USER'S MANUAL FOR
UNIVERSITY OF ARIZONA APART PROGRAM
(ANALYSIS PROGRAM-ARIZONA RADIATION TRACE)

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FOREWORD

This report describes an important new optical system analysis tool, the Analysis Program, Arizona Radiation Trace (APART). This is a computer program that is able to efficiently and accurately predict the off-axis rejection characteristics of unwanted stray radiation for complex optical systems. This program was developed by the University of Arizona under NASA contract NAS 8-27804 (MSFC--Mr. Don Griner, Technical Monitor) to aid in the design of the Large Space Telescope (LST).

The LST is a large-aperture stellar telescope intended for operation in a low-altitude earth orbit. For maximum utilization, it is necessary that the LST operate while on the "bright" side of the earth, where it is exposed to strong interfering radiation from both the sun and the bright earth. The desired performance goal for the LST is the detection of $M_V$ 29 objects, so there is clearly a need for sophisticated light rejection systems that reduce the transmittance of the radiation by a factor of $10^{14}$.

Dr. Roland Shack of the Optical Sciences Center originally conceived the unique approach used for the development of APART and has contributed invaluable aid and guidance during the development. Mr. Tom Sargent of Steward Observatory contributed a great deal to developing the more complex portions of the computer program, and Mr. Gary Hunt, a Sperry-Rand subcontractor at MSFC, was very helpful in the final stages of the program development.

Special thanks go to Mr. Bill Fannin, Research Associate, whose patience helped me endure some of the more trying moments.
ABSTRACT

The Analysis Program, Arizona Radiation Trace (APART) demonstrates the capability of using modern-day, high-speed computers to do deterministic radiation calculations on rotationally symmetric optical systems. The advent of computers with large central memory and/or random access disk files has made the necessary computations feasible. The basic problems have been solved and an extension of the same techniques to general systems, i.e., nonrotationally symmetric systems, can be foreseen.

Routines to model vane structure proved to be both convenient to use and instructive in clarifying the scattering mechanism of the vane structure subsystem including the effect of vane edge scatter.

Although the run time of the program was to be considerably reduced compared to that of other programs in existence that measure stray radiation, this is not necessarily true. Program three may run a relatively long time. But once generated, subsequent runs will, in fact, be shorter as that portion of the analysis need not be rerun.

Caution should be exercised when using refracting optical systems. The program has not been tried on any such system although it was intended to be able to handle them. Later versions presently being developed are designed to handle this problem along with asymmetric systems in general.
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I. INTRODUCTION

Before the start of the development of this program, most of the sophisticated available stray radiation programs used the unmodified Monte-Carlo statistical techniques. For systems with high attenuation this involves long computer runs. Subsequent runs are just as expensive. Since that time the GUERAP programs have been developed or released thereby reducing many of the disadvantages of earlier approaches. The Arizona program (APART) is a unique deterministic program because it utilizes the $\gamma$-$\gamma$ techniques to determine the critical objects or areas that scatter radiation to the image plane either directly or through imaging elements. Thus, even before expensive radiation calculations begin, one has the opportunity to modify the design so that the number of critical areas "seen" by the image plane is reduced or the radiation to these critical areas is minimized.

Once radiation calculations are made, APART not only gives the power distribution reaching the image plane (as do most other programs), but also gives a sectional power map of all internal surfaces, so one can understand the power distributions involved. Any surfaces that scatter power onto the image plane are identified, and the increment of power is printed out. With this information it is possible to determine which sections of the optical system are the major contributors of scattered radiation, so that any system redesign can concentrate on the problem areas. In addition to the power mapping information, angular information is provided that relates the angle by which the radiation came into a surface to the angle by which the radiation is scattered out of the surface; this permits one to determine if a redesign of the baffle system would be beneficial.

Although APART is technically not a design program, its analysis is so complete that it usually clearly defines what must be done to improve the system. Most other programs give final answers only, with little or no diagnostic information, so that attempts to improve system performance
are largely a trial and error approach, with little understanding of the basic principles involved. In addition, APART is broken down into five subprograms so that additional computer runs can usually be made at very low cost if no major changes are made in the system. For example, changes in baffle vane structure or surface characteristics may be evaluated without regenerating the power transfer relationships, so that reruns require a few dollars of computer time rather than the hundreds of dollars for a complete evaluation.

Because APART was developed specifically to analyze proposed designs for the LST, in its present form it is in several respects unsuited for the analysis of general optical systems. The most important of the limitations are

(1) The optical system must be rotationally symmetrical about its central axis (i.e., no off-axis mirrors, no noncircular apertures, etc.). However, a number of nonsymmetrical designs may be handled by such techniques as introducing "dummy" surfaces to complete the symmetry, and assigning these surfaces zero reflection characteristics, etc.

(2) APART is not intended to handle transmission optical elements (refracting elements); the optical system is no problem, but the program has never been checked out for such systems.

(3) APART has no provisions for predicting the diffraction effects of a bright radiation source close to the field of view impinging on a baffle edge. (This problem does not arise with the LST because the look angle of the telescope is restricted to angles somewhat removed from bright objects such as the sun or bright earth.)

It is hoped that an improved version of APART will be developed that will remove these (and other) restrictions and will make the program a more universal tool.
II. GENERAL OVERVIEW OF THE APART PROGRAM

There are five basic programs to the University of Arizona computer analysis program for the study of stray radiation suppression. It is intended that programs two through five be run separately but sequentially as one job train, each creating files for the succeeding programs. Program one is the only one that does not create nor depend on any external files. Figure 1 shows the interrelationships of the programs in APART.

Program one looks out from a point in the image plane and determines those objects that are seen from this point. These are the sources of scattered radiation reaching that point in the image plane. This program, along with the remaining programs, can handle only rotationally symmetric objects. Program one indicates those surfaces that are seen and the angle at which they are seen in real space. Any surface seen is divided into five segments; the position and angle of each segment is printed out. This initial program helps to quickly see any major flaws in the design (from a scattered radiation standpoint), and will reduce the amount of calculations needed to be executed by the succeeding programs.

Program two is similar to program one; both use the same data deck input and both lay out the imaged space as seen from the image plane. Program two does not calculate what segments are seen or any angular information; instead, it lays out the image space as seen from object space. That is, "Looking into the first imaging aperture, what do the imaged spaces look like?" This is necessary to determine to what sections the radiation can scatter. This is also done for the space between the primary and secondary, which turns out to be a partial combination of the other two cases. Although this may appear redundant in the case of two-mirror systems, it may not be so for other systems. The output is plotted for each space so that one may see how and where real space objects are imaged or reimaged. The printout gives the numerical data of the imaged objects. This includes distances, heights, y-ŷ bar values,
Fig. 1. Interrelationships of the programs in APART.
and any objects whose image passes through infinity. It creates an important file (BASICA) that is necessary for the succeeding programs.

Program three attaches most of the information it needs from BASICA. It will take any object from program two and treat it as a source of radiation to any other object, including imaged objects. The data input at this stage can be as simple as two numbers--source object number and collector object number. This program creates four important files: (1) the geometrical percentage of power transferred from each segment of the sources to each segment of the collectors (BDRDF), (2) the angle out of the source (ANGOUT), (3) the angle into the collector (ANGIN), and (4) more information is added to BASICA.

Program four is one of several programs that loads the sun shield with power. One version is a general power-loading program whereas others are more specialized and intended for specific optical designs or to provide a model earth, etc. This information is passed on tape two.

Program five is the driver program for determining the scattered radiation levels throughout the system. The amount of power reaching the image plane from scattered radiation is printed out so that it can be determined which surfaces are the major contributors and just how much power is received from each section. It requires the following files: (1) file BDRDF, file ANGIN, and file ANGOUT from program three, (2) file BASICA from programs two and three, and (3) the input file. The input to this part of the program can be large. The program considers only those radiation paths that contribute scattered radiation to the image plane for the level of scattering being considered; this avoids unnecessary and expensive calculations of scattered energy to surfaces that are not seen from the image plane and do not scatter to surfaces that are seen. This provides the opportunity to study individual radiation paths.

Program five also needs information as to vane configuration--position, vane angle, reflectance of the coating, etc. The total output map of all the energy transfer to each segment is put on tape by a utility program for later analysis.
A. System Flow Chart--Program Functions

Program One
Objects seen from the image plane
   Angle seen
   Position seen

Program Two
Real and imaged spaces calculated and plotted

Program Three
Calculates the geometrical power transferred
   Calculates two necessary angles to specify the angle out of
      the source
   Calculates two necessary angles to specify the angle into the
      collector

Program Four
Loads power (stray radiation) into the system

Program Five
Calculates the scattered radiation distribution.
B. System Flow Chart--File Generation and Requirements

Program One
Independent

Program Two
Gives plot
Creates file 10 = BASICA

Program Three
Requires tape 10 = BASICA
Adds information to tape 10
Creates file 5 = BDRDF = geometrical power transferred
file 8 = angles out (/ANGOUT)
file 9 = angles in (ANGIN)

Program Four
Creates tape 2 = initial power loaded

Program Five
Requires tape 2 = initial power loading
Requires tape 5 = BDRDF
Requires tape 8 = ANGOUT
Requires tape 9 = ANGIN
Requires tape 10 = BASICA
Adds information into tape 10
Adds information into tape 2
Creates tape 3
C. Block Diagram of Programs 2 through 5

(Program one is independent)

MAIN Y-Ɣ PROGRAM
IMAGES ALL OBJECTS
SHORTENS CALCULATIONS

PROGRAM TWO

ANGLE OUT
ANGLE IN
% OF POWER
TRANSFERRED

PROGRAM THREE

DRIVER PROGRAM
(BOOKKEEPING)
DO AS DIRECTED

PROGRAM FOUR

SURFACE INFO
SOURCE INFO

POWER (WATTS)" ON ALL SECTIONS

POWER THAT EACH SECTION CONTRIBUTES TO IMAGE PLANE
D. Program and Subroutine Functions

1. Program One--Object Seen from Image Plane

Program Baffle
Reads in system information:
(1) Baffles
(2) Apertures
(3) Image plane reference point
Calls the subroutines in the desired order

Subroutine SLOPES
Determines the slopes of the lines in the y-\(\bar{y}\) diagram

Subroutine YYBARIN
Fills in the missing \(y\) and \(\bar{y}\) information on the objects

Subroutine SPACES
Determines which space the objects are in, as seen from the image plane

Subroutine PRIMEX
Calculates the imaged positions and \(y-\bar{y}\) information

Subroutine POLARS
Puts the spaces seen from the image plane into polar coordinates as seen from the reference point

Subroutine SPLIT
Splits any objects whose image passes through infinity

Subroutine APTOBST
Any surface passing behind a mirror is obstructed by the aperture and any surface behind an imaging element (mirror) cannot be imaged by that surface

Subroutine CLAPT
All imaged objects must pass through the appropriate apertures

Subroutine ORDERP
Orders polar space by angle

Subroutine BAFSEE
Determines those objects that are seen and that obscure other objects

Subroutine OBJSEE
Prints out which objects are seen and their imaged space information

Subroutine ANGSEE
Determines the real space angles and positions of the baffles that are seen

Subroutine ELLIPSE
Projects all the objects into the exit pupil to produce a vignetting type diagram
Subroutine DOUBLER
Stores the necessary information for OBJSEEN AND ANGSEEN

Subroutine TPOLARX
When an object is split or shortened due to some other baffle or aperture, the new end points are determined

Subroutine ENLARGE
When an object is split, this program enlarges all the necessary arrays, and stores the new information

Subroutine LOWER
Looks for objects seen in the lower half (below the optical axis) of the imaged spaces
2. Program Two—Real and Imaged Spaces

Program CALRAD
  Reads the input and calls the subroutines in the desired order

Subroutine SLOPES
  Calculates the slopes of the lines in the y-ŷ diagram.

Subroutine LAGRANG
  Calculates the Lagrange invariant

Subroutine YYBARIN
  Determines the missing y-ŷ information in real space

Subroutine SPACES
  Determines which space the real space objects fall in.

Subroutine IMGLINE
  Determines the y value in the plane of the image of the stop as seen from the space being considered. Also determines the ŷ value in the plane of the image of the collector object in the space being considered. These two values are very useful in the y-ŷ approach.

Subroutine IMAGPRI
  The work horse of this program. Projects all objects along the desired image line. It determines the heights and distances as seen from this space. It splits any objects whose image passes through infinity and enlarges the arrays to store them.

Subroutine SEE
  Plots the image space as determined by IMAGPRI. The scale is internally set but can be overridden to "blow" up points of interest.

Subroutine LOWER
  Restores the original ALAYOUT array to start the next image space.

Subroutine SCALES
  Sets the scale of plot if one is not read in.

Subroutine CHANGEA
  Changes the relative distances in ALAYOUT to distances from the reference plane in the final space. This information is required for program three.
3. Program Three—Geometrical Power Transfer

Program VIEWFAC
Reads in the sources and collectors, and proceeds to section them in the desired manner. From these subsections the configuration power transfer factors are calculated and stored. The vectors of the line connecting points in real space and imaged space are passed to BDRDF and the important angles—angle out of the source and the angle into the collector—are stored.

Subroutine SETAPT
Determines the critical aperture, if one exists, that the radiation must pass through. If it is an imaged aperture it determines the imaged distance and height.

Subroutine BDRDF
Changes the vector information into a single angle to be used by subroutine SURFACE in program five.

Subroutine VECTOR
Called by BDRDF to create the necessary local system of basis vectors.

Subroutine NORMAL
Normalizes the vectors.

Subroutine MIRRORS
Images all the objects into any desired image space. This 14-line program does the work of a ray-tracing program. It is the basic $y$-$\tilde{y}$ diagram that facilitates the calculations.

Subroutine MIRRORA
Images the apertures for SETAPT.

Subroutine APERT
Determines if any intermediate object or its image shadows the collector so that the energy is not transferred.
4. Program Four--Loader Program

Program SPOTS

This program reads in parcels of power loaded onto the initial source section. Any section on the object can be specified with a specified amount of power. When finished loading the source object, the program processes the data and creates tape 2 for use by program five. The data need to be in a special format acceptable to program five. There are no subroutines to this program.
5. Program Five--Calculation of Radiation Distribution

Program DRIVER

Does the bookkeeping for the power transferred throughout the system. The systems of calculations are controlled by input cards for any level of scattered radiation desired. The benefits realized by this are (1) for the final level of scatter only radiation scattered to the image plane need be calculated, (2) if a change has been made to one surface that was the main source of power reaching the image plane, the radiation path can be run separately at a considerable savings.

Subroutine ARRANGER and ARANGE

Takes the data from tape 2 or 3 and arranges them in the array as required.

Subroutine WHERE

Shows where the power is distributed on all the objects considered.

Subroutine SHOWIT

If any power reaches the image plane, the array of power from that source is printed out. This tells how each parcel of power reached the image plane and how much it was.

Subroutine SURFACE

From the vane information and the angle into the source and angle out of the source an apparent reflectance coefficient is calculated for every section of every collector specified for this source.

Subroutines FFACTOR and GFACTOR

Calculates the power transferred within the vane structure itself to determine the radiant exitance of the surfaces of the vanes.
III. INPUT DATA REQUIRED

A. Programs One and Two Inputs

The data deck for program two is compatible with the data input deck for program one. More information is required for the second program, but this information is not read by the first program. Unless otherwise noted, any variables mentioned apply to both programs.

CARD 1 FORMAT (5X,F15.8,R7,3X,R7)

YZERO The reference point in the image plane. It is at this height in the image plane that the images are seen. Only program one reads these data.

PRINTS If this word reads PRINTIT, an extended printout is given. It has been used mainly to debug the program as it prints out most of the arrays whenever any major change has been made. If it reads any other word, the short form of output is printed.

PLOTSIT If this word is PLOT, program two will plot the layouts of each space.

CARD 2 FORMAT (10AB)

HID This prints a header or identification line.

CARD 3 FORMAT (8X,R8)

VERSION If VERSION is read as relative or eight blanks, the program will assume that the distances that will be read into column four of ALAYOUT will be the distance to the next object plane. If version reads the word ABSOLUTE, all such distances are from a common plane.

CARD 4 FORMAT (F3.0,F12.6,3E12.6,F7.4,F5.0)

ALAYOUT Column 1
A code to the program. A zero means that this is not a refracting nor reflecting element, but the y-\(y\) heights are known. A -1 is a refracting or reflecting surface and the y-\(y\) values are known. A +1 means that this is the position of some object and the program should calculate the y-\(y\) data.

Column 2
The y value at this plane in this space, if it is known.
Column 3
The \( \tilde{y} \) value, if it is known.

Column 4
The distance to the next object plane. For any given space the objects can appear in any order, or, if VERSION is absolute, the distance from a common plane.

Column 5
The radius of the object in this plane.

Column 6
The index of refraction of this space.

Column 7
Each object is tagged with an object number. A cone is specified by two positions along the optical axis and two radii. Hence there are two lines in ALAYOUT with the same object number.

Column 8
The program needs to know the direction of the surface normal. For cones a -1. is the inward normal and a +1. is the outer surface. For a disk the positive z direction is a +1. Read only by program two.

Column 9
The number of sections that this surface will be subdivided into. Read only by program two.

CARD 5 FORMAT (10X,F15.7,5X,F15.7,5X,F5.0)

APERTUR
Reads the maximum radius of the aperture and the minimum radius (the radius of the hole in the primary) and the line position in ALAYOUT. If this information is not included, the program will determine the maximum radius as the sum of \( y \) plus \( \tilde{y} \). Zero will be the minimum value.

CARD 5 FORMAT (7X,F13.10,7X,F13.10,7X,F13.10,7X,F13.7)

YREF
Value of the marginal ray at a reference plane in this space. This plane becomes the zero distance. This and remaining information read only by program two.

YBARREF
The \( \tilde{y} \) value in the reference plane in this space.

INDEX
The index of this space.

SCALE
The override scale factor of the plot. If blank, all objects will be scaled such that even the largest object will fit. Sometimes this is not desirable as other detail becomes too small.
B. Program Three Inputs

This program calculates the geometrical transfer factors.

CARD 1 FORMAT (5X,F5.1,5X,F5.1,5X,R7,3X,R3)

DELTA The number of subdivisions of each section. Default is 3 x 3.

SECJ The number of rib sections involved in the symmetry. Default value is five, but can be any odd number. It should be greater than one, and it would be unwise to be very large. If the value is other than five, program five needs to be altered slightly.

PRINT Print should normally be left blank. If the word is PRINTIT then for each factor stored there is a printout of about 30 words. It is only for the curious or for checking source coordinates and imaged collector positions.

NEWITAB If any punch is made in these columns the program will read off the mass storage file, the array ITAB. If a file is being partially redone, the final ITAB values are printed out and can be checked.

CARD 2 FORMAT (R6,4X,F3.0,3X,F3.0,4X,F3.0,3X,F3.0,3X,F2.0,4X,F3.0,4X,F3.0,4X,F3.0,2X,F3.0,2X,F3.0,7X,F3.0,12)

SOURCE If the word SOURCE is not punched in these columns, the program will treat the data as an obstruction. If the word is SOURCE, the card contains the source collector combination and any other pertinent information.

*******If the word is not SOURCE, the following******** meanings apply to the data card

OS1 If the shadow is a hole or disk, OSI refers to the row in ALAYOUT that is the obstruction. If the shadow is a cone OSI is the object number in ALAYOUT of the cone.

OS2 If OS2 is greater than zero, the shadow is caused by a disk. If OS2 is less than zero, the device causing the shadow is a cone. If OS2 equals zero, the shadow is caused by an aperture (hole).

*******If the word is SOURCE, the following******** meanings apply to the data cards

OBJS If the object has been defined in program two, then this is the source object, and the following word need not be filled in.

OS1 If the desired object was not numbered in program two, but there are lines from which the desired object can be made,
the two lines of interest go in OBJS and OBS. In particular
a disk may be made by specifying a single line twice. If the
object number is from program two, then fill in only OBJS.

OBJC
This is like OBJS but is the collector number.

OC1

OB2
This is like OBJSS but is the second surface of the collector.

OC2

NOTE: If both the object and collector numbers are known, none of the
following information is necessary.

ISS=XSS= Maximum sections into which this newly defined object SOURCE
HOLD (5) is divided.

IMAX=XMAX Maximum sections into which this newly defined collector object
HOLD (6) is divided.

SNORMAL The normal of the newly defined source
HOLD (7)

DNORMAL The normal of the newly defined collector.
HOLD (8)

NS=SN The number this newly defined SOURCE is called.
HOLD (9)

NC=CN The number this newly defined COLLECTOR is called.
HOLD (11)

BLOCKIN If this word is left blank, the program assumes that this
BLOCK information is to be stored into block one and the next source
HOLD (11) will go into block two unless its block is specified. This
feature allows for the extension of files or replacement of
blocks of information.
C. Program Four Inputs

Program SPOTS
Card 1
FORMAT(515)
ICOL The random access mass storage BLOCK into which the data will be stored.
MS The total number of radial sections around the source. (With the present version of the program, it must be 5.)
NS The number of axial sections on the source. It can have 1. to 10. sections, but they must correspond to the number of sections it had in program three.
MLOAD Like MS, it must be 5. It represents the maximum number of radial sections on the fictitious object that is putting power onto the so-called "source" object.
NLOAD The number of axial sections on the object that load the "source object."

The first set of power transfers calculated by program three should be to any object that will be considered as a possible source. Any power transfer will do. If one is clever he can make these be some of the required transfers in some cases. Program five needs to fetch an array for how the power was loaded onto the source and an ANGIN array. Program four writes the power array. Program three sets up the ANGIN array. If this is a dummy transfer choose the object with the least number of axial sections (in the same space as the source) as the MLOAD-NLOAD object to load the source.

Card 2
FORMAT(215,E20.10)
IR The radial section of the source to be loaded.
IZ The axial section of the source to be loaded.
X The amount of power to be loaded on section (IR,IZ) of the source.

As long as power is being loaded onto the same "source" object, more cards may be read in. To terminate the loading of this object, the
The program will check for an end-of-file card. Having found one it will then check for another object to load as an additional source. If none is found the program will terminate normally. Any number of objects may be considered as sources. ICOL must correspond to the power transfer ICOL of program three.
D. Program Five Inputs

This program is mostly bookkeeping of many thousands of words in several large arrays.

CARD 1 FORMAT (I5,F5.0,2I5,F10.8,I5)

LEVEL The level of scatter from which the program is starting. The program can be run through level one and stopped, if all looks well, and the files have been preserved; second-order scatter can be considered by starting at that level. The program can presently go up to fourth-order scatter. An order of scatter may in fact be two scatters. One "scatter" means the radiation came into a section and left the section after any number of internal scatters.

ANG The ANG of radiation on the initial surface. For diffuse scatter 90° is a starting value. It will not accept a zero value.

L The program will start with level LEVEL scatter and do up to and including level L scatter.

IM The object that will be treated as the special collector and all increments of power onto this object will be printed out. Usually this should be the image plane.

RAD The radius of the edge of the vanes in the same units as the data in the previous programs.

IS The number of the object that has been sliced: like the cutaway portion of a cone used as a sun shield.

CARD 2 FORMAT (16I5)

INKEY The number of objects being considered.

CARD 3 FORMAT (16I5)

KEY(I) An integer array with INKEY number of words in it. Each word is the number of sections in object numbered I. I is the Ith word in KEY.

CARD 4 FORMAT (16I5)

ITAB2 The number designation of the collectors corresponding in order to the number designation of the sources in IEMIT.

CARD 5 FORMAT (16I5)

IEMIT The sources as emitters to the corresponding collectors in ITAB2.

CARD 6 FORMAT (16I5)

LIMITS(I) An integer array informing the program to use as sources at level I the sources in IEMIT up to the value LIMITS(I).
CARD 7 FORMAT (2F20.10,4F10.5)

SURFACE
Contains the basic average characteristics of each section of the system.
Word 1--the vane angle.
Word 2--the vane separation.
Word 3--the vane depth.
Word 4--the total diffuse reflectance coefficient of the coating.
Word 5--the section length. This gives information about the number of edges involved.
Word 6--the radius of the section involved. Do not confuse it with any edge radius. It is the radius of the cone, or whatever, at the location of this section.

CARD 8 FORMAT (5I5)

LOOK4
A two-dimensional array; the level of scatter being considered is read across (columns), then at this level of scatter the objects whose numbers fall in that column are considered scatterers at this level.

CARD 9 FORMAT (5F15.10)

SLICE
The percent of area of each section of object IS that physically exists. It slices away sections or portions of sections when there is, for example, a 45° cut in a cylindrical or cone-shaped baffle.
IV. OUTPUT

Although many months can be spent on the design of a baffle system and considerable foresight can be put into its design to utilize the proper principles of baffling, there are few data that will predict its performance quantitatively, unless a quantitative analysis program has been run. There are several approaches that can and have been used to indicate how the system performs. However, one would like to know why the system performed as it did. And, ideally, all this would be done relatively inexpensively. APART does this by using five programs as levels of improvement. These programs are compatible and can be run as a single program, but that is not desirable from a cost standpoint. It may seem a formidable task to learn five programs, however, this is an illusion. It is really one big program with five parts in series instead of overlayed. By running them separately, one can make improvements without having made costly computer runs that will no longer be of any use as the system is changed.

Briefly, the five levels of information are

1. Program one--What are the areas that are seen from the image plane, and at what angle are they seen in real space?
2. Program two--What are the principal paths of power to the critical areas that are seen from the image plane?
3. Program three--What is the power transfer relationships and the angles that the power leaves a source section and enters a collector section?
4. Program four--What is the loaded power distribution?
5. Program five--How is the scattered radiation distributed throughout the system for the given conditions of power loading from the sources? What are the parcels of power from each contributing section that reach the image plane?
A. Program One Output

Because there is very little knowledge about the performance of the system to be analyzed, this program needs to establish those areas of the system that assume a special importance. These "critical" areas are those areas that are seen from the image plane. Besides knowing the exact locations of these critical areas, it is helpful to know the angle at which these objects (or imaged objects) are seen. This will assist in determining if a different vane structure design would be beneficial or whether the radiation to these areas must be minimized so as to reduce their contribution. Changes in the system can now be made without even knowing how much power is being transferred because one will develop a "sense" that it is going to be too much.

A general overview of the different arrays of output will help keep things at a simple level. Later the discussion will be about the inter-relation of these arrays. For the purpose of this discussion, certain definitions are created that may not exist in the program but that will help to separate the overall output into modules of information.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>TITLE PAGE</td>
<td>The first page of information, it may contain some or all of the following: &lt;br&gt; (1) The title or identification of the run. &lt;br&gt; (2) The reference point in the image plane. &lt;br&gt; (3) The value of the Lagrange invariant. &lt;br&gt; (4) The array SLOPE, containing the slope of the line in the y-y diagram along which each object is positioned.</td>
</tr>
<tr>
<td>ALAYOUT</td>
<td>The printout of the array ALAYOUT during its various stages of development. The printout may appear under the heading of REAL SPACE or RESECTIONED REAL SPACE. This array contains the majority of the input from which the program works. It contains the location and size of the baffles and the y-y information at various points. See the input for program one for a more detailed discussion.</td>
</tr>
<tr>
<td>SPACE</td>
<td>The array SPACE numbers the spaces in which each object is located.</td>
</tr>
<tr>
<td>PRIME</td>
<td>The array PRIME contains the imaged objects as seen from the image plane space. It appears in the output under the</td>
</tr>
</tbody>
</table>
headings of PRIMED SPACE IN RECTANGULAR COORDINATES or RESECTIONED PRIMED SPACE.

POLAR The array POLAR is the array PRIME put into polar coordinates relative to the reference point in the image plane. It will appear under the headings PRIMED SPACE IN POLAR COORDINATES or THE POLAR SPACE AS SEEN FROM THE DESIGNATED POINT IN THE IMAGE PLANE.

PPRIME The majority of this page is the array PPRIME, which is that set of imaged objects seen from the reference point in the image plane, to the exclusion of all other objects. The heading of this page is THE NUMBER OF OBJECTS SEEN FROM THIS IMAGE POINT IS I, where I is the number of objects in PPRIME.

RECAP A list of all the objects in numerical order, indicating whether an object is seen or not. If it is seen, the coordinates of the two ends of the imaged object are printed.

REAL SEEN The objects that are seen are printed in the order that they are seen. For each object seen, certain real space information is printed. In PPRIME and RECAP the information was about the imaged space. REAL SEEN yields information such as what portion of the real object is seen from the image plane and at what angle is it seen in real space.

ELLIPSE The last array of program output. It is the information about the projection of all the objects onto the exit pupil plane.

There are two versions possible for output. For simplicity they will be called the long and short versions. If the word PRINT reads PRINTIT on the input card, the long version will be printed. With any other word, the short form will be printed. The long version includes all of the output of the short version, so the long version will be described.

TITLE PAGE

(1) The program will first print the title or identification of the system as it is input into the array HID.

(2) The slope of the line in the y-ŷ diagram that follows the object plane I (row I) in the array ALAYOUT.
(3) In the case above, the slope of the line between points one and
two is 0.00000, whereas for point three the slope of the line after it
is -32.70133 and before it it is 0.00000. Point three is a break point,
so at this point there is some refracting or reflecting element.

(4) The reference point used is printed as follows:
THE REFERENCE IMAGE POINT IS (0.0, 90.00).
The value of YZERO read in was 90.00, which designated the point in the
image plane from which the system is looking out. Because the program
presently assumes rotational symmetry, the x coordinate will always be
0.0.

(5) The Lagrange invariant is next printed.
CHI = 10.42500000.
ALAYOUT is printed with all previously unknown y-ŷ information
included. Because the output is in Fortran F format, and usually the
object plane is a large distance from the first surface, the first line
of ALAYOUT may have values too large to be printed.
SPACE is the next array to be printed.

<table>
<thead>
<tr>
<th>REF SUR</th>
<th>SPACE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
</tr>
</tbody>
</table>

Each row in ALAYOUT is considered as an object plane and is in a
specified space. If the object is along the first line in the y-ŷ
diagram, it is considered to be in space one, along the second line it
is in space two, etc. Two other variables printed on this page are:

YEPRIME is the y' value (the height of the marginal ray) at the exit pupil.

IMGLNES is the slope of the last or image line in the y-\( \bar{y} \) diagram.

The array PRIME is printed giving the distance that the imaged object planes in ALAYOUT appear to be from the image plane, the height of the images, and the y-\( \bar{y} \) of the imaged planes. The first column is the row number, identical to the corresponding object (in real space) in ALAYOUT. The last column is the object number. At this stage there may be negative object numbers, which were not there before. The program has checked and found that the images of these objects pass through infinity. The negative object number codes the program to split this object into two objects; one object will retain the original object number and the other will be 100 larger.

PRIMED SPACE IN POLAR COORDINATES is the next printout (see p. 29). The information in the array PRIME, which is rectangular coordinates, is now put into polar coordinates relative to the point (0,,YZERO,ZIMAGE). YZERO is the reference point in the image plane, and ZIMAGE is the z coordinate of the image plane. Column one is the reference row in the array POLAR. The reference row in the array PRIME corresponding to this row is in column four. It is important that the two are not interchanged. Whereas any row of object information in POLAR can be relocated into the order that the objects are seen, the arrays ALAYOUT and PRIME are enlarged only to make rows available for split objects. Column two is the distance between the reference point in the image plane and the edge of the imaged object. Column three is the angle from the plus z axis to the edge of the imaged object. Column four is the reference row in PRIME (or ALAYOUT) for the referenced object number. Column five is the object number. Column six is the status of this object.

(1) A zero means that this object number will no longer be considered. This may be because from the start it was only a reference plane or because it has been processed and for one reason or another it
is not seen from the image plane.

(2) There is no status number one.

(3) A two means that the object was seen up to this edge of the object. As explained previously, there are two rows of information for each object. The status number two will appear in the row where the object number appears for the second time in the array POLAR. The status for the object the first time it appears will be a three or four.

(4) A three means that the object is seen starting from this edge of the object and object space is seen between the start of this object and the end of the previous object. By checking the last edge seen one will notice that its angle is not the same as the start of this new object. For example, in a Cassegrainian system with an inner conical baffle in the hole of the primary, the surface beyond the edge of the primary is seen in reflection by the secondary (this surface may be the tube wall or the annulus surface between the primary and the tube wall). The next surface seen in reflection is the primary (which both scatters and reflects the object field). Then the inner conical baffle is seen in reflection. When the start of this object is seen, its status will be three because of the intervening object space.

(5) A four means that the object is seen starting with this point. The angle in column three should be the same as the angle at the end of the previous object after all the objects are processed. Keep in mind that there is no previous object for the first status number four and the entire column is initialized to the value of four to start with, and only by processing are the numbers changed to threes, twos, or zeros.

The row order that the objects are finally assigned has only minor significance. Objects whose status becomes zero are passed over by the program from that point on and will no longer be rearranged. Hence, they may appear anywhere in POLAR. For objects that are seen, the row with status four or three must appear before the end of the same object, which will have a status two. It must also appear before the start of the next object seen. POLAR is ordered by increasing angle (column three). Because in most cases the angle that ends one object is
the same angle that starts the next object (because the first object shadowed the second object) the row that ends the first object may appear before or after the start of the second object.

Primed space in polar coordinates

<table>
<thead>
<tr>
<th>SUR NUM</th>
<th>RADIUS</th>
<th>ANGLE</th>
<th>REF NUM</th>
<th>OBJ NUM</th>
<th>STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0000</td>
<td>0.000</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>90.0055</td>
<td>-1.570</td>
<td>65.0</td>
<td>33.0</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>2390.5952</td>
<td>2.511</td>
<td>62.0</td>
<td>34.0</td>
<td>4.0</td>
</tr>
<tr>
<td>4</td>
<td>10.0005</td>
<td>1.561</td>
<td>64.0</td>
<td>33.0</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>1944.6777</td>
<td>3.041</td>
<td>60.0</td>
<td>26.0</td>
<td>4.0</td>
</tr>
<tr>
<td>6</td>
<td>1940.3274</td>
<td>3.041</td>
<td>63.0</td>
<td>34.0</td>
<td>2.0</td>
</tr>
<tr>
<td>7</td>
<td>5413.4261</td>
<td>3.100</td>
<td>58.0</td>
<td>26.0</td>
<td>2.0</td>
</tr>
<tr>
<td>8</td>
<td>7571.4417</td>
<td>3.107</td>
<td>29.0</td>
<td>14.0</td>
<td>3.0</td>
</tr>
<tr>
<td>9</td>
<td>7213.1160</td>
<td>3.107</td>
<td>42.0</td>
<td>19.0</td>
<td>0.0</td>
</tr>
<tr>
<td>10</td>
<td>7213.1260</td>
<td>3.107</td>
<td>43.0</td>
<td>19.0</td>
<td>0.0</td>
</tr>
<tr>
<td>11</td>
<td>7602.3658</td>
<td>3.108</td>
<td>30.0</td>
<td>14.0</td>
<td>2.0</td>
</tr>
<tr>
<td>12</td>
<td>0.0000</td>
<td>0.000</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Up to this point in the program, information has been filled in, imaged, and transformed, but not processed in the sense that it has started to determine which objects are seen. Most of the information discussed so far will appear in both the long and short versions of output. It is essentially the starting conditions for the calculations. The user should check this information against other sources to verify the accuracy of the input. For instance, one may check the value of the Lagrange invariant computed by this program with that from the optical system design program. The value and position of the exit pupil are another example of an easy check.

In the short version of the output the final values of the arrays ALAYOUT, PRIME, and POLAR are printed after all (not each) steps of the process are completed. In the long version, which we will now follow through, the arrays are printed after each step.

The objects whose image passes through infinity have been flagged with negative object numbers. The program sorts for these objects and
resections them into two objects, one whose image approaches minus infinity, and the other whose image approaches plus infinity. One of the two sections will retain the original object number, whereas other sections will be given an object number 100 larger. Presently, the arrays can hold 100 rows of information, so all object numbers greater than 100 are recognized as split objects. After an object that passes through infinity is split, it may again be split later by the subroutine BAFSEEN. In this case, an object number in the hundreds is incremented by 100 again. Subroutine BAFSEEN determines which baffles are seen and which are obscured. It is possible that the image of an object will be seen and then have its image shielded behind the image of some other object and then appear again at the termination of the shielding object. In this case, the object will be split again. BAFSEEN will be discussed in greater detail later.

When an object is split because its image passes through infinity, the program checks for three maximum values of the objects with positive object numbers. These values are the maximum size, the maximum z coordinate, and the minimum z coordinate of any object or image. The program will attempt to image the split objects from one plane (end point of the object) toward plus or minus infinity, whichever is appropriate. If the image is going in the plus z direction, it will use the maximum z value as the other "end" of the imaged object. The program will check for the case where this would give an image of zero length. This would happen when the original end of the object happens to have the maximum z coordinate. If this is the case, the maximum z value will be increased, and this value will be used as the "end" of the imaged object. The imaged object height is determined for this new end point. If it is larger than the maximum height of all the other objects, and the maximum height value is not that of its end point, the program will use the maximum height to determine the z coordinate of the imaged object.

The approach above does not throw out any lines, provides enough information to plot the layout, but yet does not print out values that
are unmeaningfully large. A word of caution is in order because the image of the object may be seen beyond this arbitrary cutoff point. Usually, awareness of this fact is sufficient, but one has the option to split the object on just each side of the plane that is imaged at infinity (say a hundredth of a millimeter), and then the program will not put a large gap about that plane.

After the new end points are determined, two new rows of information are added to the arrays ALAYOUT, PRIME, and POLAR. In ALAYOUT the information is for the real space positions of the two new end points, in PRIME the image space data are entered, and in POLAR the image space information is entered in polar coordinates. After this is completed, the three arrays are printed out so they can be checked for accuracy.

The program then calls the subroutine APTOBST, which stands for aperture obstruction. There are two ways that an imaging aperture can act as an obstruction. One example is that of a simple lens inserted halfway down a tube. As one looks into the tube, one sees the tube wall as an object in real space until the lens. Then the tube wall is seen as imaged by the lens. From a given end of the tube the lens will image only that space beyond it. From the other end of the tube the lens will image the other half of the tube. In the y-y diagram it will do both, so the program checks for the appropriate space to reimage. The second way that the aperture acts as an obstruction is more straightforward. If the aperture is a mirror, then objects in its real space that go behind it are obscured. You cannot see objects through the mirror, only reflections in the mirror. Real space objects must appear outside the aperture obstruction, whereas imaged objects must appear inside the aperture. The program takes into account such things as the image of the primary that is perforated. Objects, in this case the image plane, will be seen through the hole in the primary even though it is beyond the plane of the imaging device and inside the outside clear aperture.

The program starts with the real image space and finds the first imaging device. If this happens to be a mirror, it checks for objects
in real image space that appear behind it. These objects, or portions thereof, will be obscured, and the array POLAR will be changed to indicate the new end points seen or that the object is totally obscured (such an object will be given a status of zero). As each object is checked for each space, the object number in ALAYOUT (column 8 in the printout) is changed to its negative value to indicate that the check has been completed. Only the first row in which the object number appears has its value changed. A similar flag had been set for objects whose image passed through infinity. That flag has been cleared by now and this will not cause any problems for the program.

As each space is completed, the three arrays ALAYOUT, PRIME, and POLAR, are printed and can be checked if desired. Under certain circumstances the arrays will be enlarged because a real space object can appear outside the maximum clear aperture and inside the minimum clear aperture. Under these circumstances the object will be split into two objects.

Just before the program clears this subroutine, the flags (negative object numbers) are cleared, and the three arrays are printed. This is an aid to determine if the correct information is stored in the arrays for the next subroutine CLAPT and to check for accuracy. Subroutine CLAPT (clear aperture) ensures that all images that are seen are seen through the appropriate series of imaging apertures. This subroutine does not check for clear apertures that do not image. This will be done in subroutine BAFSEEN. After this is completed the long version of the output will print the three arrays ALAYOUT, PRIME, and POLAR.

The program has now arranged the array POLAR so that the objects it sees are legitimate objects (or imaged objects). Starting with the object with the largest positive angle in POLAR it proceeds to determine which objects are seen and what portions are obscured. Again there are cases where an object may be seen, then obscured, and then seen again. As before, the necessary arrays are enlarged and in the long printout the new arrays are printed for checking. At the termination of this program the array SPACE will be printed in the long version. From this point on there is no difference between the long and short versions of the output.
The final form of the arrays ALAYOUT, PRIME, and POLAR are printed. One will notice that in the array POLAR the status of the objects has been changed from almost all four-four combinations (four for the first row in which the object number appears and also the second row), to four-two or zero-zero combinations. If the status of the object is now zero, it cannot be seen from the given reference point. For all other objects, the row in which its object number first appears must have a status of four or three. For these objects the row in which its object number next appears must have a status number of two. The difference between a status of three or four is that there are three signals that the object field (or some unaccounted space) intervenes between the end of the last object seen and the start of the new one. This would signal such cases as where the object field is seen directly from the image plane. It is necessary that the object field be seen, so the user needs to determine whether the baffles need redesign or not.

The program calls the subroutine OBJSEEN (objects seen), which will process the data in POLAR slightly and make the necessary changes in the array PPRIME (not the array PRIME). The meaningful results of the program are now printed, starting with

THE NUMBER OF OBJECTS SEEN FROM THIS IMAGE POINT IS N

where N is the number of objects seen. In reality, one may actually see fewer objects because the program may have split an object. It is easy for the user to determine if this is the case because there will be an object with an object number 100 larger than any object initially read in.

Then the RECAP is printed. A list of all the objects in numerical order indicates whether an object is seen or not. If the object is seen, the coordinates of the two ends of the imaged object are printed.

The data printed from PPRIME and in the RECAP are for image space. In the subroutine ANGSEEN, which the program calls next, the conjugate image points of the imaged objects are found in real space. The y-\(\bar{y}\) coordinates and the object's real space coordinates (of the section that is seen) are printed, along with the angle from which the object is seen in real space. This angle will normally be different than the angle
made with the imaged object, but it is the angle at which the radiation is scattered to reach the next collector. The long version also prints the direction cosines of the real space object (OBJM, OBJN) and the direction cosines (CRITM, CRITN) of the ray connecting the reference point and the end point of the collector section.

FOR OBJ N.

<table>
<thead>
<tr>
<th>OBJM</th>
<th>OBJN</th>
<th>CRITM</th>
<th>CRITN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>0.00</td>
<td>-1.00</td>
<td>0.995</td>
</tr>
<tr>
<td>1.00</td>
<td>0.00</td>
<td>-0.250</td>
<td>0.968</td>
</tr>
<tr>
<td>1.00</td>
<td>0.00</td>
<td>-0.384</td>
<td>0.923</td>
</tr>
<tr>
<td>1.00</td>
<td>0.00</td>
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<td>0.868</td>
</tr>
<tr>
<td>1.00</td>
<td>0.00</td>
<td>-0.590</td>
<td>0.808</td>
</tr>
</tbody>
</table>

Distance to Angle of
next imaging sur Baffle height Angle of
real image space reflection

<table>
<thead>
<tr>
<th>Y</th>
<th>Y</th>
<th>Distance to</th>
<th>Baffle height</th>
<th>Angle of</th>
</tr>
</thead>
<tbody>
<tr>
<td>80.43</td>
<td>193.02</td>
<td>1930.50</td>
<td>285.00</td>
<td>95.76</td>
</tr>
<tr>
<td>80.43</td>
<td>193.02</td>
<td>1930.50</td>
<td>588.75</td>
<td>104.49</td>
</tr>
<tr>
<td>80.43</td>
<td>193.02</td>
<td>1930.50</td>
<td>892.50</td>
<td>112.57</td>
</tr>
<tr>
<td>80.43</td>
<td>193.02</td>
<td>1930.50</td>
<td>1196.25</td>
<td>119.81</td>
</tr>
<tr>
<td>80.43</td>
<td>193.02</td>
<td>1930.50</td>
<td>1500.00</td>
<td>126.14</td>
</tr>
</tbody>
</table>

FOR OBJ M.

etc.

In the example above, N and M would be object numbers. In this case object N is a vertical object. For all objects OBJL, the direction cosine from the x axis is zero because all calculations are done in the meridional plane. The y value (the marginal ray) in this plane in real space is 80.43, and the \( \tilde{y} \) (the chief ray) value is 193.02. The distance to the next imaging surface (if this is the real image space, the distance to the image plane) is given as 1930.50 units, the units being whatever was input. The baffle in real space varies from 285. to 1500. units. The program has taken the coordinates of the two end points and split the length of the object into four sections. To describe the four sections, it needs five sets of coordinates, hence the five rows of printout at this stage. The last column of data is the ANGLE OF REFLECTION at which this point on the object is seen in real space.
By knowing which sections are seen, at what angle, and some basic concepts of baffling, one can determine some of the more blatant flaws in the design of the baffle system. An ideal design would keep stray radiation off all the sections that are seen from the image plane. Because this is impossible in a practical case, the design should be such that as many scatters as possible are made before power reaches these areas. If there is any vane structure, the design should also attempt to keep the power off the critical surfaces (those seen by the image plane). Sometimes, better coatings or redesigning the vane structure on these critical areas will give the necessary improvement in performance. If this is not the case, one will have to determine the path of the radiation to the critical area and attempt to remove or reduce the amount of power transferred to it. Sometimes this may be obvious, but if it is not, then the third program will be the next level to use. It will give the percent of power transferred from section to section and angular information (see the discussion of program three for more detailed information).

The program has considered only objects whose image lies above the optical axis. It now returns to do the calculation for the lower half. This was done for computer convenience, as all that needs to be done is to establish the original ALAYOUT array and to change the YZERO value to -YZERO. The sequence of printouts repeats itself with the new objects that are seen in the lower half.

The final array to be printed contains the necessary information to plot the projection of all the apertures onto the exit pupil. These plots help visualize the series of apertures that are seen from the image plane. The format of the printout is as follows:

```
REF CENTER RADIUS XMAX YMAX YMIN
```

REF is the row in ELLINFO in which the information for this aperture is stored. CENTER is the point in the exit pupil to which the center of the aperture is projected. Remember that everything has been done in the meridional plane so the value given is the y value, the x coordinate being zero. RADIUS is the radius of the aperture at its projection in
the exit pupil. The next three values are easily calculated from columns two and three and are printed for convenience. $X_{\text{MAX}}$ is the maximum $x$ coordinate that this aperture will appear to have when projected onto the exit pupil. It obviously must be the value of the radius. $Y_{\text{MAX}}$ is the maximum height of the projected aperture and is equal to $\text{CENTER}+\text{RADIUS}$. $Y_{\text{MIN}}$ is the minimum height of the projected aperture in the exit pupil and is equal to $\text{CENTER}-\text{RADIUS}$. $I$ is the row in ALAYOUT for which the information for this aperture was taken.

This completes the types of output that the user can presently expect from program one. It may be desirable to further limit the output of the short version for most users because the pertinent information in many cases is contained in the last four types of information printed. At the present time, the arrays ALAYOUT, PRIME, and POLAR are helpful in confirming that the data were input correctly and in the explanation of "why" certain objects are seen or not. Another aid in checking the accuracy of the input data is program two's array that is printed out as CHANGEA. (See the explanation of the data output for program two.) The data decks for programs one and two are compatible and are relatively inexpensive to run, so running both programs to check the data input is sensible.
B. Program Two Output

The purpose of program two is to establish the principal radiation paths to the critical areas, i.e., those areas that are seen from the image plane as annotated in program one's output. Program one has already established the radiation path from these critical areas to the image plane, be it by reflection, refraction, or directly. There are two important aids in program two to help determine these radiation paths, the plots of all the objects as seen from each space, and the file BASICA, which this program creates, prints out, and catalogs for use by program three. Most of the data that are printed have the format of some program one output. In fact, some of the information is identical. Program two does more than program one in the sense that it not only looks back from the image plane, but it also looks into the system from object space and all intermediate spaces. By looking into the optical system one can establish most of the radiation paths that propagate the radiation through the system. This program is not the one that will determine how much power is transferred, but it does eliminate the necessity for many calculations by the third program, which is the most time consuming. Unfortunately, program two cannot do as much as program one because it does not determine which sections see other sections as program one does. One could write such a program, but in most cases it would not be worth the time to run it. This program needs to establish the radiation paths to the image plane, which can, in most cases, be done by looking at the plotted output of program two. In the cases where one would not be sure, it can be left to program three to determine. It may turn out that no power is transferred, in which case one can ignore this set of arrays.

A general overview of the various arrays of output will help keep things in perspective. As in program one, there are two forms of output, a long one and a short one. The long one is a debugging aid, and the short one contains all the necessary information for understanding what the program has done and for determining the radiation paths. Anyone
familiar with program one output will easily recognize most of the output formats in program two. The modules of information are

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>TITLE PAGE</td>
<td>The first page of printout. The short version does not contain the items that have an asterisk. *(1) The title or identification of the run. *(2) The array SLOPE, containing the slope of the line in the $y^2$ diagram along which each object is positioned. *(3) The value of the Lagrange invariant.</td>
</tr>
<tr>
<td>ALAYOUT</td>
<td>The printout of the array ALAYOUT during its various stages of development. The printout will appear under the heading REAL space, CHANGEA, or without the heading. The differences will be explained later. This array contains the majority of information that the program works with, including the location and size of the baffles and the $y^2$ information for the various points in real space.</td>
</tr>
<tr>
<td>SPACE</td>
<td>The array SPACE numbers the space each object is in.</td>
</tr>
<tr>
<td>PRIME</td>
<td>The array PRIME contains the imaged objects as seen from the space presently being considered. Unlike program one, this program images all the objects for each of the spaces. The array will always be printed under the heading POSITIVE PRIMED SPACE IN RECTANGULAR COORDINATES. Under this heading the program prints out which line was used in the $y^2$ diagram to image the objects. It also indicates the space from which the program is looking. Both are the same, line one meaning space one, etc. But for those less familiar with the $y^2$ diagram the duplication in different words is helpful.</td>
</tr>
<tr>
<td>CHANGEA</td>
<td>Although this page of output has already been mentioned as one of the various forms of ALAYOUT, it is of such importance that it will also be considered as a separate module. This array is put on file BASICA for later use by program three.</td>
</tr>
</tbody>
</table>
TITL'E PAGE

(1) The program will first print the title or identification of the system as input into the array HID.

(2) The slope of the line in the \( y \)-\( y \) diagram that follows the object plane 1 (row 1) in the array ALAYOUT.

<table>
<thead>
<tr>
<th>Object plane I</th>
<th>Slope I to I+1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.00000</td>
</tr>
<tr>
<td>2</td>
<td>0.00000</td>
</tr>
<tr>
<td>3</td>
<td>-32.70133</td>
</tr>
<tr>
<td>4</td>
<td>-32.70133</td>
</tr>
<tr>
<td>5</td>
<td>-1.40676</td>
</tr>
<tr>
<td>6</td>
<td>-1.40676</td>
</tr>
</tbody>
</table>

(3) In the case above, the slope of the line between points one and two is 0.00000, whereas for point three the slope of the line after it is -32.70133 and before it it is 0.00000. Point three is a break point, so at this point there is some refracting or reflecting element. This array, SLOPE, is printed in the long version only.

(4) The Lagrange invariant is next printed.

\[ \text{CHI} = 10.42500000 \]

ALAYOUT

When the array ALAYOUT was read from the data cards, certain blocks of information may have been missing. In particular the \( y \)-\( \bar{y} \) values probably will not be known for all the planes of the objects. Before the program starts imaging the objects, it proceeds to fill in the missing data. The full array is then printed. The power of using the \( y \)-\( \bar{y} \) diagram is stored in this array.

The array will appear several times for different reasons. These reasons will be discussed in the sequence in which they appear. It should also be noted that the output is in Fortran F format, and usually the object plane is a large distance from the first surface. Therefore, the first line of ALAYOUT may have values that overflow the allotted space.

SPACE is the next array printed in the long version.
Each row in ALAYOUT is considered as an object plane and is in a specified space. If the object is along the first line in the $y$-$\bar{y}$ diagram, it is considered to be in space one, along the second line, it is in space two, etc.

After the array SPACE, the long version may have the array ALAYOUT printed twice before the image space (the array PRIME) is printed. The program has taken the object line, line one in the $y$-$\bar{y}$ diagram, and has checked to see if any imaged objects pass through infinity. If so, the program will print ALAYOUT as the subroutine was entered (the array will not have the words REAL SPACE printed at the top of the page), and again print ALAYOUT as it exits the subroutine (REAL SPACE will head the page). The user can then check that the object was split correctly and that the correct $y$-$\bar{y}$ values were assigned.

If no object needs to be split or if the short version is requested, the ALAYOUT arrays mentioned above will not be printed and the array PRIME will be. This page of information has the heading:

**POSITIVE PRIMED SPACE IN RECTANGULAR COORDINATES**

**ALL OBJECTS ARE IMAGED ALONG THE Y-YBAR LINE NUMBER 1.**

**OBJECTS AND IMAGES APPEAR AS THEY WOULD BE SEEN FROM SPACE 1.**

<table>
<thead>
<tr>
<th>REF SUR</th>
<th>SPACE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
</tr>
</tbody>
</table>

The array PRIME is the array ALAYOUT imaged along the line mentioned in row two of the output for this page. This will be done for all the (imaging) lines in the $y$-$\bar{y}$ diagram, or, in other words, for all spaces. The information for the plot is taken from these arrays.

The first column (SUR) is really the reference row in PRIME (also ALAYOUT) that stores the information about this image object (or real object). $Y$ PRIME is the $y'$ value of the imaged object, while $YBAR$ PRIME...
is its $\tilde{y}'$ value of the imaged object. The program has read in the
reference $y-\tilde{y}$ values of the plane that will be used as the origin for
the calculation of distances $Z$ FROM REF PLANE. IMAGE BAFFLE HT is the
imaged baffle height, the height at which the object appears to be when
looking from the space noted in line two. OBJ NUM identifies the object
number that was imaged. The plotted output will be discussed later,
but it is worthwhile to point out that it is this array that the plot
routine attempts to plot. Because the scale of the plot can be selected,
the possibility exists that the entire image of the object will be out­
side the bounds of the plotting paper and hence cannot be plotted. If
part of the image is on the paper, that portion will be plotted, and a
message in the printout will inform the user. It is for the above
two reasons that sometimes not all the objects in the array PRIME are
plotted.

If a plot has been requested, the following message will be printed
beneath the array PRIME:

**IF ANY INFORMATION FOLLOWS IT PERTAINS TO THE PLOT AS SEEN FROM SPACE 1**

If all the images have dimensions that will plot on the paper, there will
not be any further messages. Examples of all the possible message
formats are

- THE MIN HGT FOR OBJ num EXCEEDS THE PLOTTING PAPER SIZE FOR THE DESIRED SCALE
- Z1 AND Z2 FOR OBJECT NUMBER num IS LESS THAN -60. INCHES FOR THIS SCALE
- Z1 AND Z2 FOR OBJECT NUMBER num IS GREATER THAN +60. INCHES FOR THIS SCALE
- ONLY A PORTION OF OBJECT num WAS PLOTTED

The first three messages shou.d be self-explanatory. If the end
points of the object have a $y$ value (height) greater than 5.5 in., it is
entirely off the paper. The plotting paper that has normally been used
is a scroll 11 in. wide. With the optical axis along the center line
of the paper, this allows scaled objects to be 5.5 in. high and many
feet long. Sixty in. was chosen as the maximum distance from the origin
(in either direction) that any object would be plotted, for each space.
For a Cassegrainian type system there are three spaces, so the plot could
be 30 ft long. The 60 in. can be changed if one finds that desirable.
Experience has shown that in most cases plots do not reach the maximum length because the images tend to go off the paper in the vertical direction and therefore are self-limiting.

The fourth possible message (ONLY A PORTION OF OBJECT num WAS PLOTTED) can lead to some confusion because of the present logic of the program. If only one of the two end points of the imaged object has a y value of less than 5.5 in. the program will print the fourth message implying that a portion of the object will always be plotted. The program will calculate the coordinates where the plot of the image would go off the plotting paper in the vertical direction. Next it checks the z coordinates for that portion to be plotted. It can happen that both these points are beyond 60 in. from the origin. Then message two or three will be printed indicating that the image was not even partially plotted. Because the sequence is first message four and then message two or three for the given object, it should not cause too much confusion.

After all the plotting is done, the program prints ALAYOUT corresponding to the array PRIME that was printed and plotted. The Ith row in PRIME is the image of the Ith row in ALAYOUT for this space. For each space the program will print the image space (array PRIME) and the real space (the array ALAYOUT). One may question why the real space would be changing. From each space, different objects have their images pass through infinity, so the array ALAYOUT will have different objects split.

After each space has been plotted, the program reestablishes the original ALAYOUT array. The objects that had been split are merged to give the original object. In the long version this array will be printed. The program then proceeds to the next space until all spaces have been plotted. It will start by checking for images that pass through infinity and proceed as described above.

After all the spaces have been considered, the program will make two important changes to the array ALAYOUT. Up until now the program has taken the data from column four to be the distance from the plane of this object to the plane of the object as referenced in the next row of
ALAYOUT. The program now changes this to the distance from the reference plane in the last space considered. For example, if row 1 indicated that the distance to the object in row 1+1 was 7000 mm, but the object itself (the object in row 1) was -13,000 mm from the reference plane, the value in the column will be changed from 7000 to -13,000.

The other change interchanges rows with the same object number if the first row in which the object number appears has a greater value in column four than the value in column four of the row the second time the object number appears.

These two changes arrange ALAYOUT for use by program three. Program three will subdivide each object and keep track of all the images of each section and the real space section to which they correspond. Because a single reflection will reverse the ordering of the section numbers, the program orders the direction in which the sections appear in real space and keeps track from there.

Consider the case of a baffle divided into 10 subsections, for instance, the baffle around a primary mirror. The mirror is oriented such that the object field is to the left, which is in the minus z direction. If the baffle is 6000 mm long and extends from the plane of the vertex of the primary toward the object, the data will be stored in ALAYOUT with the plane that is at -6000 mm from the vertex appearing before its other end, which will have a zero z value. Section one will be the section from -6000 mm to -5400 mm, and section 10 will be from -600 mm to 0.0 mm. The image of this baffle will extend from the primary to some positive z value (assuming here that the image does not pass through infinity). Section 10 (prime) will start at the plane of the primary and go to the plane that is conjugate to the z = -600 mm plane. Section one (prime) of the image will be still further away. Hence, the sequence of numbers will be from one to 10 in real space, but will be from 10 to one in image space. Power transferred to the leftmost section of the image (section 10 prime) corresponds to power added to section 10 of the real object.
The last physical piece of output to discuss is the plot. It has been discussed several times already in connection with the printed output, and one might think that it is simple to understand, interpret, and use. After all, it is just the cross-sectional plot of an object or image. In fact, the lines are also numbered according to their object number in the plots. However, as easy as it is to talk about such plots, it can be difficult to interpret them from a multiple mirror system. Images can appear anywhere, to the right of the real space, to the left of it, or on top of it. Any given plot may have images in all those areas. Hence, it takes considerable understanding to interpret what the images are and, more importantly, which apertures these images must pass through to be seen.

If the user numbers all the objects in space one with values less than 20 (or some other number), and then starts using 21 to 40 for the second space (even though there were only 12 objects in space one), and 41 to 60 for space three, etc., it will aid in interpreting the plots. One will then easily recognize that the low numbered objects are from space one and therefore must pass through certain apertures. The program does not draw in a vertical line for the aperture, but the user is advised to do so with a colored pen. Take care when drawing the image of an aperture that you ink in only that portion that exists, i.e., the image of a hole in a primary does no imaging and can act as an obstruction.

For each space there will be a plot and at the bottom of the plot, near the \( z = 0.0 \) plane, the following message is printed on the plot:

\[
\text{OBJECTS AS SEEN FROM SPACE num}
\]

This identifies from which space we are looking. If it is space one, then we are seeing the images as they would appear as we looked into the system from object space.

As mentioned previously, the lines in the plots are numbered according to their object numbers and should therefore be easily identifiable. There is no provision in the program for not over-writing previously written numbers. Therefore, sometimes a line cannot be identified by
the printed number. Several options can be exercised: first, try to
determine visually what the image is; second, enlarge the scale factor
and rerun the job hoping that at the larger scale the numbers will not
superimpose themselves; and third, for a particular run, eliminate some
of those objects that might be the ones overlapping.

Ideally, one would like the program to have a routine that keeps
track of such things but at this stage the need is not justified.

Just prior to termination the program writes onto disk a large file
of several arrays and two numbers. This file is cataloged as BASICA.
It is used by programs three and five. Twenty blocks of storage space
are allocated, of which the first eight are filled in by this program.
The eight blocks are

<table>
<thead>
<tr>
<th>Variables</th>
<th>Total number of words</th>
<th>Block number</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHI (the Lagrange invariant)</td>
<td>1.</td>
<td>1.</td>
</tr>
<tr>
<td>ALAYOUT(100,9)</td>
<td>ARRAY</td>
<td>900.</td>
</tr>
<tr>
<td>OMEGA(10,2)</td>
<td>ARRAY</td>
<td>20.</td>
</tr>
<tr>
<td>REFER(10,2)</td>
<td>ARRAY</td>
<td>20.</td>
</tr>
<tr>
<td>APERTUR(10,3)</td>
<td>ARRAY</td>
<td>30.</td>
</tr>
<tr>
<td>SPACENO</td>
<td>1.</td>
<td>6.</td>
</tr>
<tr>
<td>SPACE(100)</td>
<td>ARRAY</td>
<td>100.</td>
</tr>
<tr>
<td>N</td>
<td>1.</td>
<td>8.</td>
</tr>
</tbody>
</table>

Several of these variables may be unfamiliar, so they will be
explained. The array OMEGA contains the normalized $u$ and $\bar{u}$ angles of
each line in the $y-\bar{y}$ diagram. The program calculates these values and
stores them for later use by program three. The limit of 10 lines
in the $y-\bar{y}$ diagram has been chosen arbitrarily and can be changed.
REFER is the array that stores the reference points, specified by the
$y$ and $\bar{y}$ values, for each space. These values were read in by program
two and are being passed along. It has already been explained that
care must be taken to make the planes of reference coincide with the
reference plane of the last space because CHANGEA has referenced all
object distances from it. APERTUR is the array that contains the
maximum clear aperture size, the size of any hole in the aperture,
and the row in ALAYOUT in which the information for this object can
be found. SPACENO is the maximum number of spaces in the \( y-\tilde{y} \) diagram for the set of points considered. SPACE is the array that annotates the space in which each row of ALAYOUT is located. There are 100 rows allocated to ALAYOUT, and 100 for SPACE. N is the number of rows in ALAYOUT that have been initialized.

When the output of programs one and two is understood, little more can be learned without doing the power transfer calculations. The programs have established the critical areas that are seen from the image plane, calculated some of the preliminary angular information, and established most, if not all, of the paths of radiation from the source to the image plane. The array CHANGEA that is printed at the end of program two will be needed to punch the data for program three. Most of the radiation paths have been established, but program three will need to be told what objects it will have to pass through or around. The user will do this by looking at the plot from program two and reading the data CHANGEA. This is explained in the writeup on program three's input.
C. Program Three Output

After analyzing the output from programs one and two, the user should be well aware of the critical areas of the system and the principal paths of radiation. Up until now the programs have been restricted to calculations and relationships in the meridional plane. We have learned about as much as we can under these restrictions and must now face the three-dimensional problem that the system poses. We need relationships between the sections that will help determine how much power is being transferred and at what angles this power is leaving one section (the source) and the angle that it enters the other sections (the collectors). Program three makes these calculations and stores them in three files: BDRDF contains the "fraction" of power transferred from each section to all other sections; ANGOUT contains the "adjusted" angle that the radiation leaves the source section; and ANGIN contains the "adjusted" angle that the radiation enters the collector sections. These files are then cataloged for later use by program five.

The above paragraph alludes to "adjusted" angles and the "fraction" of power transferred, which will need considerable explanation to understand. If one checks the input for the first three programs he finds that nowhere is the surface structure described, the programs have not read in any reflectivities, nor has any power been put on any surface. Yet, this program is calculating the "fraction" of power transferred.

To understand what is meant it is necessary to discuss the information that has been passed to this program and the data that it reads in, and then discuss the three files separately in great detail.

There will be five blocks of data discussed:

1. BASICA--the basic information that is passed on by program two and added to by this program.
2. BDRDF--the percent of power transferred factors.
3. ANGOUT--the "adjusted" angles out of the source.
4. ANGIN--the "adjusted" angles into the source.
5. ITAB--the number of words stored in each block of the files BDRDF, ANGOUT, and ANGIN.
When requested, by using the code word CHECKPO (check passed on information), all the information that has been stored in BASICA is printed out. It is usually desirable to request this printout, especially if one is running several systems with the files cataloged with different cycle numbers. It will establish which file the system used for its calculations. Almost all the information has already been scrutinized, and the user will learn little more from studying it. But it is handy to confirm that the correct data are being used and for making corrections to the run or making additions to the run. One need not go back to the program two data as BASICA contains all the necessary information. At present the data are printed without any headings, and therefore an understanding of the output from program two and the sequence in which the data are printed, as shown below, is required.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Total number of words</th>
<th>Block number</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHI (the Lagrange invariant)</td>
<td>1.</td>
<td>1.</td>
</tr>
<tr>
<td>ALAYOUT(100,9) ARRAY</td>
<td>900.</td>
<td>2.</td>
</tr>
<tr>
<td>OMEGA(10,2) ARRAY</td>
<td>20.</td>
<td>3.</td>
</tr>
<tr>
<td>REFER(10,2) ARRAY</td>
<td>20.</td>
<td>4.</td>
</tr>
<tr>
<td>APERTUR(10,3) ARRAY</td>
<td>30.</td>
<td>5.</td>
</tr>
<tr>
<td>SPACENO</td>
<td>1.</td>
<td>6.</td>
</tr>
<tr>
<td>SPACE(100) ARRAY</td>
<td>100.</td>
<td>7.</td>
</tr>
<tr>
<td>N</td>
<td>1.</td>
<td>8.</td>
</tr>
</tbody>
</table>

CHI is the Lagrange invariant.

ALAYOUT is the array that contains the real space information about the system. This is the changed form of ALAYOUT called CHANGEA. From this array the user can check that the correct rows of data were used when calculating disk type obstructions or apertures.

The array OMEGA contains the normalized $\mu$ and $\bar{\mu}$ angles of each line in the $y-\bar{y}$ diagram ($\Omega = \mu/\mathbf{K}$, $\bar{\Omega} = \bar{\mu}/\mathbf{K}$). These are of no great use until the user needs to check certain calculations, at which time they are very helpful.

REFER is the array that stores the $y-\bar{y}$ values of the reference plane for each space. Again their usefulness is when one is checking the data.
APERTUR is the array that contains the characteristics of each imaging aperture and the row number in ALAYOUT that contains the other data on this aperture.

SPACENO is the number of spaces in the system.

SPACE is the array that lists the space in which each row of data in ALAYOUT is located.

N is the number of rows in ALAYOUT that have been initialized. This number is not specifically printed out but is easily determined by checking the number of rows of ALAYOUT that are printed. Each row is numbered in the left-most column, so the largest row number value is the value of N.

***

BDRDF

The most significant data stored in this section of the printout are the percent of power transferred. There are three important aspects to learn about this type of number:

1) Most important of all is, what does the number mean, what does it represent that one can understand?
2) How are the data printed? The format on the page is not any trivial matter.
3) How does the fifth program use this number?

To help explain these aspects it is beneficial to analyze some sample data output (see Fig. 2).

SOURCE NUMBER 1--This implies that the power calculations will be from all the sections (and possibly subsections) of the object that the user has numbered as number one. There are several ways that the source can be numbered; it can retain the number that it had in program two, it can be changed from what it was in program two, or it can be an object that did not exist before, and so it is just given the number. It is possible that the same number could mean two different objects, but that is not recommended because the user is more likely to make a mistake.
**Fig. 2. Sample data output from BDRDF.**
COLLECTOR NUMBER 15--The power will be calculated from all the sections on source number 1 to all the sections on the collector number 15. If the sections are subdivided into "subsections," then the power transfer is calculated from all subsections to all subsections. As for the source number, the collector can also be numbered in three ways.

O--O is the omega value for the line along which the images are seen. Omega is the normalized u (marginal ray angle) value \( \Omega = \frac{\nu}{\chi} \). In the example shown, the images will be seen from the space in which object one is located, and therefore along the line that represents that real space.

\( \Omega_{\text{BAR}} \)--The omega bar value is the normalized \( \bar{u} \) (chief ray angle) value equal to \( \frac{\nu}{\chi} \), for the line along which the images are projected in the \( y-y \) diagram.

\( Y_1 \ Y_{\text{BAR}1} \)--The \( y-y \) values for the plane in real space that represents the end of the object (to be imaged) that has the lowest \( z \) coordinate. This point can now be imaged along the "imaging" line.

\( Y_2 \ Y_{\text{BAR}2} \)--The \( y-y \) values for the plane in real space that represents the end of the object to be imaged that has the largest \( z \) coordinate.

\( Y_{\text{REF}} \ Y_{\text{BAR} \ \text{REF}} \)--The \( y-y \) values of the reference plane in the space of the source.

\( \text{NDEX} \)--The index of refraction of the space of the source.

\( \text{DMIR} \)--Looking from the source toward the collector, DMIR is the imaged distance of the last imaging aperture. The program automatically checks that the radiation passes through this imaged aperture.

\( \text{RMIRX} \)--The imaged radial size of the last imaging aperture between the source and the collector.

\( \text{ZCRIT} \)--The distance from the section on the source of the first imaging aperture (if one exists for this source-collector combination). The program will check that the radiation passes through this aperture.

\( \text{MMAG} \)--The magnification of the last imaging aperture (if imaging is done). If the radiation does pass through the imaged aperture, its position will be found on the imaged aperture. MMAG will then be used
to determine its location on the same aperture in real space. Knowing this point and the collector point, the real space angular information can be calculated.

FIX--Whenever a surface is specified, the normal to the surface will determine on which side of the cone or disk is the object. If a disk is reflected by a mirror, the normal to the surface reverses direction. With two reflections it is back to the same direction as real space. FIX keeps track of the direction of the normal for disk-type surfaces.

SJLOW--There are $2 \cdot SJLOW - 1$ radial sections on the objects. Both the source and collector object will be divided in the same manner.

BISS--The number of axial sections into which the source is sectioned. If the source object is not a disk, the axial sections will be of equal axial length. If the source object is a disk, BISS is the number of radius sections. The radius sections are divided into BISS sections all of equal area. Because the area goes as $R^2$, the difference in radius sections goes as $R^2$.

IMAX--The number of axial sections on the collector. If the collector is a disk, then IMAX is the number of radius sections on the collector. For nondisk-type collectors the collector sections are of equal axial length. For disk-type collectors the radii of the IMAX sections go as $R_i^2$ so that each $i$th section has equal area.

NSIZE--The number of words in this block of transfer information. \( NSIZE = SJLOW \cdot BISS \cdot IMAX \).

NBLOCK--The NSIZE words of information are stored into block NBLOCK of the following files:

| Geometrical configuration factor | into BORDF |
| Angle out of the source | into ANGOUT |
| Angle into the collector | into ANGIN |

GEOMETRICAL CONFIGURATION FACTOR--The numbers in this array represent the fraction of incident power on the source section that would be transferred to the collector section if the source section had unit power and unit Lambertian reflectivity. If the source has a radiance
of \( L(\theta, \phi) \), incremental area \( dA_s \), an angle \( \theta_S \) between its normal and
the vector from the source to the collector, and the collector being
a distance \( r \) from the source, of incremental area \( dA_c \), and at an angle
\( \theta_C \) from the vector from the collector to the source, then the incremental
power transferred \( dP \) is

\[
dP_c = L(\theta, \phi) * dA_s * \cos(\theta_S) * dA_c * \cos(\theta_C) / r^2.
\]  

(1)

If the source is Lambertian

\( L = M / \pi, \)

(2)

where \( M \) is the radiant exitance, the power per unit area of the source.
The power on the source is

\[
dP_s = E * dA_s = \rho * dP_s + \alpha * dP_s + t * dP_s,
\]

(3)

where \( E \) is the irradiance (watts per square cm), \( \rho \) is the reflectivity,
\( \alpha \) is the absorption, and \( t \) is the transmittance. The scattered power is
\( \rho * dP_s \) and is equal to

\[
\rho * dP_s = M * dA_s.
\]

(4)

Substituting Eqs. (4) and (2) into (1) gives

\[
dP_c = \rho * dP_s * \cos(\theta_S) * \cos(\theta_C) * dA_c / \pi r^2.
\]

The geometrical configuration factor calculated in the program is

\[
gcf = \cos(\theta_S) * \cos(\theta_C) * dA_c / \pi r^2,
\]

therefore

\[
dP_c = \rho * dP_s * gcf.
\]

The bidirectional reflectance distribution function (BRDF) will be deter­
mined in program five as will the incremental powers \( dP_c \) to complete the
equation for power transferred. Unless the physical shape of the collector
or source is changed, the gcf need not be recalculated. The power
loadings of the system and the coatings can be changed, and these factors
are still valid. Because \( \rho \) is a function of the angle in \( \theta_i, \phi_i \) and
the angle out \( \theta_o, \phi_o \), it is desirable that \( \rho \) is not included at this stage.
If the coating were truly Lambertian for all input angles it could be incorporated in gcf. Also, the $\rho(\theta_i, \phi_i; \theta_o, \phi_o)$ for a section with vane structure is significantly a function of the input and output angles.

Program three prints out the gcf in the following format. The axial collector sections are listed from left to right (see Fig. 2). Axial source sections are listed in the left column. In the case shown there are three numbers listed for each source section-collector section combination. SJLOW is equal to three, which means that there are five radial sections on the objects. The program takes advantage of two symmetry conditions that reduce the number of calculations to $3/25$. The source section is always considered to be the radial section in the six o'clock position, in this case section three. Figure 3a shows that the power transferred from section three to section one and five should be the same owing to the symmetry. The same applies to sections two and four. In Fig. 3b, the power transferred from radial section two to sections five and four should be the same factor as the power transferred from section three to sections one and five. All the sections have rotated one position. Obviously this rotation can be done five times, reducing the calculations $4/5$. The first symmetry condition implies that the program need calculate only three of the power transfers from section three on the source to the five collector sections.

![Fig. 3. Power transfer symmetries of rotationally symmetric objects.](image-url)
One should note that this procedure, which limits the program to rotationally symmetric objects, reduces the computer run time. Asymmetrical objects could be handled in a straightforward manner, and plans are under way to modify the program for those cases.

In the example shown (Fig. 2), the gcf from source section (3,1) to collector section (1,1) or (5,1) is 0.; from source section (3,1) to collector section (2,1) or (4,1) it is .982E-05; from source section (3,1) to collector section (3,1) it is .212E-04.

Because of obstructions (apertures, disks, cones) between the source sections and the collector sections, certain transfer factors are reduced or go to zero. In the example shown, this occurs with source sections 8 through 10. Section 10 transfers no energy to any of the collector sections of object 15.

The NSIZE words in this array are stored into block NBLOCK of the random access file BDRDF (tape 5). Note that the gcf is neither the solid angle of the collector as seen from the source nor the percent of power transferred from the source to the collector. It has aspects of both. The calculation assumes that the reflectivity of the source is uniform as seen from any position of any section on the collector. For very specular coatings, this will not be valid, and the calculation will be erroneous.

ANGLE OUT OF THE SOURCE—For each source section-collector section combination the program will calculate two angles that specify the angle that the radiation left the source section. If the source sections are subdivided (DELTA ≠ 1.), the average values will be calculated. Figure 4 is an example of the output. The ANGLE OUT data are shown in Fig. 5. The angles are relative to the local section coordinate system; one for the source section and one for the collector section. For a cone, the Z' axis vector in the surface of the cone points either toward or away from the vertex of the cone, whichever direction is in the +z direction. The Y' axis is the outward normal of that surface. The X' axis is tangent to the cone and orthogonal to the Y'Z' plane. For a disk, the Z' axis is the outward radius vector, the Y' axis is the
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Fig. 4. Angle out of the source sections.
Fig. 5. The vector 0 is the vector from the source section to the collector section. \( \vec{0}' \) is its projection into the \( Y'Z' \) plane. \( \theta_o \) is the angle from the \(-Z'\) vector to the \( O' \) vector, both are in the \( Y'Z' \) plane. \( \theta_A \) is the azimuthal angle and is the angle from \( O_A \) to \( O \).

normal to the disk, and the \( X' \) axis is tangent to the radius and orthogonal to the \( Y'Z' \) plane (see Figs. 6 and 7).

The format of the rows and columns in which the two arrays are printed corresponds to their geometrical configuration factor (see the description of the geometrical configuration factor output for a further description).

ANGLE INTO THE COLLECTOR--Because there were two angles that described the angle out of the source, there are two angles that describe the angle into the collector for each source-collector section combination. Figure 8 is a sample output. Figure 5 also represents how these two angles are measured. The \( \vec{0} \) vector points toward the source section. The local coordinated systems are the same as described for the angle out of the source.
Fig. 6. Local coordinate system for a section on a cone. If the surface was the outside surface of the cone $Y'$ and $X'$ would point in opposite directions. $Z'$ would remain the same.

Fig. 7. Local coordinate system of a disk. The $+z$ side of the disk is the source. If the other side is the source, $Y'$ and $X'$ would change directions. $Z'$ would remain the same.
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Fig. 8. Angle into the collector sections.
ITAB--The last array printed is the ITAB array. An example is shown in Fig. 9. The array reads from left to right, the numbers being the number of words, ITAB(I), in the Ith block of stored data on files BDRDF, ANGOUT, and ANGIN. The number of blocks that now have significant data is printed last. In the case shown, 18 blocks of data were written, and the second block has 60 words.

Fig. 9. ITAB, the number of words stored on the random access mass storage files.
D. Program Four Output

Program four is the simplified loader program. An array such as shown in Fig. 10 is printed. It depicts the power distribution on this particular source object. Because there are, by default, five radial sections, the data are stored on disk in five blocks, one for each radial section. It is the disk file created by this program as output that primes program five for the stray radiation calculation.

Fig. 10. Program four printout of the power on the sections of the objects loaded.
E. Program Five Output

The analysis of a system would not be complete until the power distribution in the image plane was determined. Program five completes the sequence of programs by doing this calculation. It has basically two parts, a bookkeeping routine and several surface reflectivity routines, the largest being the routine SURFACE that calculates the apparent reflectivity from baffles with vane structure. The program's basic role is to multiply the gcf from program three by the incremental unit of power and the apparent reflectivity of the sections in the system. This product is the power on the succeeding collector section. The calculation is continued until the power distribution on the image plane is determined.

A series of three types of arrays will be printed. One will give the power, added section by section, to all of the objects that were considered collectors at each level. The second array type will give the running total power, section by section, of all the objects input into the system. The third array type will print all the increments of power from each section of a source object that are added to each section of the "important" surface that is specified in the input deck. This surface is usually the image plane, but can be any other object. Examples of the three arrays are discussed in the following paragraphs.

POWER ADDED and TOTAL POWER arrays are so similar in form they will be discussed as a pair, which is also the way they always appear in the output. Figures 11, 12, and 13 are examples of the POWER ADDED and TOTAL POWER arrays for an object number two at three levels of scattered radiation. Figure 11 shows the power distribution on object number two from level one scatters. Regardless of the sources at this level of scatter, this is the calculated power distribution on object two, section by section. This power distribution is for the programmed radiation paths, which may not be all the significant paths. Object two has 10 axial sections and five radial sections. The first radial section of the first axial section [section (1,1)] has 1.43E-05 watts of power.
The power distribution on object two after one level of scatter is

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</tr>
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The total energy received by object 2 thru 1 levels of scattered radiation is

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<td>Level 8</td>
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Fig. 11. Power distribution on object two after one level of scatter.
**The Power Distribution on 2 from Level 2 Scatters Is**

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<th>Value 4</th>
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<th>Value 7</th>
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<td>6.33E+00</td>
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<td>1.43E-11</td>
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**The Total Energy Received by Object 2 Through 2 Levels of Scattered Radiation Is**

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<td>5.27E-11</td>
<td>3.85E-11</td>
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</tr>
</tbody>
</table>

Fig. 12. Power distribution on object two after two levels of scatter.
NO RADIATION FROM ANY OF THE EMITTING SURFACES WAS TRACED TO OBJECT 2 AT LEVEL 3.

REMEMBER THAT FOR THE FINAL LEVEL OF SCATTER BEING CONSIDERED, THIS MIGHT NOT BE A SIGNIFICANT PATH, AND WAS NOT CONSIDERED EVEN THOUGH RADIATION IN FACT DID FALL ON THIS OBJECT.

THE TOTAL ENERGY RECEIVED BY OBJECT 2 THRU 3 LEVELS OF SCATTERED RADIATION IS

- Fig. 13. Power distribution on object two after three levels of scatter.
incident on it. The second radial section (1,2) has 2.95E-06 watts of power, and so on for the remaining sections. The initial loading was symmetrical, so the power distribution on the object is also symmetrical. The program would handle an asymmetrically loaded system just as easily. The higher numbered sections, 8 to 10, receive no power because an entrance aperture prevented the radiation from reaching those sections.

The TOTAL POWER received by object two through one level of scattered radiation is the same as the POWER ADDED because there was no power previously scattered to this object.

Figure 12 shows the power added or the power distribution from level two scatters onto object two. Note that now all the sections of object two have power on them. The power added to axial sections one are two or three orders of magnitude less than the power loaded at level one. The TOTAL POWER on object two is the sum of this array with the TOTAL POWER array from level one scatter.

Figure 13 is third-level scatter and indicates that no power was transferred to object two or that the program was not asked to trace power to object two. Because no power was added, it is not unexpected that the TOTAL POWER on object two remains the same as for level two scatter. The run from which this example was taken put power onto the image plane at level three. Therefore, the requested power transfers at level three were only from the critical objects to the image plane. Other power transfers were not necessary. In fact, it would be a waste of computer time to do them.

By analyzing the above set of arrays, one can begin to quantitatively understand how the power is being propagated through the system and how the power distribution in the image plane has been determined. However, one does not know the increments of power from all the objects that put power onto the image plane. Which sections of which objects contribute the most power to the sections in the image plane? This information is clearly seen when the third type of array is printed. Every increment of power from every section of every object that transfers power to the
image plane is printed. A quick study of these arrays will determine which sections are the major sources of power to the image plane.

Figure 14 will serve as an example of the type of output that can be expected and how to interpret the data format. For the case shown, the image plane was a disk that had five radii and five radial sections. The source object for Fig. 14a-d was object four, whereas object eight was the source object for Fig. 14e-j.

Looking at Fig. 14a, there are five sets of arrays. They represent the increments of power that are added to five of the 25 sections on the collector. Figure 14b-e represents five more of the sections for a total of 25. The first array is preceded by the statement THIS IS THE POWER ON SPACE 1,1. The five by three array that follows represents the dimension (sections) of the source object number 4. Remember the image plane (the collector object) is five by five. The array indicates that no power was transferred to section (1,1) of the image.

The next array in the same figure represents the power added to the one image section (1,2); the first radial section and the second radii section. The third radial-first axial section of the source object contributes .19E-16 watts to the image collector section (1,2). The third radial-second axial section of the source object four contributes .13E-16 watts and so on. The zero power transfers occur for one of two reasons, no power was on that particular source section, or those source sections could not "see" the image plane section.

There are only five radial sections in this example, hence, only five pages of data. Each page contains all the units of power from all the sections on object four to all the radius sections of a given radial section on the collector.

Figure 14f-j shows the increments of power transferred from object eight to the image plane. The increment of power from section (1,2) to section (1,1) is .22E-16 watts. From the comparison of the units of power transferred from objects four and eight, one can conclude that object eight sections are contributing about 100 times the power of the sections from object four. Therefore, the system redesign should
Fig. 14. Incremental power transfer from object 4 to image plane.
Fig. 14. Continued.
THIS IS THE POWER TRANSFER FROM OBJECT TO THE IMAGE PLANE

THIS IS THE POWER ON SPACE 3, 1
0. 0. 0.
0. 0. 0.
0. 0. 0.
0. 0. 0.

THIS IS THE POWER ON SPACE 3, 2
1.4E-22 .50E-21 0.
0. 0. 0.
0. 0. 0.
1.4E-22 .50E-21 0.

THIS IS THE POWER ON SPACE 3, 3
1.5E-22 .51E-21 0.
0. 0. 0.
0. 0. 0.
1.5E-22 .51E-21 0.

THIS IS THE POWER ON SPACE 3, 4
1.5E-22 .52E-21 .10E-17
0. 0. 0.
0. 0. 0.
1.5E-22 .52E-21 .10E-17

THIS IS THE POWER ON SPACE 3, 5
1.6E-22 .53E-21 .10E-17
0. 0. 0.
0. 0. 0.
1.6E-22 .53E-21 .10E-17

Fig. 14. Continued.
**Fig. 14. Continued.**

This is the power transfer from object 4 to the image plane.

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<th>0.0</th>
<th>0.0</th>
</tr>
</thead>
<tbody>
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<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
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</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

This is the power on space 4, 2:

| 1.4E-27 | 5.0E-21 | 0.0 |
| 9.4E-17 | 6.7E-17 | 0.0 |
| 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 |

This is the power on space 4, 3:

| 1.5E-22 | 5.1E-21 | 0.0 |
| 9.7E-17 | 7.2E-17 | 0.0 |
| 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 |

This is the power on space 4, 4:

| 1.5E-22 | 5.2E-21 | 1.0E-17 |
| 1.0E-16 | 7.6E-17 | 7.7E-17 |
| 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 |

This is the power on space 4, 5:

| 1.6E-22 | 5.3E-21 | 1.0E-17 |
| 1.0E-16 | 7.9E-17 | 7.8E-17 |
| 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 |
THIS IS THE POWER TRANSFER FROM OBJECT TO THE IMAGE PLANE

THIS IS THE POWER ON SPACE 5, 1
0. 0. 0. 0. 0. 0. 0. 0.

THIS IS THE POWER ON SPACE 5, 2
0. 0. 0. 94E-17 67E-17 0. 19E-16 13E-16 0. 0. 0. 0. 0.

THIS IS THE POWER ON SPACE 5, 3
0. 0. 0. 97E-17 72E-17 0. 19E-16 14E-16 0. 0. 0. 0. 0.

THIS IS THE POWER ON SPACE 5, 4
0. 0. 0. 10E-16 76E-17 77E-17 20E-16 15E-16 13E-16 0. 0. 0. 0.

THIS IS THE POWER ON SPACE 5, 5
0. 0. 0. 10E-16 79E-17 78E-17 21E-16 16E-16 14E-16 0. 0. 0. 0.

Fig. 14. Continued.
This is the power transfer from object A to the image plane:

<table>
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<tr>
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<tr>
<td></td>
<td>2.2E-16</td>
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</table>

Object transferring power to the image plane was sectioned 5 by 2.

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<td></td>
<td>7.1E-16</td>
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<tr>
<td></td>
<td>5.7E-16</td>
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<tr>
<td></td>
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</table>

The image plane had five radius (or axial) sections. Output for the other four radial follows.

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<td></td>
<td>5.7E-16</td>
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<table>
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<th>Power</th>
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<tr>
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<table>
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<td></td>
<td>2.2E-16</td>
</tr>
</tbody>
</table>

Fig. 14. Continued.
**Figure 14. Continued.**

This is the power transfer from object A to the image plane.

| Space 2, 1 | 0.22E-16 | 0.58E-16 | 0.71E-16 | 0.58E-16 | 0.22E-16 |
| Space 2, 2 | 0.22E-16 | 0.71E-16 | 0.57E-16 | 0.22E-16 |
| Space 2, 3 | 0.22E-16 | 0.71E-16 | 0.57E-16 | 0.22E-16 |
| Space 2, 4 | 0.22E-16 | 0.71E-16 | 0.57E-16 | 0.22E-16 |
| Space 2, 5 | 0.22E-16 | 0.71E-16 | 0.57E-16 | 0.22E-16 |
Fig. 14. Continued.
This is the power transfer from object 8 to the image plane.

This is the power on space 4, 1

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<th>71E-16</th>
<th>58E-16</th>
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</table>

This is the power on space 4, 2

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<th>71E-16</th>
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<th>22E-16</th>
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</table>

This is the power on space 4, 3

<table>
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<th>22E-16</th>
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</table>

This is the power on space 4, 4

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<th>71E-16</th>
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<th>22E-16</th>
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This is the power on space 4, 5

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<th>22E-16</th>
<th>57E-16</th>
<th>71E-16</th>
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<th>22E-16</th>
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</table>

Fig. 14. Continued.
<table>
<thead>
<tr>
<th>Space</th>
<th>Power Transfer from Object A to the Image Plane</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>5, 2</td>
<td>0.22E-16, 0.57E-16, 0.71E-16, 0.58E-16, 0.0</td>
</tr>
<tr>
<td>5, 3</td>
<td>0.22E-16, 0.57E-16, 0.71E-16, 0.58E-16, 0.0</td>
</tr>
<tr>
<td>5, 4</td>
<td>0.22E-16, 0.57E-16, 0.71E-16, 0.58E-16, 0.0</td>
</tr>
<tr>
<td>5, 5</td>
<td>0.22E-16, 0.57E-16, 0.73E-16, 0.58E-16, 0.0</td>
</tr>
</tbody>
</table>

Fig. 14. Continued.
focus on reducing the scatter from object eight by improved coatings, vane structure, or by preventing the power from reaching object eight. When the scatter from object eight is reduced by two orders of magnitude, then attention can be focused on improving object four.

If the system was satisfactory with the present power transfers from object eight, it might be financially beneficial to reduce the efficiency of object four by using less expensive coatings or less structure. In a well designed system, most of the critical objects should be contributing about equal power to the image plane.

ICOL--Besides the three arrays, program five prints out the variable ICOL, when at any level the program has found a source-collector combination in tables ITAB2 and IEMIT that satisfies the request of LIMITS and LOOK4. See above for the description of the input data. ICOL will assist the user in determining if all the desired transfers were input and will indicate approximately where the program was if a time limit is encountered during a computer run. The single integer value printed, ICOL, indicates that the program did or was doing the power transfer from source section IEMIT(ICOL) to collector section ITAB2(ICOL).
V. PROGRAM VARIABLES

A. Program One

The variables that are considered to be of importance are briefly described to aid the programmer in making additions or changes in the program. The variables appear alphabetically by program or subroutine. If a variable appears in common, it will be described in the first routine in which it appears. Sometimes it will be described in a subsequent routine if it is very significant or used frequently.

* * *

Program BAFFLE

ALAYOUT(100,7) An array that stores the information about the layout of the optical system being analyzed. Column one is coded information that tells whether the y-ŷ heights are known or not. Column two is the y value (marginal ray height) at the plane in space. Column three is the ŷ (chief ray height) at this plane in space. Column four is the distance from the present plane to the plane containing the next object. Column five is the radial height of the object in this plane. Column six is the index of the space containing the plane under consideration. Column seven is the object number. Each object has two planes with the same object number. Two z locations and corresponding radii describe cones, cylinders, and disks. Column eight is the direction of the normal to the surface. Column nine is the number of axial sections on the object.

ALPHA The y value on a conjugate line parallel to the image line where the ŷ value is that of the plane being considered.

ANGLE1 The angle from the reference point to the first edge of the aperture as the scan is made in a counterclockwise direction.

ANGLE2 The angle from the reference point to the second edge of the aperture when the scan is in a counterclockwise direction.

APERS The number of apertures in the system. Presently it can handle up to 30 apertures.

APERTUR(30,3) The array that holds the information about the apertures. Column one is the maximum height of the aperture. Column two is the minimum height of the aperture (for example the radius of the hole in the primary of a Cassegrainian system). Column three is the row in ALAYOUT in which this aperture appears.
Program one
BAFFLE (continued)

**BETA**
The y value on a conjugate line parallel to the image line where the y value is that of the plane being considered. It is like ALPHA but for a different y value.

**CHI**
The Lagrange invariant.

**CRITH**
The critical height at which the imaged baffle is seen at the critical distance CRITL.

**CRITL**
The critical distance at which an imaged baffle is seen.

**DMAX**
The maximum distance at which any object edge is imaged.

**DMIN**
The minimum distance at which any object edge is imaged.

**EXTRA**
EXTRA = 100, an integer constant. Whenever the image of an object is split because it passes through infinity or is partially obscured by another object and is seen as two parts, the second part is made into a separate object and is given an object number 100 more than the original object.

**HID**
An 80-letter heading to be printed out at the start of the output to briefly describe the system being analyzed.

**HMAX**
The maximum height of all the imaged objects.

**IMGLINES**
The slope of the image line in the y-\(\bar{y}\) diagram.

**JOBJS**
Counts the number of objects that are seen from the reference point in the image plane.

**LIMIT1**
The reference line in ALAYOUT into which new object data are entered when an object is split.

**LOCAT1**
The critical baffle height (imaged or otherwise) of the end of the object that shadows or is shadowed by another object.

**LOCAT2**
The critical baffle distance (imaged or otherwise) of the end of the object that shadows or is shadowed by another object.

**LOWSIDE**
If its value is one, then the program is checking objects above the optical axis. If the value is two, the reference point in the image plane has been changed to its negative value. By symmetry, the same program is used to check the objects appearing below the optical axis.

**N**
The number of reference planes in ALAYOUT. This number is increased when objects are split.

**NOBJS**
The number of objects in the system as described in ALAYOUT.
Program one
BAFFLE (continued)

NPOINTS Twice the value of JOBS. It takes two sets of values
of z position and radius to describe a cone.

PHI The value of PI = 3.14159265358979.

POLAR(100,5) Holds the values of the imaged objects in polar coordinates
relative to the reference point in the image plane.

PPRIME(100,7) Contains the sections of the imaged objects that are
seen from the reference point in the image plane. Column
one is the y' value. This is the value of the marginal
ray at the image plane of the object. Column two is
the y' value. Column three is the distance of the image
from the image plane. Column four is the imaged baffle
height. Column five is the object number. Column six
is the status. Column seven is the row number in ALAYOUT
by which this object is described.

PRIME(100,4) The image of all objects in ALAYOUT into image space as
seen from the image plane. Column one is the y' value.
Column two is the y' value. Column three is the distance
from the image plane. Column four is the imaged baffle
height.

PRINTS If this word is read as PRINTIT, then the long version
of the printout will run. This should be done only if
one wants to follow the calculations of each subroutine.

SIGHT The imaged height of the object under consideration minus
the reference point height.

SLOPE(100) The slope of the line in the y-y diagram on which this
reference plane falls.

SPACE(100) The space in which this object falls.

SPACENO The total number of spaces considered. It equals the
number of lines in the y-y diagram.

TPOLAR1 The distance from the reference point to a possible
critical point along some object or image of an object.

TPOLAR2 Similar to TPOLAR1 but handles the second point along
an object where it may reappear from behind the object
shadowing it.

VALUE1 The code number (2.) for the end of an object that is seen.

VALUE2 The code number (4.) for the start of an object that is
seen.

YEPRIME The y value at the exit pupil.

YZERO The height in the reference plane from which the system
sees out for the analysis.
Program one
Subroutine YYBARIM

M The row in ALAYOUT being considered.
***** See BAFFLE for other variables

Subroutine PRIMEMX

CONJK The slope of the conjugate line.
DMAX The maximum positive distance of any object edge.
DMIN The longest distance from the image plane in the negative z direction.
HMAX The maximum height of all the imaged objects.
***** See BAFFLE for other variables.

Subroutine POLARSP

SIGHT The image height of the object under consideration minus the reference point height.
X The slope of the line connecting the reference point and the imaged object.
***** See BAFFLE for other variables.

Subroutine ORDERP

***** See BAFFLE for identification of variables.

Subroutine SPACES

***** See BAFFLE for identification of variables.

Subroutine SLOPES

L The line reference number of an aperture as it appears in ALAYOUT.
NMINUS1 NMINUS1 equals the number of reference lines in ALAYOUT (which is N) minus one.
NN The line referenced in APERTUR.
***** See BAFFLE for other variables.

Subroutine SPLIT

B The line referenced in ALAYOUT. Used to check if an object falls before or after an aperture.
CONJK The slope of the conjugate line.
D If an object passes through infinity, the program splits the original object into two objects. In order to do this, it must define two new planes to describe the two cones. One plane describes the distance and radius of
Program one
Subroutine SPLIT
(continued)

the imaged object that is imaged toward minus infinity, and the other plane is the distance and radius as the object is imaged toward the plus infinity distance. D is that distance at which the program calculates the reference plane information. It is the minimum (or maximum) distance of all objects not passing through infinity. If this distance happens to be the distance D, then D is decreased (or increased) by 10% so that the object passing through infinity has a finite length.

DIST
When an image passes through infinity, a new plane of information is created in ALAYOUT. DIST is the fourth column entry, which is the distance from one reference plane to the succeeding one.

HPRIME
The radius of the imaged object that passes through infinity. HPRIME is that radius at distance D from the image plane.

M
M holds the old N value while certain arrays are enlarged to hold the new planes of information.

NOMORE1
The line number minus one in ALAYOUT of the first plane appearing in ALAYOUT of an object passing through infinity.

NOMORE2
The line number minus one in ALAYOUT of the second plane describing an object in ALAYOUT that passes through infinity.

OBJH
Object height of the new edge of a split object. This object height is the real object height that appears in ALAYOUT.

S
The slope of the real object as taken from ALAYOUT.

SP
The slope of the imaged object as taken from PRIME.

X
The length of the object in real space.

XFOUR
The distance from one object plane in ALAYOUT to the next reference plane. Column four in ALAYOUT.

XONE
The distance from the first reference plane after the object to the reference plane under consideration.

XPRIME
The distance that is used to terminate an object that passes through infinity.

XTHREE
The distance from one reference plane in ALAYOUT to the next.

XTWO
The distance from the first reference plane after the object to the reference plane under consideration. It is like XONE but the reference plane is the second one appearing in ALAYOUT for a given object number.
Program one

Subroutine SPLIT
  (Continued)

Y  The change in height of a given object. Also the \( y \) value for the new plane of information for a split object.
YBAR  The \( \bar{y} \) value for the new plane of information for a split object.
YBARP  The \( \bar{y} \) prime value of the split object.
YONE  The real object height of the first reference plane of a given object.
YP  The \( y \) prime value of the split object.
YTWO  The real object height of the second reference plane of a given object.

Subroutine APTOBST

AA  Object number from ALAYOUT.
APTDIST  Aperture distance.
APTHP1  Aperture height in real space or image space of the first point (maximum height) in APERTUR.
APTHP2  Aperture height in real space or image space of the second point (minimum height) in APERTUR.
CUT  The distance of the aperture that precedes the image space under consideration. All imaged objects of this space must pass through it.
IBB  Counter from the line in ALAYOUT of the referenced aperture.
ICC  Counter to the second line in ALAYOUT corresponding to the object number of line NN+IBB, where NN is the line of the referenced aperture.
ICUT  The number of lines in ALAYOUT.
IFIRST  The first line in ALAYOUT to which the object being split is referenced.
IT  The line number in ALAYOUT of the aperture to the next image space. This aperture acts as an obscuration to the preceding image spaces.
ITT  The line number in ALAYOUT of the aperture through which all objects of the space being considered must be seen.
LOKATP1  The reference line in POLAR in which the reference object first appears.
LOKATP2  The reference line in POLAR in which the reference object appears for the second time.
Program one
Subroutine APTOBST
(Continued)

NN
The line in ALAYOUT while searching for apertures.

SPACEZ
The space that determines the apertures through which all images of objects must appear and by which all real objects in this space are obscured if they pass behind it.

TMAG
The magnification of the aperture that acts as an obscuration for the space under consideration.

XX
The farthest point of an object (imaged or not) from the image plane.

YBARFST
The $\bar{y}$ value of the first aperture, which is the one that acts as an obscuration.

YBARSEC
The $\bar{y}$ value of the second aperture, which is the aperture through which all the imaged objects must pass.

***** See BAFFLE for other variables.

Subroutine CLAPT

APTDPRM
The distance of the referenced aperture in imaged space.

APTHP1
Aperture height in real or imaged space (whichever is being referenced) of the first point (maximum height) in APERTUR.

APTHP2
Aperture height in real or imaged space (whichever is being referenced) of the second point (minimum height) in APERTUR.

CLINES
The slope of the line of the imaged object.

IAT
The space in which the referenced object exists.

INS
As the scan is made in POLAR, INS is the reference number appearing in column three of POLAR that tells which space the object is in.

LOKATP1
The line reference number (column three) in POLAR the first time the object number is referenced.

LOKATP2
The line reference number (column three) in POLAR the second time that the object number is referenced.

MAPT
The third column of APERTUR that holds the line number in ALAYOUT of the aperture.

SIGHTSL
The slope of the line of sight from the reference point in the image plane to the upper or lower edge of the aperture.

X
The angle of either the front or back edge of the object as in column two of POLAR.

***** See BAFFLE for other variables.
Program one
Subroutine BAFSEEN

CLINES  The slope of the line of the imaged object.
IJKL   The line number in POLAR the second time the object
       number appears in column four.
IPK    The line number in POLAR the first time the number of
       the object being shadowed appears (or at least appears
       after the original object that does the shadowing).
IPP    The line number in POLAR the first time the object number
       appears in column four.
IPPRIME The line into which information is stored in array PPRIME.
K      The counter from line I in POLAR to the first time the
       second object number appears in column four of POLAR.
L      The counter from line I+K in POLAR to the second time
       the second object appears in column four of POLAR.
LA     The line in ALAYOUT in which the first object number
       appears in ALAYOUT for the first time.
LB     The line in ALAYOUT in which the first object number
       appears in ALAYOUT for the second time.
LOCATCP Locates what is considered to be the critical point in
       POLAR.
LOKATP1 The reference line in ALAYOUT of the first object the
        first time it appears in POLAR.
LOKATP2 The reference line in ALAYOUT of the first object the
        second time it appears in POLAR.
LOKATP3 The reference line in ALAYOUT of the second object the
        first time it appears in POLAR.
LOKATP4 The reference line in ALAYOUT of the second object the
        second time it appears in POLAR.
M      The line in POLAR the second time the first object
       appears in POLAR.
SIGHTSL The slope of the line from the reference point to the
        critical point.
TPOLAR The distance from the reference point to the critical
       point on the second object.

***** See BAFFLE for other variables.

Subroutine ANGSEEN

BAFFSEC One-fourth the axial length of the baffle that is seen.
CONJKPC The slope of the conjugate line through all the subsections
        of the baffle that is seen.
Program one
Subroutine ANGSEEN

CRITL  The direction cosine from the z axis.
CRITM  The direction cosine from the y axis.
CRITPTS  The array holds the following information: column one has the y value in real space of this section of the baffle that is seen, column two is the y value, column three is the distance from the subsection in real space to the next refracting or reflecting surface, column four is the subsection baffle height in real space, column five is the angle at which this baffle subsection is seen (the angle is in degrees).
DENOM  The distance from the reference point in the image plane to the different subsections. It is used in the calculation of the direction cosines.
FORSLOP  Defined as an integer. The line number in SLOPE of the object.
HPRIMEI  The radius at each subsection of the baffle that is seen.
HREFOBJ  The height of the ray from the reference point to the subsections on the last (nearest the baffle) refracting or reflecting surface in image space.
HREFPRI  The height of the ray from the reference point to the subsection on the last (nearest the baffle) refracting or reflecting surface in real space.
H1  The height of one end of the baffle that is seen in image space.
H2  The height of one end of the baffle that is seen in image space.
IFINDOR  The reference line in ALAYOUT of the object being processed. It is the first time that the object has appeared in POLAR, which may or may not be the first time it appears in ALAYOUT.
IFINDSE  Finds the line in ALAYOUT corresponding to the other end of the object defined by line IFINDOR.
IPPRIME  The line in PPRIME being referenced.
K  The number of the subsection. K can equal any integer from one to four.
KONIMGL  The y value at the image of the pupil for the image line in the y-y diagram being considered.
M0  The line number in CRITPTS.
NOMORE1  The line number minus one in ALAYOUT of the first plane describing an object.
Program one
Subroutine ANGSEE
(Continued)

NOMORE2  The line number minus one in ALAYOUT of the second plane describing an object.
OBJL    The direction cosine from the z axis of the object.
OBJM    The direction cosine from the y axis of the object.
REFPLAN The reference line of the last imaging surface for the given object.
RRPRMAG The magnification of the last imaging surface.
SECTION One-fourth of the length of the section of the baffle that is seen.
SLOPB   The slope of the line of the imaged baffle.
SMAGINV The inverse of the magnification of the object.
THOBJ1  The object number under consideration.
XONE    The distance from the first reference plane after the object to the reference plane under consideration. The distance is the real space distance.
XPRIME1 The distance of the subsection from the image plane in image space.
XTWO    The distance from the first reference plane after the object to the reference plane under consideration. It is like XONE, but the reference plane is the second one appearing in ALAYOUT for a given object number.
X1      The distance from the image plane of one edge of the imaged object that is seen.
X2      The distance from the image plane of one edge of the imaged object that is seen. It is like X1, but the other plane of information defining the object.
YBARFF1 The \( \bar{y} \) value of one end of the object in image space. The value is taken from column two in PPRIME.
YBARFF2 The \( \bar{y} \) value of one end of the object in image space. The value is taken from column two in PPRIME. It is like YBARFF1 but is the other plane of information defining the object.
YBARX   The difference in \( \bar{y} \) height of the two planes defining the object. \( YBARX = BYARFF2 - YBARFF1 \).
YBFFP   The \( y \) value of the subsections of the portion of the imaged baffle that is seen.
YBRBFFF The \( \bar{y} \) value of the subsections of the portion of the imaged baffle that is seen.
Program one

Subroutine ANGSEEN

(Continued)

YFF1 The y value in image space of one of the ends of an imaged object seen from the image plane. The value is taken from column one of PPRIME.

YFF2 The y value in the image space of one of the ends of an imaged object seen from the image plane. The value is taken from column one of PPRIME. It is like YFF1 but the other plane of information defining the object.

YONE The real object height of the first reference plane of the given object.

YSLOPE The slope of the image line in the y-y diagram.

YTWO The real object height of the second reference plane of a given object.

***** See BAFFLE for other variables.

Subroutine OBJSEEN

AOBJN An object number. Searches PPRIME for the largest object number in its array.

IA Line number in ALAYOUT of object being processed in POLAR.

IB Line number in ALAYOUT of object being processed in POLAR.

IJ Line number in POLAR being processed.

JOBJS2 Twice the number of objects seen from the given reference point. Because it takes two planes to describe each object there are JOBJS2 lines in PPRIME.

K The line counter in POLAR from the line where the object is first referenced in POLAR to the line where the object is next referenced.

M Line reference number in PPRIME.

MOBJN The maximum object number in PPRIME. It is equivalent to AOBJN.

***** See BAFFLE for other variables.

Subroutine DOUBLEP

I The line number in POLAR of the plane of information being processed. It is that line in POLAR where the referenced object number first appears.

IPPRIME The line in PPRIME being referenced.

J I + J is the line number in POLAR of the object the second time its object number appears in POLAR.
Program one

Subroutine DOUBLEP
(Continued)

X  The polar angle (column two in POLAR) of the object for the line being referenced.

***** See BAFFLE for other variables.

Subroutine TPOLARX

CLINES  Slope of the imaged baffle.
LOKATP1  The line reference number (column three) in POLAR the first time the object is referenced.
LOKATP2  The line reference number (column three) in POLAR the second time the object is referenced.
SIGHTSL  The slope of the line of sight from the reference point in the image plane to the point of interest in the image space.
TPOLAR  The distance from the reference point in the image plane to the point of interest in the image space.

***** See BAFFLE for other variables.

Subroutine ENLARGE

BAFHT  For any object split it is the height of the new baffle in the new plane.
CONJKPC  The slope of the conjugate line through the y-y point representing the plane where the baffle was split.
D  The distance from the end of the original object to the plane where the object is split.
DIS  The distance from the most forward plane of the object to the plane where the object is split.
IFIRST  The first line in ALAYOUT in which the object is referenced.
IMARK  It marks the increment in line number from line ISEC in ALAYOUT from which the distance D is figured.
IMOVE  Tells how many lines to move the information stored in the various arrays to make room for the newly created information.
ISEC  Either the first or second line in ALAYOUT in which the referenced object occurs.
ISIGN  Either plus or minus one in value. M - ISIGN tells the line number where the information is stored that is being relocated.
Program one
Subroutine ENLARGE
(continued)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>KONIMGL</td>
<td>The y value at the image of the pupil for the image line being considered in the y-y diagram.</td>
</tr>
<tr>
<td>LA</td>
<td>The line in ALAYOUT in which the referenced object number first appears.</td>
</tr>
<tr>
<td>LB</td>
<td>The line in ALAYOUT in which the referenced object number appears for the second time.</td>
</tr>
<tr>
<td>LC</td>
<td>The line in POLAR in which the referenced object number appears for the first time.</td>
</tr>
<tr>
<td>LD</td>
<td>The line in POLAR in which the referenced object number appears for the second time.</td>
</tr>
<tr>
<td>LIMIT2</td>
<td>LIMIT1-1 in value. See BAFFLE for the value of LIMIT1.</td>
</tr>
<tr>
<td>LOKATP1</td>
<td>The line reference number (column three) in POLAR the first time the object number is referenced.</td>
</tr>
<tr>
<td>LOKATP2</td>
<td>The line reference number (column three) in POLAR the second time the object number is referenced.</td>
</tr>
<tr>
<td>M</td>
<td>The line reference number in the various arrays from which information is taken or stored. Sometimes this information is stored some small line increment from line M.</td>
</tr>
<tr>
<td>NOMORE1</td>
<td>The line number minus one in ALAYOUT of the first plane describing an object.</td>
</tr>
<tr>
<td>NOMORE2</td>
<td>The line number minus two in ALAYOUT of the second plane describing an object.</td>
</tr>
<tr>
<td>SLOPB</td>
<td>The slope of the y-y line for the split baffle in the y-y diagram.</td>
</tr>
<tr>
<td>X</td>
<td>The value of the angle from a line parallel to the z axis through the reference point in the image plane to the point in image space being referenced.</td>
</tr>
<tr>
<td>XONE</td>
<td>The distance from the first reference plane after the object to the reference plane under consideration.</td>
</tr>
<tr>
<td>XTWO</td>
<td>The distance from the first reference plane after the object to the reference plane under consideration. It is like XONE, but the reference plane is the second one appearing in ALAYOUT for a given object number.</td>
</tr>
<tr>
<td>Y</td>
<td>The y value of the new edge in real space.</td>
</tr>
<tr>
<td>YBAR</td>
<td>The y value of the new edge in real space.</td>
</tr>
<tr>
<td>YBAR1</td>
<td>The y value of the edge with the smallest y value of the object being split.</td>
</tr>
</tbody>
</table>
Program one

Subroutine ENLARGE
(Continued)

YBAR2  The $\bar{y}$ value of the edges with the largest $\bar{y}$ value of the object being split.
YONE   The real object height of the first reference plane of a given object.
YTWO   The real object height of the second reference plane of a given object.
Y1     The $y$ value of the edge with the smallest $\bar{y}$ value of the object being split.
Y2     The $y$ value of the edge with the largest $\bar{y}$ value of the object being split.

***** See BAFFLE for other variables.

Subroutine CHECK

***** See BAFFLE for identification.

Subroutine LOWER

IAGAIN If IAGAIN equals one, the program is reinserting the original real and image space data for an object that was split and extracting the extra plane of information that was stored in the line just before the second time the original object was referenced.

INSERT The line where the extra plane of information was stored in ALAYOUT.

***** See BAFFLE for other variables.

Subroutine ELLIPSE

DEXIT  The distance to the exit pupil.
ELLINFO(100,6) Column one stores the height of the projection of the center of the referenced pupil onto the exit pupil. Similarly, column two is the radius of the projected pupil, column three is also the same radius, column four is the maximum height of the projection, column five is the minimum height of the projection, and column six is the line referenced in ALAYOUT.

NNN    Equals N, the number of lines in SLOPE.
RADIUSA The radius of the projected aperture.
SHOWI  It is intentionally undefined. It is preset to negative infinity. In this manner the program can reset certain arrays.
XONE   If XONE is negative, it is the $z$ distance from the image plane of the imaged aperture. Otherwise XONE equals zero, the location of the image plane.
Program one
Subroutine ELLIPSE
(Continued)

XTWO  The z distance of the imaged pupil if the imaged distance
      is positive (z positive), otherwise the value of XTWO
      is zero, the location of the image plane.
YBMAX  The radius of the imaged pupil projected onto the exit
      pupil.
YCENTER The height of the projection of the center of the aperture
        onto the exit pupil.
YMAX   The maximum height of the projection of the aperture
        onto the exit pupil.
YONE   The height of the imaged pupil (or YZERO if XONE is zero).
YTWO   Equals YZERO unless XTWO is not equal to zero. Then
        YTWO equals the height of the imaged pupil.

***** See BAFFLE for the other variables.
B. Program Two

Program CALRAD

ALAYOUT(100,7) This array stores the information about the layout of the optical system being analyzed. Column one is coded information that tells whether the \(y\)-\(\bar{y}\) heights are known or not. Column two is the \(y\) value (marginal ray height) at the plane in space. Column three is the \(\bar{y}\) (chief ray height) at this plane in space. Column four is the distance from the present plane to the plane containing the next object. Column five is the radial height of the object in this plane. Column six is the index of the space containing the plane under consideration. Column seven is the object number. Each object has two planes with the same object number. Two \(z\) locations and corresponding radii describe cones, cylinders, and disks. Column eight is the direction of the normal to the surface. Column nine is the number of axial sections on the object.

APERTUR(30,3) The array that holds the information about the apertures. Column one is the maximum height of the aperture. Column two is the minimum height of the aperture (for example the radius of the hole in the primary). Column three is the row in ALAYOUT in which this aperture appears.

CHI The Lagrange invariant.

DMAX The maximum distance that any object edge is imaged.

DMIN The minimum distance that any object edge is imaged.

HID An 80-letter heading to be printed out at the start of the output to briefly describe the system being analyzed.

HMAX The maximum height of all the imaged objects.

IFST The reference line number in ALAYOUT of the object that starts a new space. For the first space it is line one, which is the object. For the second space it will be the first imaging surface, etc.

IMGLNES The slope of the image line in the \(y\)-\(\bar{y}\) diagram of the line being imaged along.

INDEXT An index array initialized by the Fortran routine OPENMS and WRITMS. The array contains information as to where on the disk the information is stored so it can be retrieved. DO NOT change the program to write in this array.

N The number of reference planes in ALAYOUT. This number is increased when an object is split.

NAPT The number of apertures in the system. Presently it can handle up to 30 apertures.

NDEX The index of the space from which the program is looking.
Program two
Program CALRAD
(Continued)

NMINUS1  N-1. One less than the number of lines in ALAYOUT.
NO  The space from where the images are seen.
OMEGA(10,2)  Stores the omega-omega bar information of the lines in the y-\bar{y} diagram. \( \Omega = \nu/\J, \) where \( \nu \) is the index of the space, \( u \) is the marginal ray angle, and \( \J \) is the Lagrange invariant. \( \Omega = \nu/\J, \) where \( \nu \) is the chief ray angle in this space.
P  Equivalenced to I, the line number in ALAYOUT.
PLOTSIT  If PLOTSIT equals PLOT the output will include a plot of all the imaged spaces.
PRIME(100,4)  The array holding the information of all the objects as they are imaged from the given space. Column one is the \( y' \) value, column two is the \( y \) value, column three is the imaged baffle distance relative to the reference plane for this space, column four is the imaged baffle height.
PRINTS  A code word to print out the long or short version of the output. If PRINTS equals PRINTIT, it will print the long version. This should be done only if a mistake is suspected or if one is just learning how the program proceeds.
REFER(10,2)  Contains the \( y \) and \( \bar{y} \) values of the planes that are used as the reference planes for each of the spaces.
SCALE  The scale at which the plot will be made.
SLOPE(100)  The slope of the line in the y-\bar{y} diagram on which this reference plane falls.
SPACE(100)  The space in which this object falls.
SPACENO  The total number of spaces considered. It equals the number of lines in the y-\bar{y} diagram.
YBARREF  The \( \bar{y} \) value at the reference plane for the space being considered.
YEPRIME  The \( y \) value at the pupil or image of the pupil as seen for the space being considered.
YREF  The \( y \) value at the reference plane for the space being considered.

Subroutine SLOPES
L  Line number in ALAYOUT.
*****  See CALRAD for other variables.

Subroutine YYBARIN
*****  See CALRAD for identification of the variables.
Program two
Subroutine SPACES

***** See CALRAD for identification of the variables.

Subroutine LAGRANG

T The distance from the first plane of the system referenced in ALAYOUT to the next plane of information where the y and \( \bar{y} \) values are known.

***** See CALRAD for other variables.

Subroutine IMAGPRI

ALPHA The \( y \) value on a conjugate line parallel to the image line where the \( \bar{y} \) value is that of the plane being considered.

BETA The \( y \) value on a conjugate line parallel to the image line where the \( \bar{y} \) value is that of the plane being considered. It is like ALPHA but for a different \( \bar{y} \) value.

BIG A big number. (1.E40).

CONJK The slope of the conjugate line.

D If an object passes through infinity, the program splits the original object into two objects. To do this, it must define two new planes to describe the two cones. One plane describes the distance and radius of the imaged object that is imaged toward minus infinity, and the other plane is the distance and radius as the object is imaged toward the plus infinity distance. D is that distance at which the program calculates the reference plane information. It is the minimum (or maximum) distance of all objects not passing through infinity. If this distance happens to be the distance D, the D is decreased (or increased) by 10% so that the object passing through infinity has a finite length.

DIST When an object passes through infinity, a new plane of information is created in ALAYOUT. DIST is the fourth column, which is the distance from one reference plane to the succeeding one.

EXTRA EXTRA = 100, an integer constant. Whenever the image of an object is split because it passes through infinity or is partially obscured by another object and is seen as two parts, the second part is made into a separate object and is given an object number 100 more than the original object.

HPRIME The radius of the imaged object that passes through infinity. HPRIME is that radius at distance D from the image plane.

M The line in the various arrays into which line information is put when it is being relocated to make space available for a split object.
Program two
Subroutine IMAGPRI
(Continued)

NOMORE1  The line number minus one in ALAYOUT of the first plane appearing in ALAYOUT of an object passing through infinity.

NOMORE2  The line number minus one in ALAYOUT of the second plane describing an object in ALAYOUT that passes through infinity.

OBJH     Object height of the new edge of a split object. This object height is the real object height that appears in ALAYOUT.

S        The slope of the real object as taken from ALAYOUT.

SP       The slope of the imaged object as taken from PRIME.

X        The length of the object in real space.

XFOUR    The distance from one object plane in ALAYOUT to the next reference plane. Column four in ALAYOUT.

XONE     The distance from the first reference plane after the object to the reference plane under consideration.

XPRIME   The distance used to terminate an object that passes through infinity.

XTHREE   The distance from one reference plane in ALAYOUT to the next.

XTWO     The distance from the first reference plane after the object to the reference plane under consideration. It is like XONE but the reference plane is the second one appearing in ALAYOUT for a given object number.

Y        The change in height of a given object. Also the y value for the new plane of information for a split object.

YBAR     The \( \bar{y} \) value for the new plane of information for a split object.

YBARP    The \( \bar{y}' \) value of the split object.

YONE     The real object height of the first reference plane of a given object.

YP       The \( y' \) value of the split object.

YSS      The y value at the image of the pupil as seen from the space being considered.

YTWO     The real object height of the second reference plane of a given object.

YYYY     A frequently appearing value equal to \( YREF/YSS - 1 \).

***** See CALRAD for other variables

Subroutine SCALES

***** See CALRAD for the definition of the variables.
Program two
Subroutine LOWER

IAGAIN
If IAGAIN equals one, the program is extracting the second line of information that was added for a split object. If IAGAIN equals two it is extracting the first line of added information.

INSERT
The line in ALAYOUT where the extra plane of information was stored.

**** See CALRAD for other variables in LOWER.

Subroutine SEE

DMAXS
The maximum distance of any of the plotted objects. The objects are first scaled, and if any portion of the plot at this scale falls within the limits of ±5.4 in. in height and ±60 in. in distance, then that portion is plotted.

DMINS
The minimum distance of any of the plotted objects. See DMAXS above.

HGTMAX
The maximum height of any of the plotted objects. It will be 5.4 in. or less, so if the image of an object is larger than this, it must be scaled down.

NOTE
The words to be written on the plot to identify it.

S
The slope of the line to be plotted.

SC
The program scales all imaged objects and then determines the minimum and maximum scaled distances. If these distances are greater or less than 60 in. the program will rescan the imaged data for objects or portions of objects that fall within these limits. It will set new values for DMAXS and DMINS (usually they will now be ±60 in. and ±60 in. but not necessarily). The value of 60 in. was chosen as a large but practical plot size.

SCALE
If the scale is not read in, then the program will establish a scale such that ALL imaged objects will fall within the limits of the plotting paper. If there is one very long object, everything will be scaled down accordingly and perhaps be too small. The desired plot size can be read in and overrides the above feature. Those objects outside the limits are not plotted, and a message is written on the output. If only a portion of the object is plotted, then a message is again printed on the output.

X
The number of the object being plotted.

XX
The space from which this plot is seen.

XI
One of the x coordinates of the plotted object.
Program two

Subroutine SEE
(Continued)

X2 One of the x coordinates of the plotted object.
Y1 One of the y coordinates of the plotted object.
Y2 One of the y coordinates of the plotted object.
ZA The angle at which the letters are plotted onto the plot.
ZB The offset value used to place the numbers along an object in the plotted output.
ZZ The height at which the numbers are written on the plotted output.

***** See CALRAD for identification of other variables.

Subroutine IMGLINE

ISEC One of the two imaging apertures that defines the space that the objects are in. ISEC is line number in ALAYOUT in which the second defining aperture appears.

***** See CALRAD for identification of the other variables.

Subroutine CHANGEA

OFFSET The distance from the image plane to the reference plane of the last image space.
X The object number.
XI The line in ALAYOUT where object X first appears.
XIJ The line in ALAYOUT in which the object X appears a second time.

***** See CALRAD for identification of other variables.
C. Program Three

Program VIEWFAC

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAT</td>
<td>The difference in the z coordinate from the source point to the collector point on the image (if not imaged, then on the real collector object).</td>
</tr>
<tr>
<td>ACC</td>
<td>Each object section can be subdivided into smaller subsections. Then the power transfer is made from each subsection on the source to each subsection on the collector. Sometimes, because of obscurations, not all these possible transfers occur. ACC is the number of such transfers that do occur, and the data are averaged over this number of occurrences.</td>
</tr>
<tr>
<td>AL</td>
<td>The direction cosine from the x axis of that vector that enters the collector in REAL space as the path of radiation is traced from the source to the collector. This value is not necessarily the same as the vector BL from the source to the IMAGE of the collector section.</td>
</tr>
<tr>
<td>AM</td>
<td>The direction cosine from the y axis of that vector that enters the collector in REAL space as the path of radiation is traced from the source to the collector.</td>
</tr>
<tr>
<td>AN</td>
<td>The direction cosine from the z axis of that vector that enters the collector in REAL space as the path of radiation is traced from the source to the collector.</td>
</tr>
<tr>
<td>ANGAB</td>
<td>The angle (in radians) subtended by each subsection's circular edge.</td>
</tr>
<tr>
<td>ANGB090</td>
<td>The cosine of the angle between the vector (AL,AM,AN) and its projection in the y-z plane in the local coordinate system of the collector. The basis vectors of this local coordinate system are ZXB,ZYB,ZZB.</td>
</tr>
<tr>
<td>ANGLE(1764,4)</td>
<td>Column one is the average computed angle out of the source, that is the average SANG. Column two is the average ANGS090 angle. This is the angle between the outgoing vector and its projection in local y-z plane. Column three is the average computed angle into the collector in real space, that is the average BANG. Column four is the average ANGB090 angle. This is the angle between the incoming vector into the collector in real space and its projection into the local y-z plane.</td>
</tr>
<tr>
<td>ANGSS</td>
<td>Two PI radians divided by the number of subsections in the circumference of the object.</td>
</tr>
<tr>
<td>ANGS090</td>
<td>The angle between the incoming vector into the collector in real space and its projection in the local y-z plane.</td>
</tr>
</tbody>
</table>
APARENPEquals SSCOS, the angle between the normal to the source and the outgoing vector.

APERTUR(10,3) The array holds the information about the apertures. Column one is the maximum height of the aperture. Column two is the minimum height of the aperture (for example the radius of the primary hole).

AXT The difference in the x coordinate of the incoming vector to the collector where one point is the collector point and the other point is the point where the vector penetrates the last imaging surface.

AY The y value at the last imaging surface in real space.

AYB The y value at the last imaging surface. The y value is the real space y value.

AYT The incoming vector is defined by two points, the collector point and the point on the last imaging surface where the projection of this vector reflects at the surface. AYT is the difference in the y coordinate of these two points.

AZT Like AXT and AYT but the difference in the z coordinate of the two points.

B B is the current axial section of the collector.

BAPAREA The area of the imaged baffle subsection.

BAFCOS The cosine of the angle between the normal to the imaged collector surface and the incoming vector.

BANG The incoming vector to the collector in real space is projected into the local y-z plane of the collector point, and the angle between this projection and the plus z vector (in local coordinates) in degrees is the value BANG.

BB The number of axial sections in the collector.

BBT The vector from the source to the image of the collector is defined by two points, the source point and the imaged collector point. BBT is the difference in the y coordinate of these two points.

BISDELT The maximum number of subsections along the axis of the source.

BISS The maximum number of sections along the axis of the source. If these sections are subdivided (into delta by delta subsections) then there are BISS*DELTA subsections (BISDELT) along the axis.

BL The direction cosine from the x axis of the outgoing vector from the source.
The value read in by the program that tells the program into which mass storage block the following information should be stored. If left blank the program proceeds sequentially from one of the last BLOCK values read in. In this manner the individual blocks can be changed without redoing all the calculations.

The direction cosine from the y axis of the vector from the source point to the point on the imaged collector.

The direction cosine from the z axis of the vector from the source point to the point on the imaged collector.

The radius of the back edge (the edge with the largest z value in real space) of the subsection of the collector being calculated.

The current axial section on the source (NOT the axial subsection).

The current subsection within the section on the source being considered. BSSUBI cannot get larger than DELTA.

The current subsection within the section of the collector being considered, BSUBI cannot get larger than DELTA.

Half the axial distance between subsections of the collector.

Half the axial distance between subsections of the source.

If C reads the word SOURCE, then a new power transfer set will be calculated. Any other word, including blanks, will make the program search for other cue values and treat them as obstructions.

The sum of all the angles BANG calculated for the power transferred from the section on the source to the section on the collector.

The vector from the source to the image of the collector is defined by two points, the source point and the imaged collector point. CCT is the difference in the x coordinate of these two points.

Equals NC, the number of the collector.

Contains the percent of power transferred from the sections on the source to the sections on the collector.

The sum of all the angles ANGB090 calculated for the power transferred from the section on the source to the section on the collector.

The distance between subsections on the collector.

The direction cosines from the x, y, and z axes, respectively, of the vector connecting the imaged collector point and the point on the z axis that will make this vector lie in a plane normal to the z axis. In a sense
it is the imaged baffle radius vector. If the baffle is a cone, then the direction of this vector is determined by DNORMAL, which denotes whether the surface is the inside of the cone or the outside of it.

![Diagram of DCOSBR vector]

Fig. 15. DCOSBR vector to which the direction cosines, DCOSBRX, DCOSBRY, and DCOSBRZ are calculated.

<table>
<thead>
<tr>
<th>DCOSBX</th>
<th>The direction cosines from the x, y, and z axes, respectively, of the vector normal to the collector surface in real space at the point being referenced. The direction of the vector determines whether the inside or outside surface of the cone is being considered.</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCOSBY</td>
<td>The direction cosines from the x, y, and z axes, respectively, of the vector that is normal to the imaged collector surface at the point being referenced. The direction of the vector determines whether the inside or outside surface of the cone is being considered.</td>
</tr>
<tr>
<td>DCOSBZ</td>
<td>The direction cosines from the x, y, and z axes, respectively, of the vector that is normal to the z axis, passes through the source point and the z axis. The direction of the vector determines whether the inside or outside surface of the cone is being referenced.</td>
</tr>
<tr>
<td>DCOSIX</td>
<td>The direction cosines from the x, y, and z axes, respectively, of the vector that is normal to the surface of the source at the point being referenced. The direction of the vector determines whether the inside or outside surface is being considered.</td>
</tr>
</tbody>
</table>
Each section of the source and the collector can be subdivided into \( \text{DELTA} \) by \( \text{DELTA} \) subsections. Then the power transfer factor is computed from each subsection on the source to each subsection on the collector and then summed for the power transfer from each section to each section. If \( \text{DELTA} \) is three, that means that there are nine subsections on the source and nine subsections on the collector and the program will make 81 more power transfer calculations. The final power transfer calculations will be more accurate, but the computer costs will go up.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{DENOM} )</td>
<td>The distance between the source point and the image of the collector point.</td>
</tr>
<tr>
<td>( \text{DENOMBN} )</td>
<td>The length of the DCOSB vector.</td>
</tr>
<tr>
<td>( \text{DENOMI} )</td>
<td>The incoming vector to the collector point in real space is defined by the collector point and the point on the last imaging surface through which the collector point is seen by the source. The length of this vector is ( \text{DENOMI} ).</td>
</tr>
<tr>
<td>( \text{DENOMSN} )</td>
<td>The length of the vector DCOSS.</td>
</tr>
<tr>
<td>( \text{DENOMWN} )</td>
<td>The length of the vector DCOSI.</td>
</tr>
<tr>
<td>( \text{DMIR} )</td>
<td>Looking from the source toward the collector, DMIR is the imaged distance of the last imaging aperture. The program automatically checks that the radiation passes through this imaged aperture.</td>
</tr>
<tr>
<td>( \text{DNORMAL} )</td>
<td>The normal to the collector surface in real space. If the collector is a cone, a positive ( \text{DNORMAL} ) value indicates the outside of the cone. A negative ( \text{DNORMAL} ) indicates the inside of the cone. If the collector is a disk, a positive ( \text{DNORMAL} ) indicates the plus ( z ) direction of the disk is the collector. If ( \text{DNORMAL} ) is negative, the minus ( z ) direction of the disk is the collector.</td>
</tr>
<tr>
<td>( \text{DSS} )</td>
<td>The axial distance between subsections on the source.</td>
</tr>
<tr>
<td>( \text{E} )</td>
<td>The number of the subsection along the ( z ) axis being referenced as the collector.</td>
</tr>
<tr>
<td>( \text{ENDSIT} )</td>
<td>A code word set by the program when all the data cards have been read.</td>
</tr>
<tr>
<td>( \text{EX} )</td>
<td>The program calculates a series of vectors that are interrelated to determine the &quot;computed&quot; angle into the collector or out of the source. The angle that is finally used is the projection of the incoming (or outgoing if the source) vector onto the &quot;local&quot; ( y-z ) plane at the point on the collector in real space. Three vectors already</td>
</tr>
</tbody>
</table>
Program three
Program VIEWFAC
(Continued)

described are sufficient to establish the local coordinate system and determine the necessary angles. These vectors are \( \hat{A}(AL,AM,AN) \), \( \text{DCOSB}(DCOSBX,DCOSBY,DCOSBZ) \), and \( \text{DCOSBR}(DCOSBRX,DCOSBRY,DCOSBRZ) \) for the collector. For the source they are \( \hat{B}(BL,BM,BN) \), \( \text{DCOSS}(DCOSSX, DCOSSY, DCOSSZ) \) and \( \text{DCOSR}(DCOSRX,DCOSRY,DCOSRZ) \). If we rename these vectors as \( \hat{I}, \hat{N}, \) and \( \hat{R} \), respectively, in either case it will be easier to follow both cases. \( \hat{I} \) stands for the incoming or outgoing vector connecting the two points, \( \hat{N} \) stands for the normal to the surface vector, and \( \hat{R} \) stands for the radius vector. \( \hat{R} \times \hat{N} = \hat{E} \). \( \hat{E} \) has the direction cosines \( (OX,OY,OZ) \). \( \hat{N} \times \hat{E} = \hat{Z} \). \( \hat{Z} \) has the direction cosines \( (ZX,ZY,ZZ) \). \( \hat{I} \times \hat{O} = \hat{E} \). \( \hat{E} \) has the direction cosines \( (EX,EF,EZ) \). \( \hat{E} \times \hat{O} = \hat{F} \). \( \hat{F} \) has the direction cosines \( (FX,FY,FZ) \). \( \hat{E} \) is the projection of \( \hat{I} \) into the plane containing the \( \hat{R}, \hat{N}, \) and \( \hat{Z} \) vectors. They determine the "local" y-z plane. \( \hat{O} \) is the "local" x axis.

**F**

The current subsection along the z axis of the source.

**FIX**

When a disk is reimaged, the normal to that imaged surface can be in the opposite direction of the normal in real space. FIX fixes the normal of the imaged object accordingly.

**FRBA**

The radius of the front edge (the edge with the smallest z value in real space) of the subsection of the collector being calculated.

**G**

Equals one-fourth the distance of the closest source subsection-collector subsection combination.

**HOLES(20,2)**

It contains information as to what the obscurations are and where the information is stored in ALAYOUT. If for obscuration IH HOLES(IH,2) equals zero, the obscuration is an aperture that the radiation must pass through, and HOLES(IH,1) is the line in ALAYOUT that has the size and other information about the aperture. If HOLES(IH,2) is greater than zero, then the shadow is a disk and HOLES(IH,1) is the line in ALAYOUT that has the necessary information about the disk. If HOLES(IH,2) is less than zero, then the obstruction is a cone and HOLES(IH,1) is the object number in ALAYOUT of the cone.

**IH**

The lines in HOLES being referenced.

**IMAX**

The number of sections along the axis of the collector.

**INANGL**

The line in CONE and ANGLE being referenced.
Program three
Program VIEWFAC
(Continued)

INBLOCK  The block in the random access storage in which the
information will be stored.
INCOME   The line in cone being referenced.
INDEX(100,3) An index array initialized by the Fortran routines
INDEX(100) OPENMS and WRITMS. The array contains information as
          to where on the disk the information is stored so it
          can be retrieved. DO NOT change the program to write
          in this array.
IOBJC     The line number in ALAYOUT the first time the collector
          object is referenced.
IOBJCC    The line number in ALayout the second time the collector
          object is referenced.
IOBJS     The line in ALAYOUT the first time that the source is
          referenced.
IOBJSS    The line in ALAYOUT the second time that the source is
          referenced.
ISPC      The space the collector is in.
ISPS      The space the source is in.
ISS       The number of axial sections on the source.
ISS3      The number of sections along the axis of the source times
          the number of radial sections from section one to the
          bottom section.
ITAB(100) The number of words or the size of the blocks of informa-
          tion stored by WRITMS.
JLOW      There must be an odd number of sections on the circum-
          ference of the objects. If one starts at the 12 o'clock
          position and counts the sections clockwise, the section
          on the bottom at the six o'clock position is section
          JLOW.
JMIR      The line in ALAYOUT of the last imaging aperture from
          the source to the collector.
MMAG      The magnification of the last imaging aperture.
N         The number of lines in ALAYOUT.
NBLOCK   The block in mass storage in which the information is
          stored.
NC        The number of the collector.
NDEX      The index of the space of the source.
Program three
Program VIEWFAC
(Continued)

NEWITAB
Read as input. If blank, it will create a new ITAB index.
If it is not blank, then the program will read from
mass storage the old ITAB and overwrite where necessary.

NS
The number of the source object.

NSIZE
The number of words stored in this block of mass storage
information.

NTAB
Equals 100. This value is set to be compatible with
the other programs, DO NOT change it unless you change
all programs. Certain information is stored in INDEX and
INDEX2 in row 100.

O
Omega value for the image line of the source. Omega
equals $\nu/\omega$, where $n$ is the index of the space of the
source, $\nu$ is the marginal ray angle in the source space,
and $\omega$ is the Lagrange invariant.

OBAR
Omega bar value for the image line of the source. Omega
bar equals $\nu/\omega$, where $n$ is the index of the space of
the source, $\nu$ is the chief ray angle in the source
space, and $\omega$ is the Lagrange invariant.

OBC
If the desired collector was not numbered in program
two but there are lines in ALAYOUT from which the
desired object can be made, then OBJC and OBC are the
two line numbers in ALAYOUT containing the information.
In particular a disk may be made by specifying a single
line twice.

OBJC
If the collector is specified in program two, OBJC is
the collector number. If a new object is being made
by existing lines in ALAYOUT, then OBJC is one of the
two line numbers. OBC is the other.

OBJS
If the source was specified in program two, OBJS is the
source number. If a new object is made from existing
lines in ALAYOUT, then OBJS is one of the line numbers.

OBS
If the source was not numbered in program two, OBS is
one of the two lines in ALAYOUT which form the new source.

OC1
If the data being read in are a "SOURCE" data card, OC1
is the OBJC value, otherwise OC1 should be read in as
-0.

OC2
If the data being read in are a "SOURCE" data card, OC2
is the OBC value, otherwise OC2 should be read in as -0.

OMEGA(10,2)
Stores the omega-omega bar information of the lines in
the $\gamma-\gamma$ diagram. $\hat{\omega} = \nu/\omega$ where $n$ is the index of the

space, \( u \) is the marginal ray angle in this space, and \( \mathbf{x} \) is the Lagrange invariant. \( \mathbf{n} = \mathbf{u}/\mathbf{x} \), where \( \mathbf{u} \) is the chief ray angle in this space.

**OS1**

If the data being read in are a "SOURCE" data card, then OS1 is the same as OBJS. If the card is not a "SOURCE" card, then OS1 becomes the value for HOLES(IH,1), which is the line in ALAYOUT of the obstructing disk or aperture or it is the cone object number causing the shadow.

**OS2**

If the data being read in are a "SOURCE" data card, then OS2 is the same as OBS. If the card is not a "SOURCE" card, then OS2 is the value for HOLES(IH,2), which codes whether the obstruction is a disk, aperture, or cone.

**OX, OY, OZ**

**PCP**

The percent of power transferred from one section of the source to one section of the collector.

**PHI**

The value of \( \pi = 3.14159265358979 \).

**PRINTER**

Code word for the long or short form of printout. For the long version the code word is PRINTIT. For the power transfer from each section on the source to each section on the collector the following variables are printed: INANGLE, DCOSBRX, DCOSBRY, DCOSBRZ, BL, BM, BN, AL, AM, AN, DCOSBX, DCOSBY, DCOSBZ, DCOSSX, DCOSSY, DCOSSZ, WX, WY, WZ, XP, YP, ZP, XS, YS, ZS, DCOSIX, DCOSIY, DCOSIZ, OX, OY, OZ, VX, VY, VZ, EX, EY, EZ, WX, WY, and WZ. This is enough information to check out the calculations. If the code word is CHECKPO, the program will print out the information passed on by file 10 (BASICA).

**PWRTRAN**

The percent of power transferred from one subsection of the source to one subsection of the collector.

**QRBA**

The radius of the imaged baffle at the collector point.

**QZP**

The distance of the plane containing the imaged collector point from the reference plane.

**RBA**

The radius in real space at the collector point.

**REFER(10,2)**

Contains the \( \mathbf{x} \) and \( \mathbf{y} \) values of the planes that are used as reference planes for each of the three spaces.

**RLONGER**

A disk is subsectioned into sections of equal area. To do this there must be an inside radius (RSHORT) and an outside (RLONGER) radius.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMAG</td>
<td>The lateral magnification of the object in question.</td>
</tr>
<tr>
<td>RMIR</td>
<td>The distance from the optical axis of the vector from the source point to the collector point as it passes through the first imaging aperture.</td>
</tr>
<tr>
<td>RMIRX</td>
<td>The imaged radius of the last imaging aperture.</td>
</tr>
<tr>
<td>RSHORT</td>
<td>A disk is subsectioned into sections of equal area. To do this it finds the appropriate inner and outer radius. The inner radius is RSHORT.</td>
</tr>
<tr>
<td>RSS</td>
<td>The radius to the source point from the z axis.</td>
</tr>
<tr>
<td>RSS1</td>
<td>The radius of the source in the plane that has the lowest z coordinate as referenced in ALAYOUT.</td>
</tr>
<tr>
<td>RSS2</td>
<td>The radius of the source in the plane that has the largest z coordinate as referenced in ALAYOUT.</td>
</tr>
<tr>
<td>R1</td>
<td>The radius of the collector in the plane that has the lowest z coordinate as referenced in ALAYOUT.</td>
</tr>
<tr>
<td>R2</td>
<td>The radius of the collector in the plane that has the largest z coordinate as referenced in ALAYOUT.</td>
</tr>
<tr>
<td>SANG</td>
<td>The &quot;computed&quot; angle out of the source.</td>
</tr>
<tr>
<td>SB</td>
<td>The vector ( \vec{Z} ) in &quot;local&quot; coordinates is positive as it runs in the positive z direction. SB is set so that when the appropriate cross products are made to determine the &quot;local&quot; system, ( \vec{Z} ) will be in the correct direction.</td>
</tr>
<tr>
<td>SCP</td>
<td>The sum of the SANG angles as the power transferred is made from subsection to subsection.</td>
</tr>
<tr>
<td>SEC</td>
<td>The number of sections along the z axis on the collector.</td>
</tr>
<tr>
<td>SECJ</td>
<td>The number of sections around the z axis. The default value is five. The circumference of the objects is divided into SECJ equal segments.</td>
</tr>
<tr>
<td>SECSSJ</td>
<td>The number of subsections around the z axis. This number equals SECJ times DELTA.</td>
</tr>
<tr>
<td>SJ</td>
<td>The current radial section of the collector.</td>
</tr>
<tr>
<td>SJLOW</td>
<td>The number of the section in the six o'clock position of the source. See JLOW.</td>
</tr>
<tr>
<td>SJSUBJ</td>
<td>The number of the radial subsections within the radial section of the source.</td>
</tr>
<tr>
<td>SLANTB</td>
<td>The slant length of the section of the collector in real space.</td>
</tr>
</tbody>
</table>
Program three
Program VIEWFAC
(Continued)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLANTL</td>
<td>The slant length of the section of the imaged collector.</td>
</tr>
<tr>
<td>SLANTS</td>
<td>The slant length of the section of the source.</td>
</tr>
<tr>
<td>SLONGER</td>
<td>If the source is a disk, it is subsectioned into sections of equal area. To do this it calculates the appropriate inner and outer radius. The outer radius is SLONGER.</td>
</tr>
<tr>
<td>SLOPAB</td>
<td>The slope in the y-z plane of the collector in real space.</td>
</tr>
<tr>
<td>SLOPABI</td>
<td>The slope in the y-z plane of the imaged collector.</td>
</tr>
<tr>
<td>SLOPSS</td>
<td>The slope in the y-z plane of the source.</td>
</tr>
<tr>
<td>SN</td>
<td>The source number.</td>
</tr>
<tr>
<td>SNORMAL</td>
<td>The code for the direction of the normal to the surface of the source. If the source is a disk, a value of +1. for SNORMAL implies the source surface is the side of the disk toward the positive z direction. A value of -1. implies the other side. If the source is a cone, a value of +1. for SNORMAL implies the outside of the cone is the source, whereas a value of -1. implies the inside of the cone.</td>
</tr>
<tr>
<td>SPACE(100)</td>
<td>The space that the object is in.</td>
</tr>
<tr>
<td>SS</td>
<td>The adjustment factor so that the &quot;local&quot; coordinate Z axis always is in the direction of the plus z axis.</td>
</tr>
<tr>
<td>SSAREA</td>
<td>The area of the source subsection.</td>
</tr>
<tr>
<td>SSCOS</td>
<td>The cosine of the angle between the normal to the source and the vector from the source point to the imaged collector point.</td>
</tr>
<tr>
<td>SSHORT</td>
<td>If the source is a disk, it is subsectioned into areas of equal area. To do this, it calculates the appropriate inner and outer radius. The inner radius is SSHORT.</td>
</tr>
<tr>
<td>SSJ</td>
<td>The number of the radial subsection on the source.</td>
</tr>
<tr>
<td>SSJSUBJ</td>
<td>The number of the subsection within the section of the source.</td>
</tr>
<tr>
<td>SY</td>
<td>The y value at the plane containing the source point.</td>
</tr>
<tr>
<td>SYBAR</td>
<td>The y value at the plane containing the source point.</td>
</tr>
<tr>
<td>S90</td>
<td>The sum of the angles ANGS090, for the power transfer from section to section.</td>
</tr>
<tr>
<td>TYPE</td>
<td>The type of collector; a disk or a cone.</td>
</tr>
<tr>
<td>TYPEMIT</td>
<td>The type of emitter (source): a disk or a cone.</td>
</tr>
</tbody>
</table>
Program three
Program VIEWFAC
(Continued)

VIEW If both the source and the collector are in the same space, the VIEW is real space. If the collector is not in the same space as the source, it will be reimaged and VIEW will be blank filled.

VV The real space distance used as a reference point to calculate the \( y \)-\( y \) values at the collector point in real space. This plane is used because the \( y \)-\( y \) values are known at this position.

VX
VY
VZ
WX
WY
WZ

\( VX=ZX \) \( VY=ZY \) \( VZ=ZZ \) See EX.

\( WX=FX \) \( WY=FY \) \( WZ=FZ \) See EX.

XMAX The number of sections along the \( z \) axis on the collector.

XMIR The \( x \) coordinate on the first imaging surface of the vector from the source to the collector.

XP The \( (x,y,z) \) coordinates of the collector point in real space.

YP
ZP

XS The \( (x,y,z) \) coordinates of the source point.

YS
ZS

XSS The number of axial sections on the source.

XXW The \( (x,y,z) \) coordinates of the collector point in image space.

YW
ZW

XXX The angle in radians from the 12 o'clock position to the source point.

XXXX The angle in radians from the 12 o'clock position to the collector point.

YBAR1 The \( \bar{y} \) value at the plane with the lowest \( z \) coordinate as defined in ALAYOUT for the collector.

YBAR2 The \( \bar{y} \) value at the plane with the largest \( z \) coordinate as defined in ALAYOUT for the collector.

YBREF The \( \bar{y} \) reference value for the space containing the source.

YMIR The \( y \) coordinate on the first imaging surface of the vector from the source to the imaged collector point.
Program three
Program VIEWFAC
(Continued)

YREF  The y reference value for the space containing the source.
YS    The coordinates of the source point are (XS,YS,ZS).
YP    The coordinates of the collector point in real space are (XP,YP,ZP).
YW    The coordinates of the collector point in image space are (XW,YW,ZW).
Y1    The y value at the plane with the lowest z coordinate as defined in ALAYOUT for the collector.
Y2    The y value at the plane with the largest z coordinate as defined in ALAYOUT for the collector.
ZB    The z coordinate of the imaged collector plane that has the largest z coordinate.
ZCRIT The z coordinate of the image of the first imaging aperture. The program checks that the radiation passes through this aperture.
ZF    The z coordinate of the imaged collector plane that has the lowest value for its z coordinate.
ZHE   The Lagrange invariant.
ZMIR  The distance in real space of the last imaging surface. The vector \( \mathbf{A} \) is created from this plane to the collector point in real space.
ZP    The coordinates of the collector point in real space are (XP,YP,ZP).
ZPZERO The point on the z axis where the normal to the surface of the collector passes through the z axis.
ZS    The coordinates of the source point are (XS,YS,ZS).
ZSS1  The z coordinate of the plane of the source (as defined in ALAYOUT) with the lowest z value.
ZSS2  The z coordinate of the plane of the source (as defined in ALAYOUT) with the largest z value.
ZSZERO The point along the z axis where the normal to the surface of the source passes through the z axis.
ZW    The coordinates of the image of the collector point are (XW,YW,ZW).
Z1    The plane of the collector with the lowest z coordinate as defined in ALAYOUT.
Z2    The plane of the collector with the largest z coordinate as defined in ALAYOUT.
Program three

Subroutine SETAPT

IV The line number in ALAYOUT of the last imaging aperture.
JV The line number in ALAYOUT of the first imaging aperture for this source collector combination.

***** See VIEWFAC for other variables.

Subroutine BDRDF

ANGB180 The cosine of the angle BANG, which is the "computed" angle into the collector.
ANGS180 The cosine of the angle SANG, which is the "computed" angle out of the source.
CONVERS Equals 180/PI. Converts radians to degrees.
FX See EX in VIEWFAC. Vector F is for the source.
FY
FZ
FXB Vector F for the collector. See EX in VIEWFAC.
FYB
FZB
X Corrects the sign of the cosine values for the various angles.
ZX Vector Z for the source. See EX in VIEWFAC.
ZY
ZZ
ZXB Vector Z for the collector. See EX in VIEWFAC.
ZYB
ZZB

***** See VIEWFAC for the definition of other variables.

Subroutine VECTOR

***** See VIEWFAC for the definition of the variables.

Subroutine NORMAL

***** See calling routines.

Subroutine MIRRORS

PY The y value for the plane in real space containing the object point.
PYBAR The y value for the plane in real space containing the object point.
QC The conversion factor from the y- value of the object plane for the collector to the y- values of its image plane along the imaging line. It is equal to the y value of the image point in its real space times the omega bar.
value \((\nu/K)\) of the line onto which it is being projected minus the \(\bar{y}\) value of the image point in its real space times the omega value \((\nu/K)\) of the line onto which it is being projected.

**QY** The \(y\) value of the plane containing the image of the collector point.

**QYBAR** The \(\bar{y}\) value of the plane containing the image of the collector point.

**RMAG** The lateral magnification of the collector plane into its image.

***** See VIEWFAC for the definition of other variables.

**Subroutine MIRRORA**

**PY** The \(y\) value of the plane in real space containing the object point.

**PYBAR** The \(\bar{y}\) value of the plane in real space containing the object point.

**QC** The conversion factor from the \(y-\bar{y}\) value of the object plane for the collector in its real space to the \(y-\bar{y}\) values of its image along the imaging line. See subroutine MIRRORS.

**QY** The \(y\) value of the plane containing the image of the collector point.

**QYBAR** The \(\bar{y}\) value of the plane containing the image of the collector point.

**RMAR** The lateral magnification of the collector plane into its image.

**Subroutine APERT**

**COSC** The cosine of CRTANG. See below for CRTANG.

**CRTANG** If the obstruction is a cone (it could be the image of a cone), then there are two planes tangent to the cone and passing through the source point. Any vector passing between these planes through the cone will be obstructed. The critical angle (CRTANG) is the half angle these planes make where they intersect the x,y plane containing the source point (see Fig. 16).

**CI** The radius in real space of the projection of the shadowing cone onto the x,y plane.

**I** The line number in HOLES.
Program three
Subroutine APERT
(Continued)

Tangent Plane

Source Point

Tangent Plane

Fig. 16. Obstruction by a cone-shaped baffle.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILINEA</td>
<td>The line in ALAYOUT containing the information about the shadowing object when the shadow is a disk or an aperture.</td>
</tr>
<tr>
<td>IOBJH</td>
<td>If the shadow is caused by a cone then there are two lines in ALAYOUT that contain all the necessary information. IOBJH is the first line appearing in ALAYOUT, and IOBJHH is the line number of the second time it appears.</td>
</tr>
<tr>
<td>IOBJHH</td>
<td>The space of the shadowing object. The image of the object is projected as seen from the source if the source and shadow are not in the same space.</td>
</tr>
<tr>
<td>ISPA</td>
<td>The object number of the cone causing the shadow.</td>
</tr>
<tr>
<td>ISPsHE</td>
<td>The real height of the obscuring aperture or disk.</td>
</tr>
<tr>
<td>OBJH</td>
<td>The radius from the z axis as the vector from the source point to the collector passes through the plane of the obscuring disk, aperture, or the plane of the end of the shadowing cone.</td>
</tr>
<tr>
<td>RBAH</td>
<td>The radius from the z axis as the vector from the source point to the collector point passes through one of the</td>
</tr>
</tbody>
</table>
ends of the shadowing cone. The radius as it passes through the other end is RHOLE.

**RH1**
The radii in real space of the shadowing cone.

**RH2**

**R1ATZ**
The radius of the shadowing cone as it passes through the x-y plane containing the source point. It is in this plane that CRTANG is calculated.

**SINC**
The sine of CRTANG.

**SLOPE1**
The slope in the y-z plane of the shadowing cone.

**T**
The shadowing cone is described by two z coordinates and two radii. The two planes tangent to the cone and passing through the source point are tangent also to the two radii. The set of four points (each plane tangent to two circles) is coplanar. The vector from the source to the collector point is \( \mathbf{B} \). \( \mathbf{T} \) is the distance from the source point along \( \mathbf{B} \) to the point where \( \mathbf{B} \) passes through the plane containing the above four points.

**TYPEH**
The type of shadow: a hole or a disk.

**X**
The x coordinate of the \( \mathbf{B} \) vector as it passes through the plane containing the four points. See \( \mathbf{T} \) above.

**XCB**
The two positive x coordinates of the four coplanar points mentioned in \( \mathbf{T} \) above.

**XCK**
The x coordinate of the point on the cone and in the plane of the four coplanar points at the z coordinate of the \( \mathbf{B} \) vector as it passes through the plane containing the four points. If \( \mathbf{X} \) is less than \( \mathbf{XCK} \) at this value of \( z \), the line of sight is through the cone and is therefore obscured.

**XHOLE**
The x coordinate of the \( \mathbf{B} \) as it passes through the plane of the obscuring disk, hole, or either end of the cone.

**YBH**
The \( \bar{y} \) value for the plane of the shadow being imaged.

**YCF**
The two y coordinates of the points that have the positive x coordinates \( \mathbf{XCB} \) and \( \mathbf{XCF} \).

**YH**
The y value for the plane of the shadow being imaged.

**YHOLE**
The y coordinate of the \( \mathbf{B} \) vector as it passes through the plane of the obscuring disk, hole, or either end of the cone.
Program three
Subroutine APERT
(Continued)

Z     The z coordinate as the $\bar{E}$ passes through the plane of
      the four coplanar points. See $T$ above.
ZPH    The $z$ coordinates of the two ends of the cones after
ZPH2   they are imaged if that was necessary.

***** See VIEWFAC for the definition of the other variables.
D. Program Four

There are too few variables in program four to be listed here.
See p. 61 for more information.
# E. Program Five

**Program DRIVER**

A(980)  A dummy array used to rearrange certain arrays taken from or being put into mass storage files.

AFAC  A factor that will adjust the radiance distribution of the source to that measured in the lab. It has been found that even for normal incidence the blacks are not Lambertian.

ANG  If the load program does not supply the array of angles into each section of the surfaces receiving radiation from the source, the program will allow the value to be read in or default to 90. degrees.

ANGI  The particular "calculated" angle into the collector section being referenced. One of the values in the array ANGINS.

ANGINS(42,14)  The array of angles into the present emitter from one of its previous sources.

ANGO  The particular "calculated" angle out of the source section that is being referenced. One of the values in the array ANGOS.

ANGOS(42,14)  The array of angles out of the present emitter to the collector.

ANGV  The angle of the vanes (if this section has any) of the section of the source being referenced.

ARIHO  The apparent reflectivity of the source section for the angle at which the power came into it, and for the angle at which it is being emitted toward the collector section. This value may be greater than RHO, the reflectivity of the type of coating applied to the surfaces because the locus of the vane tips was used to calculate the percent of power transferred. The cosine of the angle between the normal to the surface and the direction toward the collector was used to determine the projected area seen by the collector. The angle of the vanes, the angle at which the power falls on the vanes (not the locus of vane tips), and the angle from the normal to the vanes at which the radiation goes off the vanes is taken into account by the program.

BDR  The percent of power transferred from the referenced source section to the referenced collector section.

CONEB(42,14)  The array containing all the BDR values for all the sections of the source to all the sections of the collector.
CONE1(70,14) The array containing the power on each section of the source. The power on the source is stored in a very precise manner, and any new loader program must arrange the loaded radiation accordingly. The manner was chosen because all the separate powers must be stored, and for certain operations the present arrangement is faster and has fewer IO calls. An example will help to show how the information is stored. If the source has two axial sections and has received radiation from an object that had three axial sections, the power on the source will be in five arrays that are 10 by 3.

The source for this collector has three axial sections and five radial sections. Hence this array 5x3. See note A.

The information is stored in five arrays of this size. Each array is for one complete axial section (the entire length of the source with the number of the radial section fixed). Since there are five radial sections, there are five of these arrays.

<table>
<thead>
<tr>
<th>Power on space 1,1 of the collector.</th>
</tr>
</thead>
<tbody>
<tr>
<td>.21E-06  .21E-06  .26E-06</td>
</tr>
<tr>
<td>.46E-06  .51E-06  .56E-06</td>
</tr>
<tr>
<td>.44E-07  .98E-06  .66E-06</td>
</tr>
<tr>
<td>.78E-06  .78E-06  .51E-06</td>
</tr>
<tr>
<td>.28E-06  .29E-06  .28E-06</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Power on space 1,2 of the collector.</th>
</tr>
</thead>
<tbody>
<tr>
<td>.77E-06  .12E-05  .89E-05</td>
</tr>
<tr>
<td>.45E-06  .24E-05  .77E-05</td>
</tr>
<tr>
<td>.56E-06  .14E-06  .58E-05</td>
</tr>
<tr>
<td>.35E-06  .69E-06  .61E-05</td>
</tr>
<tr>
<td>.68E-06  .15E-05  .75E-05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Power on space 2,1 of the collector.</th>
</tr>
</thead>
<tbody>
<tr>
<td>.22E-06  ****  ****</td>
</tr>
<tr>
<td>****  ****  ****</td>
</tr>
</tbody>
</table>

Note A: For the example shown the 10 by 3 array has really stored two 5 by 3 arrays. The source is three axial sections long and five axial sections around. The numbers in the array represent the amount of power contributed to this section on the collector. In the case shown the first value of .21E-06 is the amount of power transferred from section 1,1 on the source to section 1,1 on the collector. Going across, the value of .24E-06 is the amount of power transferred from section 1,2 of the source to section 1,1 on the collector. All the power on the collector section 1,1 is the sum of the...
values in the inner box. It is in this manner that the program can tell the direction from which all the power to a given collector section came.

CONE2(70,14) The power received on the collector is stored in the same array form as described for CONE1. This is necessary because at the next level of scatter, this collector might be a source.

COSV The cosine of the vane angle. The vane angle is the angle between the "local" minus z direction of the locus of vane tips and the vane on the source.

DISTV The distance between vanes at this section of the source.

DLENTH The slant length of this section of the source. There may be several vanes within one section on the source.

FL The length of the source (within the vane structure) being considered divided by the arc length of this section of the source.

FN The length of the collector (within the vane structure) being considered divided by the arc length of the section of the source.

HERE The current block of data from the file ANGIN. If HERE equals IHERE2, the array is already in central memory.

IBDRL (IBDRR,IBDRL) determines the section on the source object that is the present emitter.

IBDRR The number of the collector object.

ICOL The column in ITAB2 (the list of collectors) for a potential collector at this level of scatter.

IDOWN The row in CONE2 to store the power transferred. The column number is IBDRL.

IE The emitter under consideration.

IEE The emitter for the various possible collectors. A check is made against IE. If IE and IEE are equal, then this is considered an acceptable source.

IEMIT(100) The array of emitters read in as data. The numbers correspond to the sequence of numbers run in program three but need not be identical. In program three each object was given a different object number for each space. In this program all these objects should usually have a common number so that the power on each object of the output will be the total power from the various possible paths. Not all numbers need be included in this array.
Program five
Program DRIVER

IEMITER  The row number in LOOK4 as a search is made for emitters IE.
IFIND  The row number in LOOK4 as a search is made for collectors.
IFOUND  The object number in row IFIND and column LEVEL+1 in
LOOK4. If IFOUND equals IC then this is an acceptable
collector for source IE.
IHERE1  The last block of data called from file BDRDF. If
NBLOCK5 equals IHERE1, the IO call need not be made
as the information is already properly stored in central
memory.
IHERE2  The last block of data called from file ANGIN. If HERE
equals IHERE2, the IO call need not be made as the
information is already properly stored in central memory.
IHOLD  Holds the number of sections in KEY up to the emitter
object. The program needs this information to find
arrays in storage.
IK  Equivalenced to INKEY. The number of objects in KEY.
IM  The object that is considered the final collector.
Usually this will be the image plane, but it could be
any surface of interest. The program automatically
prints out all the power put onto this object.
IMGSEC  The number of sections on the object that has some por­
tion of it sliced away. It may be the sunshield that
is cut away at say 45°.
INDEXT(20)  The set of arrays used by the mass storage routines of
the programs. They must be one word larger than the
number of blocks that will be stored. The information
that is put in these arrays locates the desired blocks
of data stored randomly on the disk.
INDEX1(201)  INDEX2(201)  INDEX3(100)  INDEX4(100)  INDEX5(100)
INKEY  The number of words in KEY. The number of objects
considered for this run.
IOUT  The axial section of the collector.
IPASS(40,2)  The array that stores the collectors from ITAB2 that
received radiation at this level. This array is used by
subsequent programs to access any specified array
to aid in a complete trace, step by step, of the radiation
through the program.
ISBLOCK  The block number into which the array A (CONE2: the
power on one axial section of the collector) is stored.
IS  The object number that has a portion of it sliced away.
ISUM Equal the sum of IHOLD and IBDRL. This sum yields the line number in VANINFO where the characteristics of this section of the source are described.

ITAB(100) The number of words in the Ith block of BDRDF, ANGIN, and ANGOUT.

ITAB2(100) An array containing the sequence of collector numbers corresponding to the source numbers in IEMIT.

IX The power on the present emitter came from object IX. The program will now find all the parcels of power (and the angle at which they came) on each section of the present emitter to determine how much of this power is transferred to the collector.

IX3 Three times the number of axial sections of object IX.

I3 The number of axial sections on object IX.

JA(5,5) The symmetry relations of the power transfer operations.

JB The integer in the array JA(I,J). The symmetry relation to be used for this source section and collector section combination.

JJJ The row in CONEB containing the percent of power transferred from the source section to the collector section; the column is specified by IOUT. Also the row in ANGOS (column IOUT) containing the angle out of this source section to the collector section.

JK Like JB, but now it describes the symmetry relation to determine the angle at which the power came into this emitter section.

JOUT The radial section on the collector.

JQQ The number of sections on the surface that has been loaded with radiation initially.

KC The number of axial sections on the collector.

KC5 Five times the number of axial sections on the collector. This number equals the total number of sections on the collector.

KE The number of axial sections on the emitter.

KEY(40) Stores the number of axial sections for all objects considered.

KE3 Three times the number of axial sections on the emitter.

KE5 Five times the number of axial sections on the emitter. Equals the total number of sections on the emitter.
Program five
Program DRIVER
(Continued)

KK CONE1(KK,LL) is the power on the source section.

KK1 JA(IBDRR,KK1) is the symmetry relation to use to
determine the ANGI (angle into the source).

KPTL Determines the set of lines (inclusive) that contain the
KPTF amounts of power on this section of the source. See
CONE1, and the inner box is between lines 1=KPTL and
line 5=KPTF.

KQQ Three times the number of axial sections on the initially
loaded surface.

KZ The total number of axial sections of all the objects.
The sum of the values stored in KEY.

L The level of scatter after which when completed the
program will terminate. Provisions are made for five
levels of scatter. Usually, once radiation reaches
the image plane, successive levels of radiation do not
significantly increase the final power on the image plane.

LEVEL The level of scattered radiation being considered.

LIMIT The limit of the possible number of sources at this
level of scatter. The program searches ITAB2 through
LIMIT number of words trying to find sources that have
received power.

LIMITP The program will search through LIMITP words in the
array ITAB2 looking for a collector at this level of
scatter. This speeds program execution by not accessing
arrays not yet filled.

LIMITS(5) For the given level of scattered radiation (LEVEL) the
program will search through ITAB2 for suitable emitters
and collectors. A collector at one level is a possible
emitter at the next level if that path of radiation
wants to be continued.

LL The axial section of object IX (that object that put
power on the present emitter section), which determines
the fraction of power on the present emitter section
and the angle that it came in.

LOOK4(20,4) In column LEVEL are the possible emitters at this level
of scattered light. In column LEVEL plus one are the
possible collectors at this level. For the next level
of scatter the collectors are allowable emitters. The
program has the capability of running through to a
specified level of scattered radiation, stopping,
Program five
Program DRIVER
(Continued)
cataloging the present files, and then restarting at
the level at which it stopped, or one level above or
below. Therefore, there is the possibility that certain
objects will be collectors at one level but not emitters
at the next for a particular run, but the potential is
there to rerun the program from this level and consider
them as emitters and continue to the next higher level.

LUM
The two large files created by this program are on
logical unit numbers two and three. IPASS(ICOL,LUM) stores
the blocks loaded on each logical unit number (LUN).
When LUN is two, LUM is one, the first column of
information in IPASS. When LUN is three, LUM is two,
the second column in IPASS.

LUN
The logical unit number of the file being accessed,
either two or three. One file is the power on the
objects considered as sources at this level while the
other file stores the amount of power received by the
collectors. At the next level the collectors become
the sources and the previous source file will be
written over by the new set of collectors.

MAXNO
The number of words (collectors in ITAB2, emitters in
IEMIT) read into the arrays ITAB2 and IEMIT.

NBLOCK5
The block where the power on the present emitter is
stored. This array is put into CONE1.

NTAB
The size of the index stored for files five (BDRDF),
eight (ANGIN), and nine (ANGOUT). NTAB must be less
than or equal to the size of the arrays INDEX3, INDEX4,
and INDEX5.

NWORDS
The number of words stored in block NBLOCK5.

R
The radius of the section of the source.

RAD
The edge fit factor for determining the amount of scatter
contributed by the edge.

RHO
The total diffuse reflectivity for the sections of the
objects.

SINV
The sine of the angle of the vanes.

SLICE(5,20)
The program handles only rotationally symmetric objects.
If one surface is a cone or cylindrical surface that has
a segment sliced away, it can still be considered
rotationally symmetric. The percent of area of each
section of the object that has not been removed is
entered in the array SLICE. Then the power received
Program five
Program DRIVER
(Continued)

by the sections is multiplied by the appropriate percent of area remaining. If no area remains that section will have zero power on it and therefore not transfer any power.

VANINFO(100,6) Stores the characteristics of each section in the system. Column one is the angle of the vanes (ANGV). Column two is the average distance between the vanes (DISTV). Column three is the average vertical height of the vanes (VH). Column four is the reflectivity of the section (RHO). Column five is the length of the section (DLENGTH). Column six is the radius of the object (R).

VH The average vertical height of the vanes at each section.

WATTS(5,80) The total power on each section in the system considered. All the increments of power on all the sections (regardless of angular information) are summed to get this total power. This is a running total and includes all power from previous levels.

Subroutine ARANGER
B(42,14) The array A (which can be the information for array CONEB, ANGOS, or ANGINS) is rearranged into array B and passed back to the main program (DRIVER).

I The number of rows in the final array B passed back to DRIVER.

J The number of columns in array B as it is passed back to DRIVER.

IA The word in the array A being accessed.

***** See BAFFLE for the definition of other variables.

Subroutine ARANGE
B(70,14) The information taken from the mass storage file and put into array is rearranged properly for CONEl. The power on the sections of the system.

I The number or rows containing pertinent information in array B.

IA The word in A being accessed.

J The number of pertinent columns being passed back in array B.

***** See BAFFLE for the definition of the other variables.
Program five
Subroutine WHERE
(Continued)

I The number of the object being processed.

IDIDC The row in LOOK4 being checked for the collector number. If the collector I is not found, then no radiation was traced to it at this level. It may have received radiation at this level but it was desired by the user that this path not be considered.

IFST From word IFST to ISEC in the array A are the powers that must be attenuated by the appropriate value in SLICE.

II The arrays containing the parcels of energy on a specified section (see CONE1 in BAFFLE; the inner box represents such an array) are summed. There are III inner arrays that are five by KE, the number of sections that emitted the energy to this collector. III are the number of sections on the collector. The III inner arrays make up one block of data stored on disk. The outer box described by CONE1 in BAFFLE. II varies from one to five for the five blocks that represent all the power transferred from all the sections on the source to all the sections on the collector.

ISIZE The size (number of words) of the block being accessed.

J The location in ITAB2 as a search is made to find collector number I.

JJJ The radial section of the collector.

JS The row in LOOK4 as a search is made for a source to this collector.

JWATT1 The collector I has the power on its sections stored on lines JWATT1 to JWATT2, inclusive, in the array WATTS.

JWATT2 The collector I has the power on its sections stored on lines JWATT1 to JWATT2, inclusive, in the array WATTS.

KC The number of axial sections on the object I, the collector.

KE The number of axial sections on the emitter to object I.

KE5 The total number of sections on the emitter to object I. This is five times KE.

NBLOCK The block in mass storage being accessed for power on collector I.

NONE If no power is transmitted to object I, NONE will be true, and a message to that effect will be printed out. In the system power may in fact be transmitted to object I, but in this run this path was not desired.

***** See BAFFLE for the definition of the other variables.
Program five
Subroutine SHOWIT
(Continued)

I The section on the collector. This is the special collector for which all powers are printed out. Usually this will be the image plane.

II The radial section on the collector.

IMGSECT The number of axial sections on the collector IM.

NL The number of axial sections on the emitter to the special collector IM.

***** See BAFFLE for the definition of other variables.

Subroutine SURFACE

A The major axis of the ellipse.

ANGW $\pi$-ANGV, where $\pi$ is 3.14159265358979 and is called PHI in the program.

ANG90 90 degrees in radians, $\pi$/2.

ARCL The arc length of this section of the source.

A2 Equals $A^2$.

B The minor axis of the ellipse.


C The power transfer within the vane structure is being calculated as the sum and differences of certain parallel vane sections. $C$ is the slant length of one of these sections.

CON Converts the input angles from degrees to radians.

COST The cosine of the angle TIN, which is the adjusted specular angle out. It has been found that there is significant difference between the angle of incidence and the specular angle out for surfaces like Martin Black.

COSW The cosine of the angle ANGW (which equals $\pi$-ANGV, the angle of the vanes).

CT When solving for the value x, in the elliptical equation $(x/a)^2 + (y/b)^2 = 1$, where y is known in terms of x, there is the square root of a set of terms. CT is the value of this set of terms.

CZ The y value as the radiation is traced off the surface on the rotated ellipse at the value of x equal to zero.

Cl If the section of the source has vane structure on it, Cl is the length depicted in Fig. 17.
Program five
Subroutine SURFACE
(Continued)

If the surface section has no vanes, $C_1$ equals the expression $1/A^2 + (\tan \phi/B)^2$, where $A$ is the major axis and $B$ is the minor axis, and $\phi$ is the angle of the line through the rotated ellipse.

If the section has vane structure, $C_2$ is the length of the vane structure receiving radiation directly from the source. If the section has no vanes, $C_2$ equals the expression $2C \tan \phi/B^2$, where $C$ is the $y$ intercept and $\phi$ is the angle of the line through the rotated ellipse.

If the section has vane structure on it, $C_3$ is that section of the vane structure not seen by the collector. The slant vane length minus $C_3$ is the section that is seen. If the section has no vanes, $C_3$ equals the expression $(C/B)^2 - 1$, where $C$ is the $y$ intercept of the line through the rotated ellipse, and $B$ is the minor axis of the ellipse.

If the section has vane structure, $C_4$ is the length of the vane structure not receiving direct radiation, vane slant length minus $C_2$. If the section has no vanes, $C_4$ is the square root of $CT$.

In addition to the scattered radiation from the internal vane structure there is the scatter from the vane edges. $\text{EDGE}$ is that fraction added to the apparent reflectivity of the whole section contributed by the edge. The program can be run with no scattered radiation from the edges to determine if this is a significant propagator of the energy to the image plane.

The percent of edge compared to the length of the section times the reflectivity.
Program five
Subroutine SURFACE
(Continued)

F For a surface without vanes. It is the angle of incidence from the normal divided by PI/2. Used to scale the major axis.

FBOT A set of variables that are the "configuration factor" for the sections involved. The sum and difference geometry of sections involved determines the final "configuration factor" between the surfaces receiving radiation directly and those seen by the collector.

FP FT FVANE F1 F12 F123 F13 F14 F15 F16 F2 F23 F4

HD When only a fraction of the vane receiving radiation directly is seen directly by the collector, HD is the length of the section receiving the direct radiation.

HN HN is the length of the section seen directly by the collector.

PB The percent of radiation striking the side wall of the baffles: the wall of the tube between the vanes. PV is the percent of radiation striking the vanes.

PV PCENTH The percent of the surface receiving radiation directly that is seen from the collector, or a "configuration factor" like FBOT, etc.

PCENTL 1 - PCENTH, or a "configuration factor" like FBOT, etc.

PHI2 The adjusted specular angle out of a surface.

PHI2 PHI2, where PHI=PI=3.14159265358979

PV PX Because the program is designed to use the locus of vane tips as the surface to calculate the percent of power transferred from any section on a source to any section on the collector, an adjustment must be made to the RHO value (reflectivity) because surfaces within the vane structure are seen at a different angle from its normal; PX is this correction factor.

S 1.E-10 a small value used to check for round-off errors.

SEP The separation between the vanes along the normal to their surface.
Program five
Subroutine SURFACE
(Continued)

SINI
The sine of the angle into the surface.

SINT
The sine of the angle TIN, the adjusted specular angle out.

SINT2
Equals \((\text{SINT})^2\).

SQ
Equals the expression: \((B^2 \cos^2 \phi - A^2 \sin^2 \phi)^{\frac{1}{2}}\), where \(A\) is the major and \(B\) the minor axes of the ellipse, and \(\phi\) is the angle of the line cutting the rotated ellipse.

TANI
Tangent of the angle into the surface.

TANI2
The tangent of the angle equal to the angle in \(-90^\circ\).

TANO
The tangent of the angle out of the surface.

TANO2
The tangent of the angle equal to the angle out \(-90^\circ\).

TANP
The tangent of the adjusted angle out, PHIOUT.

TANV
The tangent of the angle of the vanes.

TAN90
The tangent of \(90^\circ\) as stored by the library routine.

TIN
The adjustment value for the off-specular reflectance.

VHS
The vertical distance from the surface described by the locus of the vane tips down to the point where radiation strikes the vane.

VL
The slant length of the vanes.

X
The length of the section of the side wall to which or from which radiation will be calculated.

XB
The point along the side wall where the radiation passing over one of the vanes would then strike the side wall, regardless of the second vane.

XF
If the radiation strikes the back side of the front vane before striking the side wall, the \(x\) coordinate is \(XF\). The \(y\) coordinate is \(YF\).

XFNT
The \(x\) coordinate of the top of the front vane tip.

XFS
The \(x\) coordinate of the point where the collector section sees into the vane structure the deepest.

XG,YG
The \(x\) coordinate of the incoming or outgoing ray as it strikes or leaves the front side of the rear vane.

XGS,YGS
The \(x\) coordinate of the out-going ray at its lowest point or either vane surface.

XO
If a ray were to be traced from the collector to this vane structure, such that it would just pass over the first vane it encountered and then continue until it
struck the side wall, then the x coordinate on the side wall would be XO. If the same were done for the incoming ray, the point would have the x coordinate XP as shown in Fig. 18.

**Fig. 18.** Significant variables in vane structure analysis.

- **XPT**
  - XPT and YPT are the x and y points where the line passes through the ellipse as the scatter point.
- **YPT**
  - Equals XPT^2
- **XT**
  - The x coordinate of the tip of the rear vane.
- **X1**
  - From the point where the incoming ray strikes a surface (vane or side wall) a ray is projected out from this point at the angle out. The x coordinate as it passes through the surface of the locus of vane tips is the point X1.
- **X1,Y1**
  - If the surface has no vane structure, these are the two points where the line passes through the ellipse.
- **X2,Y2**
  - See XF.
- **YF**
  - See XG.
- **YG**
  - See XG.
- **YGS**
  - Equals -SQ.
- **YP**
  - See XPT.
- **YPT**
  - See XPT.

**** For the definition of the other variables see BAFFLE.

Subroutine **FFACTOR**

**FFFF**
- Stores the intermediate sums while the numerical integration is done.
Program five
Subroutine SURFACE
(Continued)

F12  The value of the function being integrated at its various points of integration.
I    The Ith integration point.
PI   3.14159265358979
S    1.E-10
SINV2 SINV^2, the sine of the vane angle squared.
SP   The number of integrations to be done along the function.
SPP  The number of integration points.
S1   S1
S2   The number of integrations to be done along the function.
VROOT The result of intermediate expressions that reoccur in the numerical integration expression.
W    XNZ
XI   Equals I+1
XL12(12) The array that stores the values at the S1 integration points.
XNZ  See VROOT.
XN2  The length of the collector section considered (XN) squared.
Z10  The length of the source section divided by the number of integrations to be done.
Z2   Equals Z^2, the length of the source section squared.
***** See BAFFLE for the definition of the other terms.

Subroutine GFACTOR
X    The length and width of the sections transferring power.
Y    ***** See SURFACE for the definition of the other variables.