H, Z_H) of the redirector due to the ray from the center facet on the heliostat. To determine the proper extent for each redirector panel, one should not only consider the energy reflected from the edges of the heliostat but also the entire cone of energy from the sun. To determine the edge points of the heliostat with the center point known, one needs only to determine two unit vectors in the plane of the heliostat. Individual heliostat facet contours are not considered here; they are assumed to be flat. These contours are accounted for in the HELIOS code.

To determine the unit vectors in the plane of the heliostat, one starts with the unit normal vector at the heliostat center, Equation (D-4);

$$\hat{N} = N_x \hat{i} + N_y \hat{j} + N_z \hat{k} \; .$$

This vector is then projected into the horizontal (x-y) plane and rotated 90° counterclockwise to obtain the unit vector.

$$\hat{e}_1 = \frac{-N_y \hat{i} + N_x \hat{j}}{\sqrt{N_x^2 + N_y^2}} \; . \qquad \text{(D-36)}$$

To complete the right-handed coordinate system, we use the cross-product

$$\hat{e}_2 = \hat{N} \times \hat{e}_1$$

or

$$\hat{e}_2 = \frac{-N_x N_z}{\sqrt{N_x^2 + N_y^2}} \hat{i} - \frac{N_y N_z}{\sqrt{N_x^2 + N_y^2}} \hat{j} + \sqrt{N_x^2 + N_y^2}\, \hat{k} \; . \qquad \text{(D-37)}$$

Any point in the heliostat plane can now be determined by means of the vector equation

$$\vec{Q} = X_P \hat{i} + Y_P \hat{j} + Z_p \hat{k} + A_1 \hat{e}_1 + A_2 \hat{e}_2 \; , \qquad \text{(D-38)}$$

where A_1 and A_2 are the distances from the center of the heliostat in the heliostat plane along the unit-vectors $\hat{e}_1$ and $\hat{e}_2$ respectively. To determine points on the solar disk, we start with the incident central ray from the sun, Equation (D-1)

$$\hat{I} = A_s \hat{i} + B_s \hat{j} + C_s \hat{k} \; .$$

We next define a sun-facet coordinate system where

$$\hat{k}_s = \hat{I} \; , \qquad \text{(D-39)}$$

$$\hat{i}_s = \frac{-B_s \hat{i} + A_s \hat{j}}{\sqrt{A_s^2 + B_s^2}} \; , \qquad \text{(D-40)}$$

and

$$\hat{j}_s = \hat{k}_s \times \hat{i}_s$$

or

$$\hat{j}_s = \frac{-A_s C_s}{\sqrt{A_s^2 + B_s^2}} \hat{i} - \frac{B_s C_s}{\sqrt{A_s^2 + B_s^2}} \hat{j} + \sqrt{A_s^2 + B_s^2}\, \hat{k} \; . \qquad \text{(D-41)}$$

If we further define α as the cone half-angle and β as the circumferential angle in the $\hat{i}_s - \hat{j}_s$ plane, shown in Figure D-5, then the unit vector describing any point on the disk periphery is given by

$$\hat{I}' = \frac{\tan\alpha \cos\beta\, \hat{i}_s + \tan\alpha \sin\beta\, \hat{j}_s + \hat{k}_s}{\sqrt{1 + \tan^2\alpha}} \; . \qquad \text{(D-42)}$$

Equation (D-42) can be expressed in the $\hat{i}$-$\hat{j}$-$\hat{k}$ system by substituting Equations (D-39) through (D-41) into Equation (D-42).

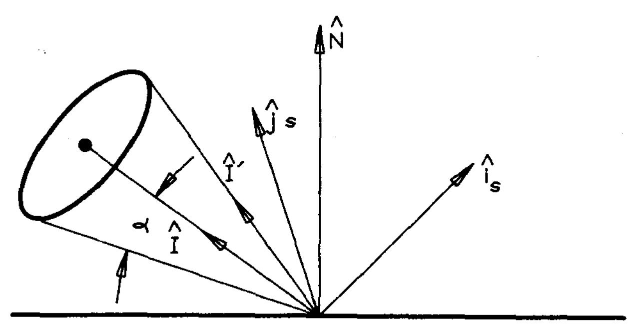

Figure D-5. Sun-Facet Coordinate System

With the above information known, the pierce point in the redirector facet plane is obtained by recognizing that the distance, D, between a point P1 (identified by the vector $\vec{P}1$) on the heliostat facet plane and the point H1 on the redirector facet plane shown in Figure D-6, can be written as

$$D = \frac{(\vec{P}_1 - \vec{H}) \cdot N_H}{-B\hat{1} \cdot \hat{N}_H} \; . \qquad \text{(D-43)}$$

The intersection point on the redirector facet plane is then given by

$$\vec{H}1 = \vec{P}_I + D\,(\hat{B}1) \qquad \text{(D-44)}$$

where the unit vector $\hat{B}1$ is

$$\hat{B}1 = -\hat{I}' + 2\,(\hat{I}' \cdot \hat{N})\, \hat{N} \; . \qquad \text{(D-45)}$$

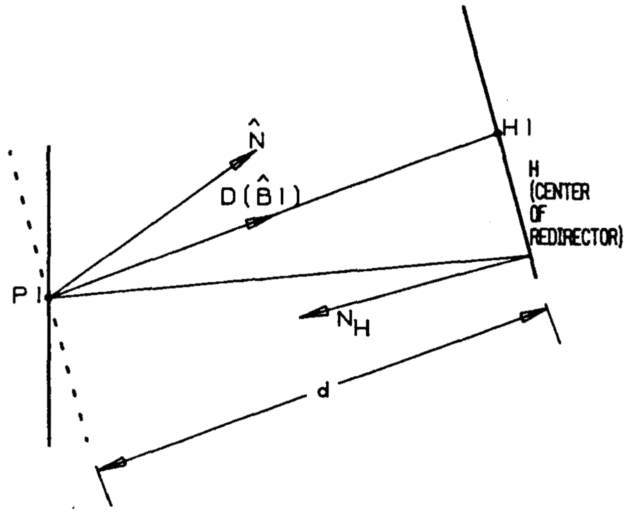

Figure D-6. Heliostat Facet/Redirector Facet Geometry

The normal vector used in Equation (D-45) is obtained in the following manner: We first locate the center point (X_{ps}, Y_{ps}, Z_{ps}) of the corner facets on the heliostat by using Equation (D-38). With this point known, the normal vector is determined by using Equation (D-1) and the reflected ray from the heliostat

$$\hat{R}_2' = \frac{(X_A - X_{PS})\,\hat{i} + (Y_A - Y_{PS})\,\hat{j} + (Z_A - Z_{PS})\,\hat{k}}{[(X_A - X_{PS})^2 + (Y_A - Y_{PS})^2 + (Z_A - Z_{PS})^2]^{1/2}} \quad \textbf{(D-46)}$$

in the general relation that describes the normal vector,

$$\hat{N} = \frac{\hat{I} + \hat{R}_2'}{|\hat{I} + R_2'|} \; . \quad \textbf{(D-47)}$$

The above procedure enables one to determine the image cast upon the redirector by the heliostat. Obviously, there will be overlapping areas from adjacent heliostats, but by carefully choosing aim strategies this should be minimized. By varying the size, shape and location inputs to the code REDIR an optimum redirector can be designed.

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