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GUERAP II - USER'S GUIDE

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A deterministic approach to stray light computation is presented in terms of:

(1) Differential ray trace methods
(2) A ray theory of diffraction
(3) A set of perturbative view factor matrices which allow the more important stray light effects to be calculated first.

Some experimental verification of the calculated results is presented, as well as a description of how to use the program.

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FOREWORD

This report was prepared by The Perkin-Elmer Corporation for the Department of the Air Force HQ Space and Missile Systems Organization under Contract No. F04701-71-C-0376. Captain Raymond W. Rasmusson at SAMSO was the Project Officer and Bruce M. Boyce, at Perkin-Elmer, was the Program Manager. Contributions to the program were made by R. Grosso, B. Harris, D. Harris, J. Kreuzer, and W. Schreyer.

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This report describes a General Unwanted Energy Rejection Analysis Program (GUERAP). In addition to being a user's guide for the program, the report presents the theory behind the program.

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SECTION I

INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

This document is the user's manual for the GUERAP II computer program (General Unwanted Energy Rejection Analysis Program), developed for the Space and Missiles Organization (SAMSO), United States Air Force, under contract number F04701-71-C-0376.

The basic purpose for the development of the GUERAP II computer program was to develop a tool for the analysis of the off-axis rejection capabilities of optical systems having the requirement that they operate in the presence of sources of unwanted energy many orders of magnitude greater than the targets of interest.

To accomplish this goal it is convenient to establish a figure of merit for the energy rejection capabilities of the system. The figure used here is the Bi-directional Reflectance Distribution Function (BRDF) which is defined and discussed in paragraph 1.3.1. The problem for the GUERAP program is thus: Given a specific telescope configuration what is the telescope BRDF associated with this configuration?

This report describes the theory of operation behind the program as well as providing a User's Guide to the operation of the program. The remainder of Section I describes some basic features of the program as well as a discussion of the off-axis rejection parameters. Section II contains a description and definition of certain concepts and terms used by the program. Sections III and IV contain the basic theory upon which the program operates, while Sections V and VI describe the procedures necessary to operate the program.

1.2 BASIC FEATURES OF THE GUERAP II COMPUTER PROGRAM

1.2.1 Ability to Handle Generalized Optical Forms

One of the basic features of the GUERAP II computer program is the ability of the program to analyze virtually any all-reflective optical system, having any number of mirrors in any configuration. The generality of optical form capability is achieved by the method of entering an optical system as a sequence of simple optical system sub-elements, such as mirrors, apertures, and baffle sections. Virtually any optical form can be synthesized by the proper sequence of these simple system elements.

1.2.2 High Sensitivity and Accuracy

The design of the GUERAP II computer program was aimed primarily at the analysis of systems exhibiting very high off-axis rejection to achieve this goal; it was felt that the method of computing the stray radiation terms should have no inherent performance (sensitivity).

To achieve this goal, a deterministic approach to the computation of the stray radiation terms was taken, rather than a statistical approach. Thus, each of the stray radiation terms arising from the phenomena of diffuse scattering from surfaces and diffraction occurring from edges is computed in a deterministic rigorous fashion.

Two achievements were required before the deterministic approach could be implemented. The first was the development of a generalized differential ray trace routine, which permits the tracing of rays through an optical system along with a measure of the ray weight, as determined by the areas of the ray. In addition, the differential ray trace method also facilitates the performance of a number of required calculations within the program that otherwise would prove difficult and costly.

The second achievement was the development of a scalar diffraction theory that permits the description of the phenomenon of diffraction by the use of rays originating from edges. This method allows the rigorous handling of multiple diffraction sequences, such as those that occur in systems limited by triple diffraction.

1.2.3 User Modes

Although the stated objective of the program was to develop a computer program capable of predicting the rejection capabilities of an optical system, it was felt that an additional capability could be added to the program at little cost in complexity. Thus, the GUERAP II computer program is designed to also serve as a design aid tool for the development of new sensors, as well as functioning as an analytical tool.

To enhance both the design aid and analytical modes of the program, GUERAP II categorizes the computed stray radiation into a number of categories, which can be used to make deductions on the system design feature that may be limiting the rejection capabilities of the system under analysis. In addition, the program has a design iteration feature in which the dimensions of various system elements (stop diameters, etc.) can be varied within a run to facilitate the examination of the effect of that design feature on the overall off-axis rejection capabilities of the system being examined.

1.2.4 Use of the Program

The GUERAP II computer program is designed to provide a measure of the off-axis rejection capabilities of an optical system design; however, before the system implications of the result of a GUERAP II analysis can be properly understood, some basic terms describing various aspects of off-axis rejection analysis must be defined. This done in the next section.

1.3 OFF-AXIS REJECTION PERFORMANCE PARAMETERS

1.3.1 Bi-directional Reflectance Distribution Function (BRDF)

The scatter characteristics of a surface can be obtained from the Bi-directional Reflectance Distribution Function (BRDF), which describes the fraction of energy scattered or diffracted in a given direction as a function of two angles - the angle of incidence θ on the surface, and the angle ϕ between the direction in which the stray light is measured and the direction in which the specularly reflected energy propagates.

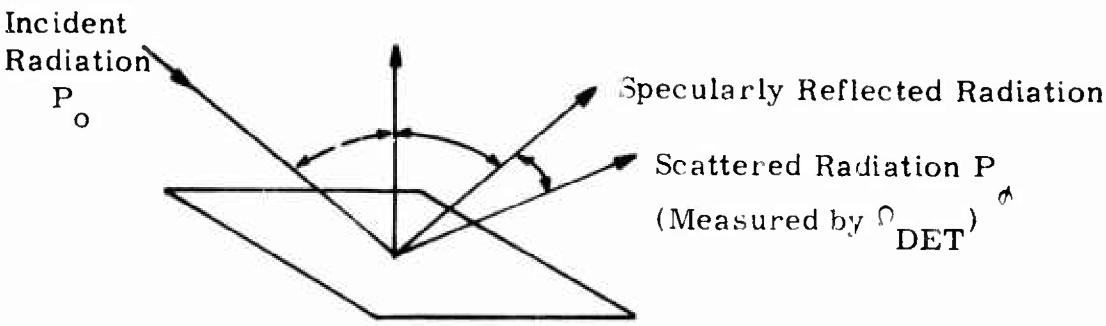
The BRDF, as shown in equation (1.1) below, has the units of (fraction/steradian), and can be physically interpreted as the amount of energy $p(\theta,\phi)$ detected by a detector located at some angle ϕ with respect to the specularly reflected component, divided by the total incident radiation P_o and the solid angle subtended by the detector Ω_{DET}. Thus,

$$\mathrm{BRDF}\ (\theta,\phi) = \frac{P(\theta,\phi)}{P_o} \cdot \frac{1}{\Omega_{DET}}\ \text{(Fraction/Steradian)} \qquad (1.1)$$

Just as the scatter characteristics of a surface can be described by a BRDF, the scatter characteristics of a complete optical system can also be described by a net system BRDF whose meaning is analogous to that of a surface; i.e., the net system BRDF describes the fraction per steradian of the incident energy that is being scattered onto a detector whose position in the focal plane is such that its angular displacement from the source of the collimated incident energy is the angle ϕ. (See Figure 1-1.) The complete system BRDF will be a combination of the effects of diffuse, diffraction and specular means of propagation of stray radiation; the use of this system BRDF in deriving two measures of system off-axis rejection performance is discussed below.

1.3.2 Point Source Rejection Ratio (PSRR)

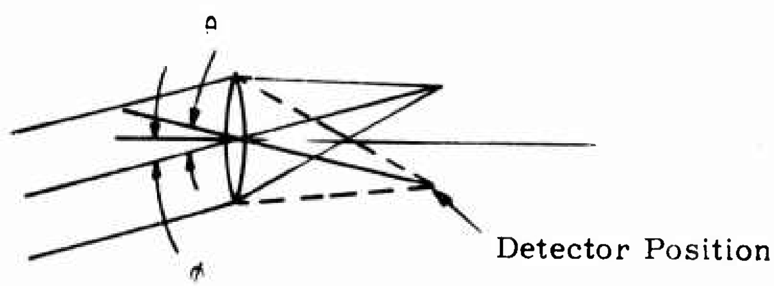
For optical systems which have the requirement that they be able to operate close to a single bright point source, the system performance parameter of interest is the Point Source Rejection Ratio (PSRR), which describes the



$$\bullet\ BRDF(\theta, \phi) = \frac{P(\theta, \phi)}{P_o} \cdot \frac{1}{\Omega_{DET}} \text{ [Fraction/Sterad]}$$

a. BRDF of Mirror Surface

$$BRDF(\theta, \phi) = \frac{P(\theta, \phi)}{P_o} \cdot \frac{1}{\Omega_{DET}}$$



b. BRDF of Optical System

Figure 1-1. Bi-Directional Reflectance Distribution Functions (BRDF's) amount of energy from the unwanted point source detected when the system's line of sight is displaced an angle ϕ from the point source, with respect to the amount of energy that would be detected if all of the energy incident on the aperture from the point source were being collected by the detector.

$$PSRR(\theta,\phi) = \frac{P(\theta,\phi)}{P_o} = S(\theta,\phi) \cdot \Omega_{DET} \qquad (1.2)$$

Thus, the point source rejection ratio is simply the BRDF of the system, multiplied by the angular subtense of the detector being used.

Using equation (1.2), the amount of stray radiation from an unwanted point source can thus be written in terms of the PSRR as

$$P(\theta,\phi) = PSRR(\theta,\phi) \cdot P_o \qquad (1.3)$$

1.3.3 Extended Source Rejection Ratio (ESRR)

For optical systems having the requirement that they be able to operate close to a bright extended source of unwanted energy (such as the earth or the sun), the system performance parameter of interest is the Extended Source Rejection Ratio (ESRR), which describes the ratio of the amount of energy from the unwanted extended source that is detected when the system's line of sight is displaced at some angle (α) from the edge of the source, divided by the amount of energy that would be detected if the source were being imaged directly onto the detector at the angular position θ.

Thus,

$$ESRR(\theta,\alpha) = \frac{H(\theta,\alpha)}{H_o} \qquad (1.4)$$

where

$H(\theta,\alpha)$ = flux density at angle θ due to extended source whose edge is displaced an angle α from the detector position.

H_o = flux density of direct image of extended source.

To evaluate the Extended Source Rejection Ratio, the integral shown in equation (1.5) below must be evaluated. Note that the numerator must be integrated over the entire offending source to yield the total scattered energy falling on the detector, while the denominator is evaluated over the angular subtense of the detector to yield the energy detected by the detector when the source is imaged directly on the detector

$$\mathrm{ESRR} = \frac{\iint_{\mathrm{SOURCE}} \Delta P_\phi}{\iint_{\mathrm{DETECTOR}} \Delta P_o} \tag{1.5}$$

where

ΔP_ϕ = incremental stray radiation flux detected from each incremental area of the source that is not directly imaged onto the detector.

ΔP_o = incremental flux detected from each incremental area of the source that is being directly imaged onto the detector.

Evaluation of equation (1.4) yields

$$\mathrm{ESRR}(\theta,\alpha) = \iint_{\mathrm{SOURCE}} S(\theta,\phi)\, d\phi \tag{1.6}$$

The Extended Source Rejection Ratio can be seen to be the integral of the system BRDF over the offending extended source; it is worth noting that the Extended Source Rejection Ratio is independent of the detector size being used, unlike the Point Source Rejection Ratio, which is dependent upon the detector size.

Using equation (1.4), the Stray Radiation Flux Density from an unwanted extended source can thus be written in terms of the ESRR as

$$H(\theta,\alpha) = \mathrm{ESRR}(\theta,\alpha) \cdot H_o \tag{1.7}$$

SECTION II

BASIC CONCEPTS

2.1 INTRODUCTION

In this section, the basic terms and concepts employed in using the GUERAP program are discussed.

As mentioned in Section I, one of the primary goals for the program is that it be capable of handling all types of reflective optical systems and baffles. This is achieved in the program by defining mirrors, stops, and baffles of such basic forms that virtually any all-reflective system can be synthesized by an appropriate sequence. In the following paragraphs the basic system elements from which a given optical system can be synthesized are defined.

2.2 BASIC SYSTEM ELEMENTS

This section is divided into the following paragraphs:

2.2.1 Coordinate Systems

2.2.2 Sections

2.2.3 Mirrors

2.2.4 Apertures

2.2.5 Tubes and Baffles

2.2.6 Standard Sections

2.2.7 Wild Card Baffle Section

2.2.8 View Factors

2.2.9 Diffraction Sequences

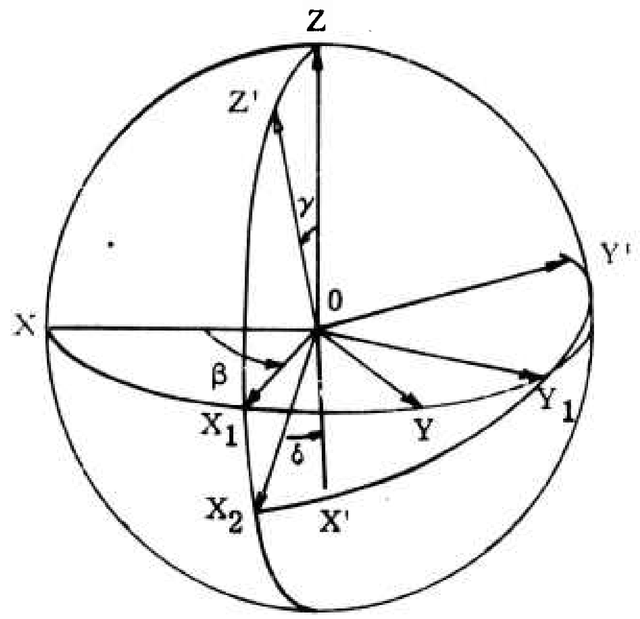
2.2.1 Coordinate Systems

In an off-axis optical system, the program requires each surface to be specified in a coordinate system natural to that surface. The following paragraphs show how these different coordinate systems can be specified.

The first step is to determine a reference coordinate system. For GUERAP the entrance aperture plane is usually defined as the reference X-Y plane since source angles are given in this coordinate system. The Z axis is normal to this plane, positive Z-axis in the direction of propagation; the X and Y axes are defined in the X-Y plane to yield a right-handed coordinate system. This system given the number 1, is the reference coordinate system and is predefined. Other coordinate systems are defined with respect to the reference system or other coordinate systems previously defined, and given the numbers 2, 3... etc., in sequence as they are defined. Thereafter, the coordinate systems can be referred to by number.

Coordinate systems are defined in terms of a translation and a rotation (by the three angles β, γ, δ called the Euler Angles of the coordinate system) from a previously defined coordinate system. (See Figure 2-1.)

Multiple coordinate systems allow all surfaces to be specified only in terms of sizes and shapes and never in terms of tilts or rotations, since the program is able to handle these by coordinate transformations within the program.



(X_1, X_2, and Y_1 Are Intermediate Axes)

Figure 2-1. Euler Angles

2.2.2 Sections

Sections are the means by which the various surfaces are linked together to form an optical system. Each section encompasses a local region of one of four types; standard baffled section, end section, concave mirror section, and convex mirror section (these section types are described in paragraph 2.2.6). A ray can pass from one section to another in three different ways: through an aperture, through a hole (described below) in the case where both sections are standard baffled sections, and by the wild card baffle mechanism, described in paragraph 2.2.7.

2.2.3 Mirrors

A mirror may be either flat or spherical, concave or convex. A concave mirror may have a central hole or obscuration, and may be limited by a circular, elliptical, rectangular, or rounded-rectangular aperture (convex mirrors must have circular edges).

Figures 2-2 and 2-3 shows some examples.

2.2.4 Apertures

An aperture is an opening cut in a plane to allow a ray to pass from one section to another. There are two types of apertures; positive apertures are holes surrounded by a plane; negative apertures are solid central areas surrounded by a clear aperture. An aperture may have one of four geometric shapes; a circle, an ellipse, a rectangle, or a circle convolved with a straight line. An aperture is always perpendicular to its axis. Apertures may be used singly or in pairs, e.g., a ring with a clear aperture on either side would be a combination of a positive and negative aperture. (See Figure 2-4.)

Apertures are used as limiting planes in the program. For example, an aperture must limit the extent of a mirror, two apertures must limit the extent of a tube, etc. Field stops and Lyot stops are described to the program as apertures. Apertures are also used to aid the program in finding paths through the system, as described in paragraphs 2.2.8 and 2.2.9.

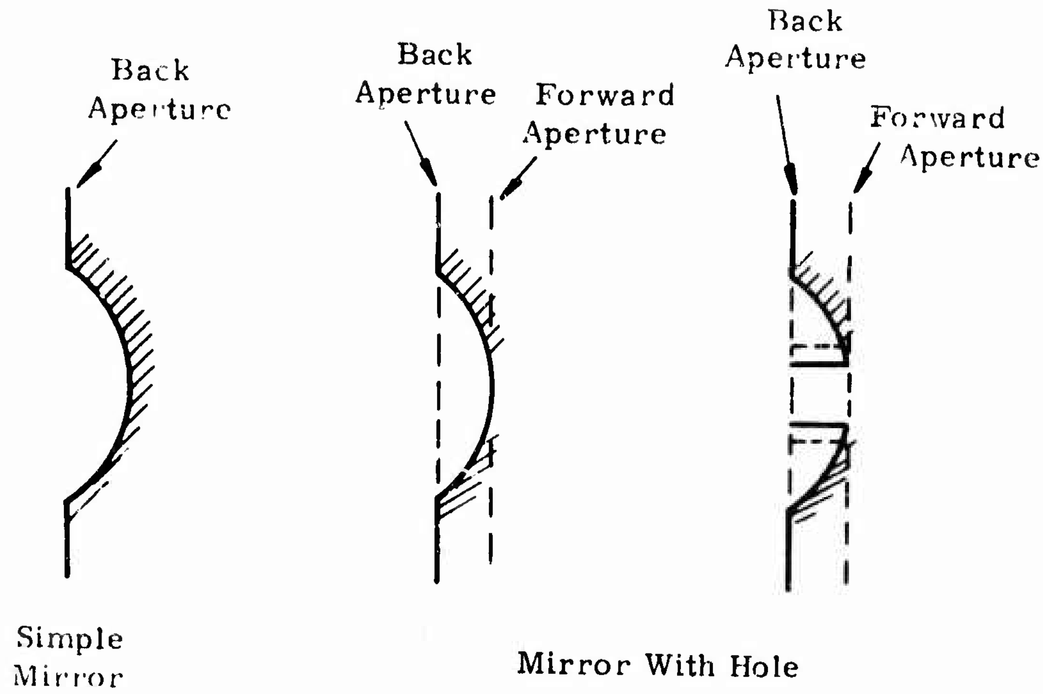


Figure 2-2. Concave Mirror Sections

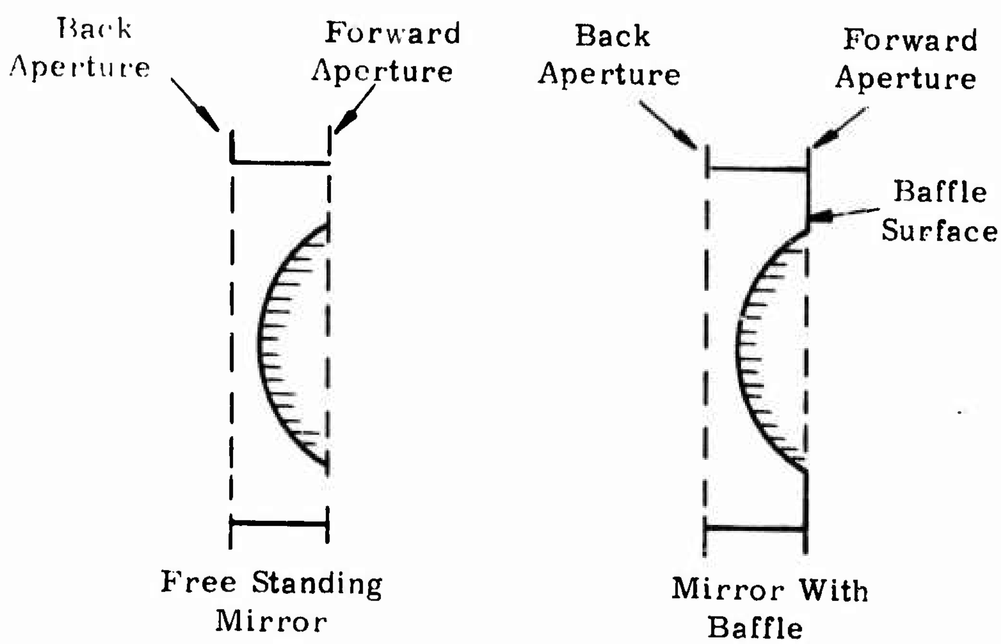


Figure 2-3. Convex Mirror Sections

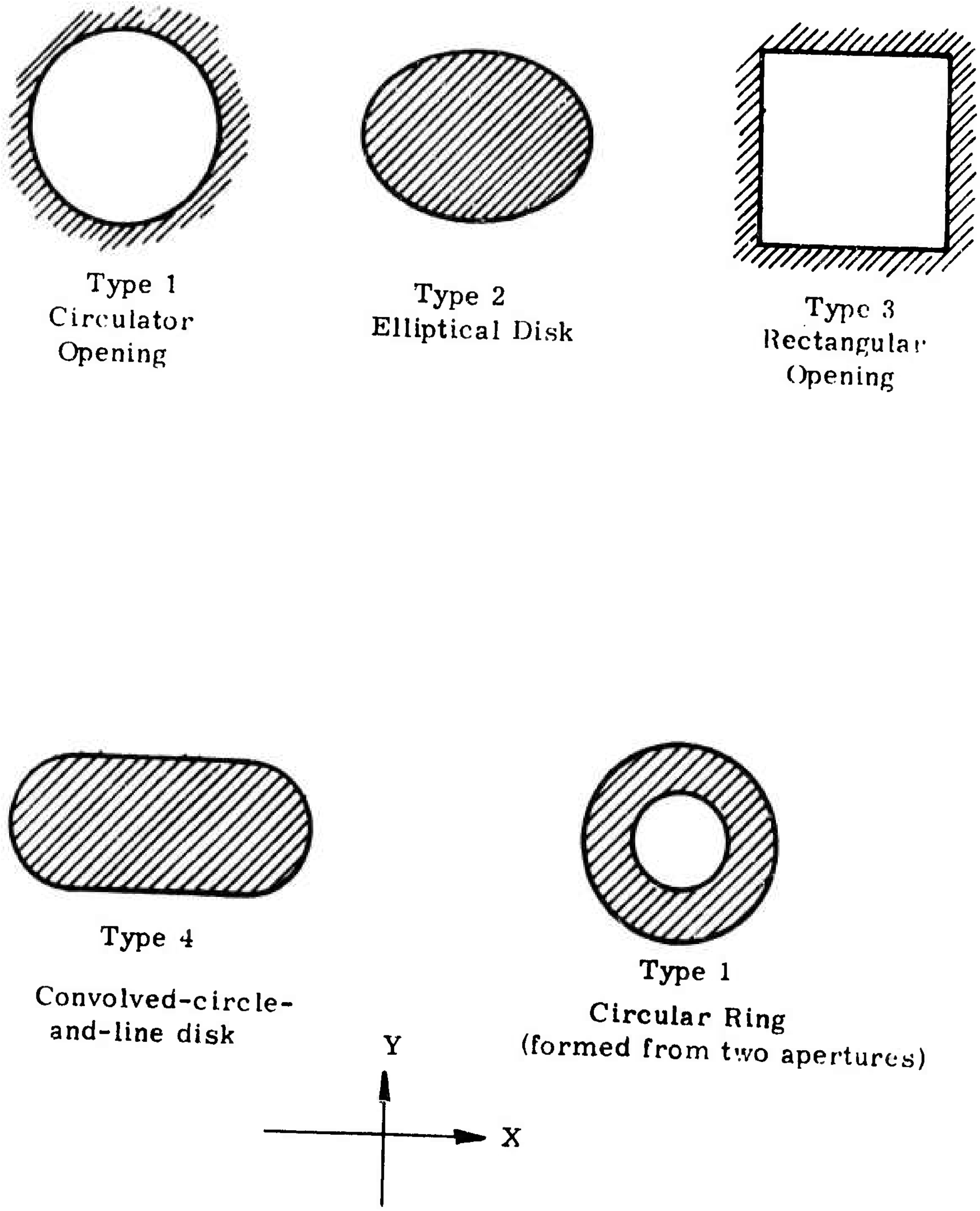


Figure 2-4. Aperture Shapes

2.2.5 Tubes and Baffles

A tube is a cone or cylinder with one of the following cross-section shapes: circle, ellipse, rectangle, or convolved circle and line. Tubes are used to limit the rays entering the system, and to limit ray paths once the rays are inside the system. Tubes may either be simple surfaces, or may be ringed with baffles. These baffles must have their edges lie on the surface of an imaginary tube. A tube may also be used to describe a hole cut in the side of another tube (sometimes necessary in a system with an optical axis folded at an angle other than 180°). Tubes may also be used to describe structural elements such as struts (ref: wild card baffles, paragraph 2.2.7).

2.2.6 Standard Sections

Each of the four standard section types: standard baffled section, end section, concave mirror section, and convex mirror section, is described below. Wild card baffles are discussed in Section 2.2.7.

2.2.6.1 Standard Baffled Sections (See Figure 2-5)

A standard baffled section consists of one or two tubes delimited by a pair of apertures. If the region being described is inside a tube, that tube is called the outer tube. If the region being described lies outside a tube, that tube is called the inner tube. A standard baffled section consisting of both an outer and an inner tube lies between those tubes. All tubes and both apertures must lie in parallel (or the same) coordinate systems.

A standard baffled section may have one to two holes to allow additional means for rays to pass from one section to another in off-axis systems. A hole is a semi-infinite tube bounded on one end by an aperture. Any part of the apertures and tubes described above that lies within the hole is non-existent. The aperture and tube describing the hole must have parallel (or the same) coordinate systems, but these coordinate systems will not, in general, be parallel to the section coordinate systems.

2.2.6.2 End Sections (See Figure 2-6)

End sections are used in off-axis systems to interface an aperture to a tube, where the normal to the aperture is not parallel to the axis of the

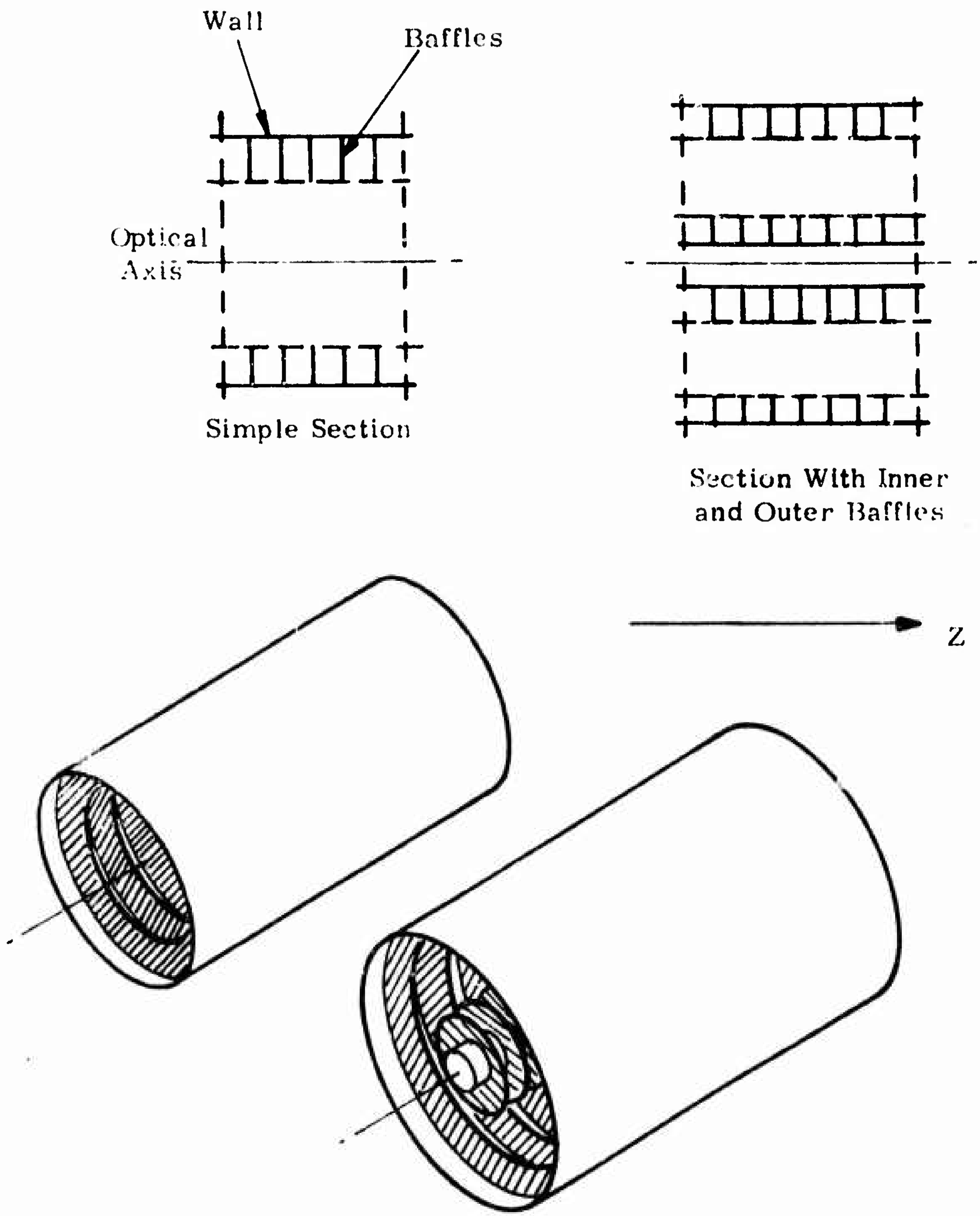


Figure 2-5. Standard Baffled Sections

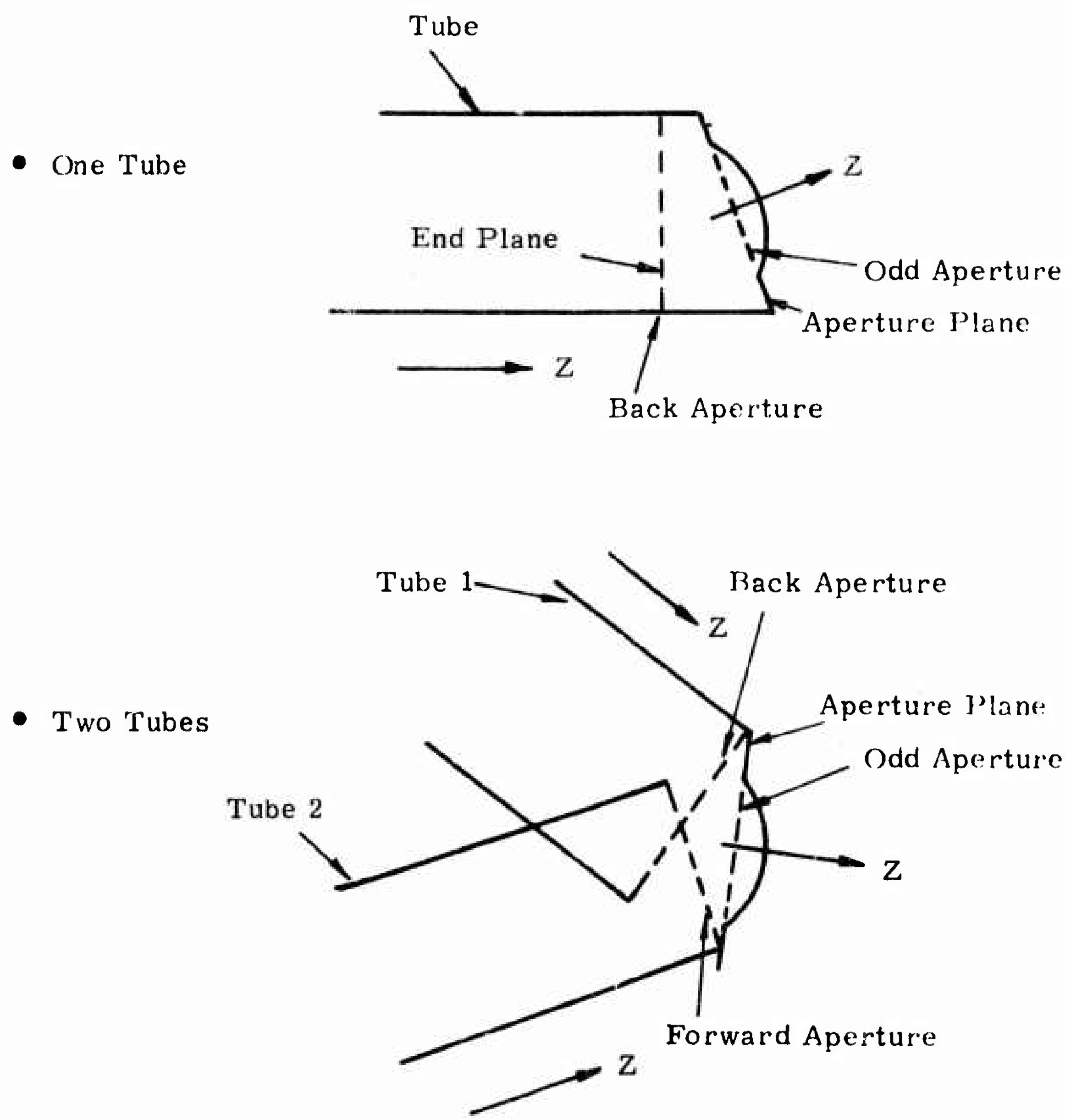


Figure 2-6. End Sections

tube. If desired, a second tube may also be interfaced. The aperture being interfaced is called the odd aperture. Each tube must also be bounded by an aperture whose normal is parallel to the axis of that tube. The end section then consists of the region in each tube between its normal aperture and the odd aperture. Portions of a tube or normal aperture lying inside the other tube (if there is one) are considered to be non-existent.

2.2.6.3 Concave Mirror Sections

Concave mirror sections consist of a concave (or flat) mirror together with one or two limiting apertures and an optional central obscuration.

A concave mirror must be limited by an aperture describing the portion of the entire surface (sphere, conic, or plane) which is the mirror surface. The center of the mirror may be cut out or obscured. If so, the concave mirror section must be bounded by an aperture describing the plane of the hole or obscuration. Further, for an obscured mirror there can be a further obscuration in the form of a tube (with or without baffles).

2.2.6.4 Convex Mirror Sections

A convex mirror section consists of a convex mirror, two limiting apertures, and a surrounding tube. One aperture describes the portion of the sphere or conic that is the actual mirror, while the other aperture must be in front of the mirror to separate it from other sections. In most systems, proper combinations of the above four standard section types should be sufficient to describe most, if not all, of the pertinent system features. For those features that cannot be so described the wild card baffle mechanism, as described below, is provided.

2.2.7 Wild Card Baffle Section

The wild card baffle section provides the user a method of describing configurations that do not conform to the rules for any of the sections described above. Examples would be struts to support a mirror or an exit aperture between a pair of baffles. At present, the only implementation of wild card baffles is to allow the user to place standard sections in places where they are not normally allowed. This implementation is sufficient to handle the examples given above, as well as many others.

Each surface within the wild card baffle section is considered to be a separate wild card baffle. Since it is also an ordinary surface (tube, aperture, mirror), it acquires both a wild card baffle number and an ordinary surface number. For a wild card baffle, the ordinary surface number is coded further by adding 100 if it is an aperture, or by adding 200 if it is a tube, so that the surface number contains a description of what kind of surface it is, as well as which one of that kind. Each wild card baffle surface lies in one or more standard sections. It is referred to in each of those sections simply by giving its wild card baffle number.

A very simple example of a wild card baffle is needed at this point. Consider a tube with a strut inside. (See Figure 2-7.) The tube is a standard baffled section with no baffles and no inner tube, and will be called "section 1". The strut is also a standard baffled section with an inner tube and no baffles and no outer tube (called "section 2"). The outer two apertures will be 1 and 2, and the strut ends apertures 3 and 4. If tube 1 is the outer tube, tube 2 the strut; the strut wild card baffle 1 and the ends wild card baffles 2 and 3, we have the following:

Section	Inner Tube	Outer Tube	Back Aperture	Forward Aperture	WCB's
1	0	1	1	2	1,2,3
2	2	0	3	4	0

Wild Card Baffles

WCB	Surface No.	Section
1	202	2
2	103	2
3	104	2

In order to place wild card baffles in the system, each wild card baffle surface is referenced in each section where it appears, with one notable exception: when a wild card baffle lies between a pair of standard baffles, it is referenced in the baffle input card, not in the section input. This enables the program to distinguish between objects within baffles and objects in the baffle free region.

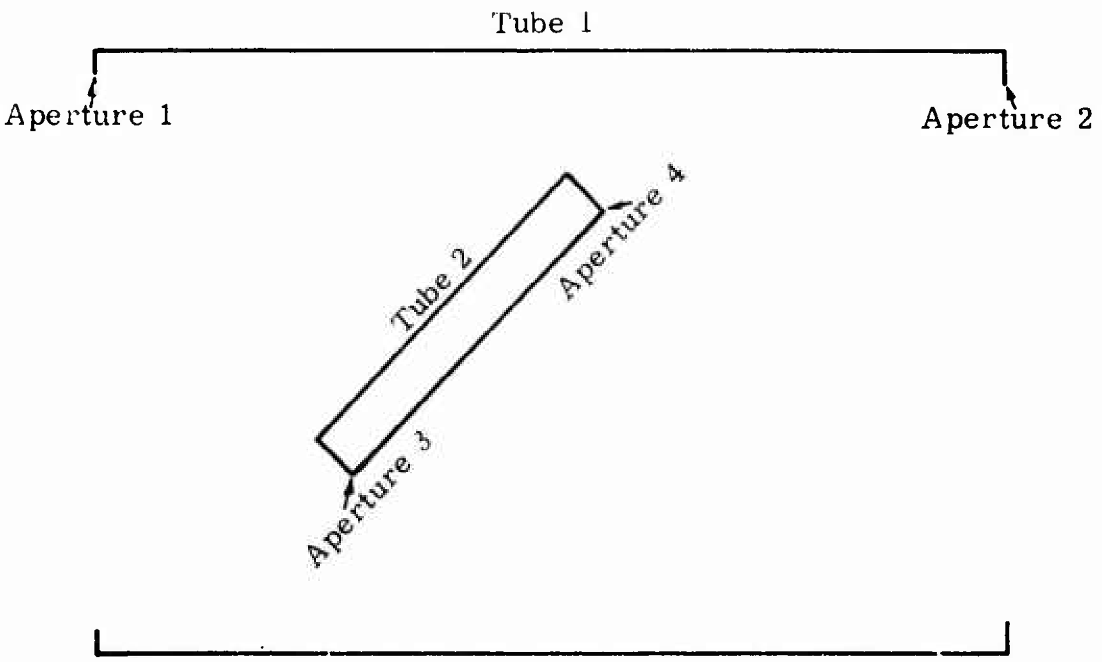


Figure 2-7. Wild Card Baffle Example - Tube with Strut

The wild card baffle mechanism gives the user freedom of choice of different ways to specify the same system. This choice should nearly always be directed toward having the fewest wild card baffle surfaces, since the user pays a penalty in run time when using wild card baffles.

2.2.8 View Factors

The GUERAP-II program calculates first-order diffuse stray radiation terms by computing and marking all areas, called critical areas, which can be seen by a detector, either directly or specularly off one or more mirrors. Higher-order terms are calculated similarly, with lower-order critical areas playing the role of a detector. Three matrices input by the user guide the TCRIT program in finding these critical areas. These matrices, called the hand calculated view factor matrices, consist of an aperture-to-aperture matrix, an aperture-to-section matrix, and a section-to-section matrix. The first two matrices are used to compute all mirror paths to the critical areas, while the third matrix is used to compute the direct paths.

The user begins by selecting a subset of the apertures in the system, called the set of critical apertures. These critical apertures describe how the imaging rays get through the system. The set of critical apertures must include the limiting aperture for each mirror in the system. In addition, each aperture that limits or obscures what one mirror can see of another must also be included in the set of critical apertures. Thus, in a typical system, the critical apertures include field stops, Lyot stops, and obscuring apertures, if any or all of these exist in the system. Once the critical apertures have been selected, they are described to the system by two parameters: the ordinary aperture number and the mirror number of the associated mirror (0 if there is no associated mirror, as in the case of a field stop, etc.).

The next step is to construct the aperture-to-aperture matrix. This matrix describes which critical apertures see which others. A critical aperture is said to see another critical aperture if, and only if, a direct path through no intervening critical aperture exists. The user is never required to specify mirror paths, as the program can calculate these paths once the direct path from a point to a mirror, and the direct mirror to mirror paths have been specified. By definition, critical apertures do not see themselves.

To complete the description of possible mirror paths, the aperture-to-section matrix is specified next. This matrix describes which critical apertures directly see which sections. If there is an aperture that limits or partially obscures this view, it is also specified. (If there is more than one such aperture, the most appropriate one is chosen.)

The program builds a list of trial mirror paths as follows: (We assume that the starting point for all paths is in Section A, while the target surface is in Section B.)

(1) The aperture-to-section matrix is checked for the next critical aperture seen from Section A. This critical aperture is placed first on the critical aperture sequence. When there are no more critical apertures, the list is complete.

(2) The aperture-to-section matrix is checked to see whether Section B sees the last critical aperture in the sequence. If so, the sequence is added to the list.

(3) Regardless of the outcome of step (2), the aperture-to-aperture matrix is checked to see whether the last critical aperture sees any other critical aperture not yet checked and <u>not already in the present aperture sequence</u>. (The above restriction is invoked to prevent the generation of an infinite number of possible paths, and requires care (and possible trickery) in the choice of critical apertures, as no critical aperture is allowed to appear more than once on any given mirror path.) If there is another aperture, it is added to the sequence and then step (2) is repeated.

(4) Otherwise the last aperture on the sequence is deleted. If there still is an aperture on the sequence, step (3) is repeated. Otherwise step (1) is repeated.

Differential ray trace techniques (described in Section III) are then used to check these potential paths to see if any actually exist in the system.

Finally, to allow the computation of direct paths, the section-to-section matrix is specified. This matrix describes which sections can directly see which other sections (limiting or obscuring apertures are also specified as in the aperture-to-section matrix described above). Unlike the critical apertures, sections can always see themselves. These paths are then checked by the differential ray trace method.

Thus, by simply stating the direct paths possible in the system, the program is able to pick out the direct and mirror paths that actually exist in an optical system.

For example, let us consider the simple Cassegrain system shown in Figure 2-8. It consists of a concave primary, a convex secondary, tubes baffling the primary and the secondary, a tube surrounding the entire system, and a detector region.

Critical apertures for this system were chosen to be: (1) the aperture limiting the primary mirror - its associated mirror is the primary; (2) the disk aperture partially obscuring the view from the primary to the secondary - it has no associated mirror; (3) the aperture in front of the secondary - its associated mirror is the secondary; (4) the aperture which allows rays to pass inside the tube baffling the primary (and leading to the detector).

The aperture-to-aperture matrix is set up to show that the primary sees only the obscuring aperture, the obscuring aperture sees the primary and secondary, the secondary sees the obscuring aperture, and the one leading to the detector, while this aperture sees only the secondary.

At this point the critical aperture-to-section, and section-to-section matrices must be constructed. The only unusual thing here is that the obscuring aperture is effectively removed. Its only reason for being a critical aperture is to obscure the view between the primary and secondary. It can (and does) act as an obscuring aperture between sections and other critical apertures.

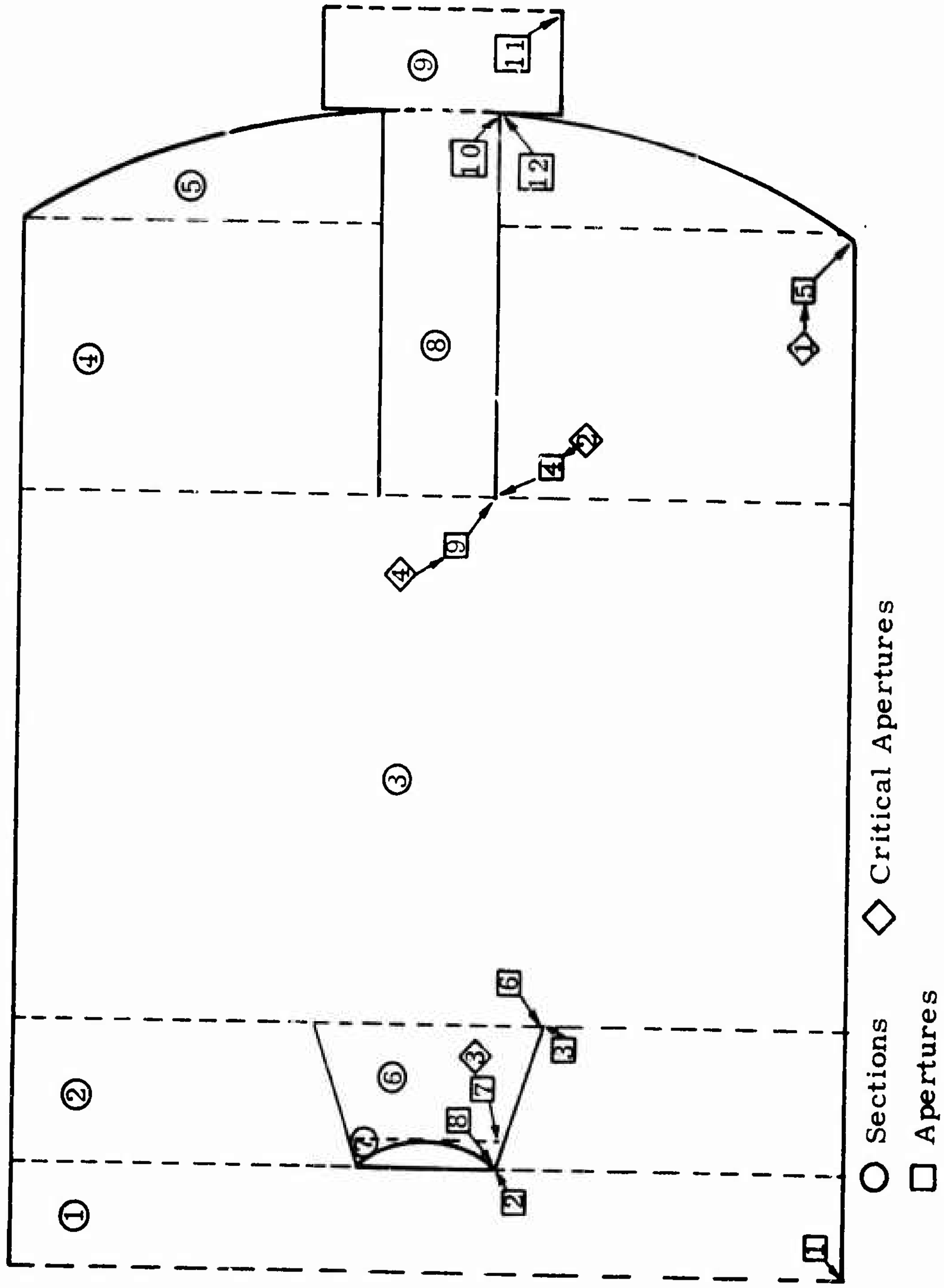


Figure 2-8. Simple Cassegrain System

Figure 2-9 gives the complete matrices. A "1" indicates that the view is possible, while an "-N" indicates that the view is possible, but limited or obscured by aperture "N".

2.2.9 Diffraction Sequences

In computing diffraction terms, unlike the diffuse case, the user must specify the edge sequences the program is to look at. The user begins by specifying the number of edges at each of Levels 1, and 2 and 3. If the user specifies I edges at Level 1, J edges at Level 2 and K edges at Level 3, then the first I edges specified are Level 1 edges, the next (J) are Level 2 and the last (K) are Level 3 edges. An edge is specified by giving its aperture or baffle number, the number of aperture or aperture-mirror pairs between that edge and its destination (the detector plane for a Level 1 edge, or a Level n-1 edge for a Level n edge), the section number of the edge if it is illuminated (otherwise 0), and its destination edge number if the edge is Level 2 or higher (the destination edge number is the position of that destination edge which has been previously defined in this list). Aperture and aperture-mirror pair sequences are defined as in the critical aperture sequences. Note that the level of an edge is the number of diffractions that occur, starting at that edge and reaching the detector.

Let us again consider the simple Cassegrain system of paragraph 2.2.8 (Figure 2-8). Assume we wish to compute single diffraction from both the entrance aperture (aperture 1) and the edge of the tube baffling the secondary (aperture 3). Also, let us consider double diffraction from each of the above edges and the edge of the tube baffling the primary (aperture 9). Since we must consider aperture 9 as a single diffraction edge also, we then have I = 3, J = 2, K = 0 as described above.

To describe the simple entrance aperture path, we note that after diffraction from the entrance aperture, the ray must hit the primary, then the secondary, before arriving at the detector plane. There is also the possibility of hitting the tube that baffles the primary, either before or after hitting the secondary. To allow for these possibilities, we put apertures 4 and 9 into the sequence. We thus need four apertures to describe the

PERKIN-ELMER


```
GUERAP II PROGRAM              01/28/74     12.11.03      PAGE    3
SYSTEM TITLE : CASSEGRAIN BAFFLE ANALYSIS
BAFFLE DESIGN ITERATION  0

* * * HAND CALCULATED VIEW FACTOR SUMMARY * * *
   CRITICAL APERTURES    ASSOC. MIRROR NUMBER

           5                        1
           4                        1
           7                        2
           9                        3

APERTURE TO APERTURE
 0  1  0  0
 1  0  1  0
 0  1  0  1
 0  0  1  0

APERTURE TO SECTION
-3 -3 -4  1  1  0  0  0  0
 0  0  0  0  0  0  0  0  0
 0  0 -6  1  0  1  1  0  0
-3 -3  1  0  0 -6  0  1-10

SECTION TO SECTION
 1 -2 -3 -3  0  0  0  0  0
-2  1 -3 -3  0  0  0  0  0
-3 -3  1  0  0 -6  0  0  0
 0  0  0  1  0  0  0  0  0
 0  0  0  0  1  0  0  0  0
 0  0 -6  0  0  1  0  0  0
 0  0  0  0  0  0  1  0  0
 0  0  0  0  0  0  0  1-10
 0  0  0  0  0  0  0-10  1
```

Figure 2-9. MATRICES for Cassegrain System sequence. In considering diffraction from the edge of the secondary tube, we need only pass through aperture 9 to hit the detector (if possible). But we also notice that a path off the primary and secondary similar to the entrance aperture sequence is possible. By adding a fourth Level 1 edge (set I-4) we could allow for this possibility. Finally, we must consider the sequence from the edge of the secondary tube to the detector plane. Since this path is direct, no apertures are required.

To do the double diffraction terms, the sequences are generated as above, only up to the point of the second edge. Since we give the number of the Level 1 edge, the program can append that sequence to get the complete double diffraction sequence. Here again, if we wish to allow two distinct paths from the edge of the secondary tube, we can set J = 3 and all the appropriate sequence.

Figure 2-10 tabulates the edge sequences described above.

Number of Edges

Level 1	Level 2	Level 3
3	2	0

Level 1 Edges

No.	Aperture No.	No. of Apertures in Sequence	Section/ Illumination	Destination
1	1	4	1	--

Aperture Sequence

Aperture No.	Mirror No.
5	1
4	0
7	2
9	0

No.	Aperture No.	No. of Apertures in Sequence	Section/ Illumination	Destination
2	3	0	2	--
3	9	0	0	--

Level 2 Edges

No.	Aperture No.	No. of Apertures in Sequence	Section/ Illumination	Destination
4			1	3

Aperture Sequence

Aperture No.	Mirror No.
5	1
4	0
7	2

No.	Aperture No.	No. of Apertures in Sequence	Section/ Illumination	Destination
5	3	0	2	3

Figure 2-10. Diffracting Edge Sequences

SECTION III

DIFFERENTIAL RAY TRACE

3.1 INTRODUCTION

The use of a routine for the tracing of rays propagating through a system via specular reflections off mirrors and baffle surfaces is an obvious requirement for any program aimed at the analysis of off-axis rejection; however, there are several other requirements that are desirable to put on the ray trace routine selected, in order to enhance the accuracy and speed of the resultant program. These additional requirements are:

(a) Have the ray trace routine carry an accurate measure of the ray weight (the ray weight, or flux, is the product of the ray energy density and the area).

(b) Have the ray trace method carry information sufficient to allow later computations on distances traveled by traced rays, on the change of magnification from one portion of the system to another.

(c) Have the ray trace method fill the entrance aperture with a high density of rays only for portions of the aperture where the rays are incident on a complex system structure (many baffle edges, etc.).

(d) Describe all rays that undergo the same sequence of reflections by a single ray and a ray weight measure.

The differential ray trace method, as implemented in the GUERAP II program, meets all of the requirements listed above. This method is described in Section 3.2, below. Section 3.3 describes how the differential ray trace routine is used iteratively to achieve goals (c) and (d).

3.2 DIFFERENTIAL RAY TRACE METHOD

3.2.1 Setting Up Differential Rays

The basis of the differential ray technique is as follows. The position of any single ray in any given plane within an optical system can be specified by four coordinates: two spatial and two angular. In order to make things easier, however, we actually specify rays by six coordinates, three spatial and three angular. Only four of these are independent. The coordinates of any other neightoring ray can be described by the coordinates of the first ray and a set of four positional and angular differentials. Thus, we can describe a ray by

$$\vec{R} = (x,y,z,c,d,e) \qquad (3\text{-}1)$$

where

$\vec{R}$ = single ray

x,y,z = spatial location of ray

c,d,e = direction cosines of ray

The ray differential can be denoted by

$$d\vec{R} = (\Delta x.\Delta y,\Delta z,\Delta c,\Delta d,\Delta e) \qquad (3\text{-}2)$$

If we denote a nearby ray as R_n, then we may write the nearby ray as a linear combination of the central ray $\vec{R}$ and differentials as follows:

$$\vec{R}_n = \vec{R} + d\vec{R} \qquad (3\text{-}3)$$

To first order, the set of nearby rays forms a four-dimensional linear space. Therefore, if we choose a set of four linearly independent differential ray vectors, any nearby ray is a linear combination of these four vectors (plus the original ray).

We choose:

$$d\vec{R}_1 = (1,0,0,0,0,0) \qquad (3\text{-}3a)$$

$$d\vec{R}_2 = (0,1,0,0,0,0) \qquad (3\text{-}3b)$$

$$d\vec{R}_3 = (0,0,0,c_3,d_3,e_3) \qquad (3\text{-}3c)$$

$$d\vec{R}_4 = (0,0,0,c_4,d_4,e_4) \qquad (3\text{-}3d)$$

where

$$c*c_3 + d*d_3 + e*e_3 = 0$$

$$c*c_4 + d*d_4 + e*e_4 = 0$$

and (c_3,d_3,e_3) and (c_4,d_4,e_4) are independent. Then Eq. (3-3) can always be written

$$\vec{R}_n = \vec{R} + a_1*d\vec{R}_1 + a_2*d\vec{R}_2 + a_3*d\vec{R}_3 + a_4*d\vec{R}_4 \qquad (3\text{-}4)$$

3.2.1.1 Spatial Differentials

If $\Delta c = \Delta d = \Delta e = 0$, then the nearby ray will be parallel to the central ray; let us set up four nearby rays defined by the four differentials shown below, with $\Delta x - \Delta y$, to describe the four corners of a small area in the entrance aperture. (See a, Figure 3-1; only two nearby rays are shown for simplicity.)

$$d\vec{R}_1^{+} = \Delta x*d\vec{R}_1 \qquad (3\text{-}4a)$$

$$d\vec{R}_1^{-} = -\Delta x*d\vec{R}_1 \qquad (3\text{-}4b)$$

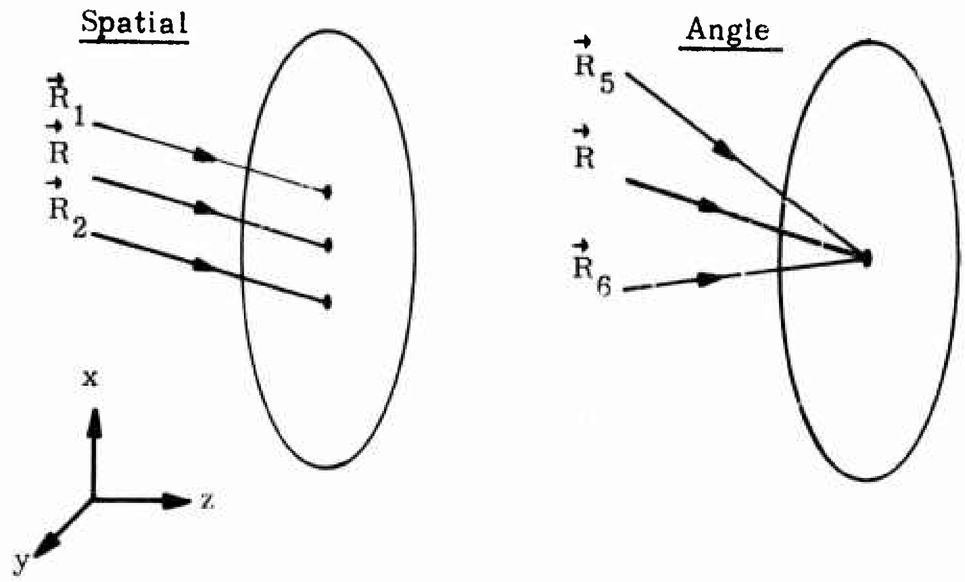
$$d\vec{R}_2^{+} = \Delta y*d\vec{R}_2 \qquad (3\text{-}4c)$$

$$d\vec{R}_2^{-} = -\Delta y*d\vec{R}_2 \qquad (3\text{-}4d)$$

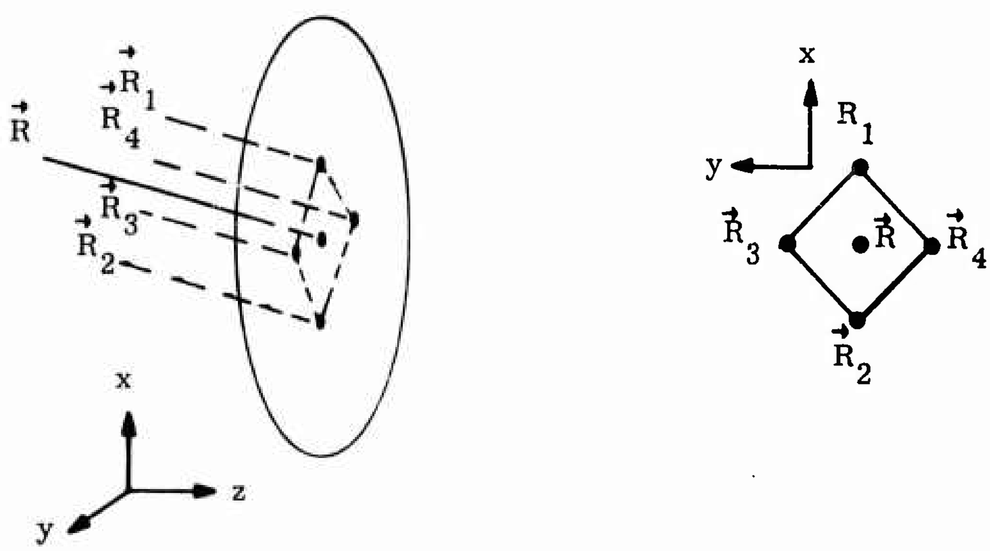
The numbers $\Delta x, -\Delta y, \Delta y, -\Delta y$ can be thought of as supplying boundary conditions for the differentials. It is by tracing these two spatial differentials with these four boundary conditions that GUERAP II is able to trace a central ray and, in effect an aperture area with it, through the system. (See b, Figure 3-1.)

3.2.1.2 Angle Differentials

If $\Delta X = \Delta Y = 0$, then all nearby rays will intersect the original ray at x,y,z, and will represent rays on a spherical wavefront centered on



a. Use of Spatial and Angle Differentials to Describe Nearby Rays



b. Use of Spatial Derivatives to Define Area in Entrance Aperture

Figure 3-1. Spatial Differentials

the original ray. (See a, Figure 3-1.) Thus, analogous to equations 3-4 a-d:

$$d\vec{R}_3^{\,+} = \Delta\alpha * d\vec{R}_3 \tag{3-5a}$$

$$\Delta\vec{R}_3^{\,-} = -\Delta\alpha * d\vec{R}_3 \tag{3-5b}$$

$$\Delta\vec{R}_4^{\,+} = \Delta\beta * d\vec{R}_4 \tag{3-5c}$$

$$\Delta\vec{R}_4^{\,-} = -\Delta\beta * d\vec{R}_4 \tag{3-5d}$$

The use of angle differentials will be described in later sections.

3.2.2 Propagation of Differential Rays

If we trace the first ray through an optical system, and simultaneously keep track of how the differentials are transferred through the same system, we can at any later position within the system describe the position of a nearby ray as the linear combination of the ray we have traced, and proper differentials.

Thus, if we denote a ray that has propagated to the distance z, then,

$$\vec{R}' = \vec{R}\,.P_r = (x', y', z', c', d', e') \tag{3-6}$$

where P_r = propagation matrix for the ray. Similarly, we can denote a ray differential that has propagated a distance z as

$$d\vec{R}' = d\vec{R}\,.Pd = (\Delta x', \Delta y', \Delta z', \Delta c', \Delta d', \Delta e')$$

where Pd = propagation matrix for the differentials.

Thus, we may write a nearby ray $\vec{R}'$ that has propagated in terms of the propagated central ray and differentials as

$$\vec{R}^{s}_{i}{}' = \vec{R}' + d\vec{R}^{s}_{i} \quad (i = 1,2) \quad (s = +,-) \tag{3-7}$$

3.2.3 Reduction of Differentials At Intersections With Edges

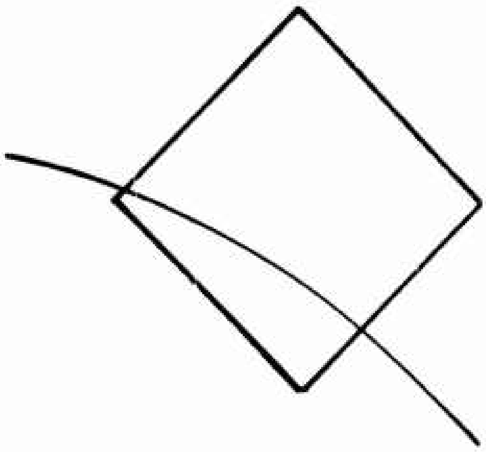
When a central ray passes near an edge, one or more of the nearby rays described by the differential may pass on the other side of the edge. Thus, for this case, the edge cuts through the propagating entrance aperture differential such that the new differential area containing the central ray does not get reduced by the edge. (See Figure 3-2.) Then, a coefficient A_i for each individual differential will be computed such that the original differential times the coefficient A_i equals the new differential. Then the ray trace will continue using the original differentials, with the coefficients carried along as a descriptor of the area reduction that occurred at the edge.

3.3 ITERATIVE DIFFERENTIAL RAY TRACE

3.3.1 Method

In the previous section, it was shown that it is possible to trace a single ray from four differentials through the system, and, in effect, trace a small area of the entrance aperture as it propagates through the system.

If the ray differential area impinges on a baffle edge such that some of the differential area goes off in a different direction, we have two choices: continue to keep track of the reduced portion of the differential that contains the central ray by re-adjusting the differentials (thus appropriately reducing the area of the differential); or backing up to the entrance aperture and starting over with a larger number of smaller differentials. We can set a threshold of area reduction (such as 80%) that automatically sends us back to the entrance aperture if the differential area drops below the threshold. If the ray propagates through a portion of the system where all adjacent rays undergo the same



Coefficients

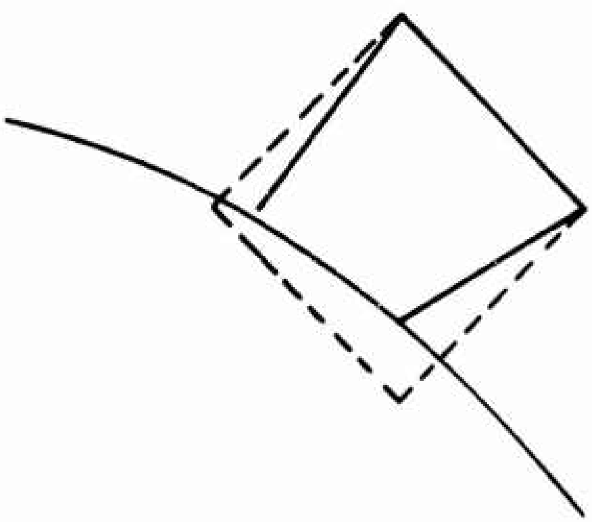
$a_1 = 1.0$

$a_2 = 1.0$

$a_3 = 1.0$

$a_4 = 1.0$

a. Original Differential Incident on Edge



Coefficients

$a_1 = 1.0$

$a_2 = 0.6$

$a_3 = 1.0$

$a_4 = 0.8$

b. Reduced Differential as Described by Coefficients

Figure 3-2. Differentials

sequence of reflections, then the threshold is never triggered and the computational density of rays for that portion of the system remains low. However, if the differential propagates through a portion of the system where the complexity is high, then the sequence of triggering the threshold and starting over with smaller differentials may be repeated (iterated) a number of times, resulting in an effective ray density which is locally very high.

Figure 3-3 illustrates the iterative differential ray trace method used to achieve the selective ray density goal of the program.

3.3.2 Use of Iterative Differential Ray Trace in Stray Radiation Calculation

The use of the iterative ray trace in making actual stray radiation calculations is shown in Figure 3-4, and listed below.

(1) Specify the permitted maximum number of iterations, the area reduction threshold, alnd the energy density threshold. (The energy density threshold allows us to stop tracing a ray altogether when its density is so low as to be negligible.) The value selected is a function of the sensitivity of the analysis to be performed. (Refer to paragraph 3.3.3.3.)

(2) Trace the rays through the system until a surface is reached; compute the scattered light terms arising from that surface (diffuse, etc.), write the scattered light contributions due to that surface on a scratch pad.

(3) Compute the new direction and differentials, the area reduction, and the new energy level.

(4) Perform three tests on the energy threshold, the area reduction, and the number of iterations, as shown in Figure 3-4. Depending upon the results of the three tests, there are three alternatives: (1) the ray trace can continue to the next surface with that differential; (2) four new

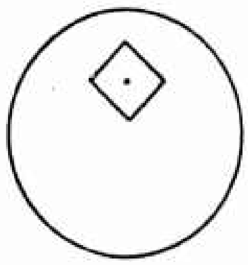
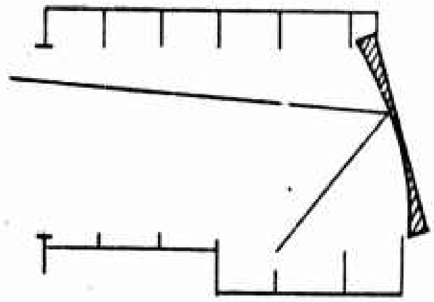
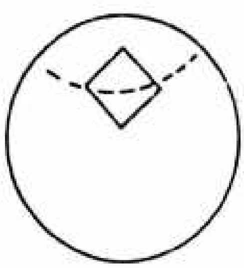
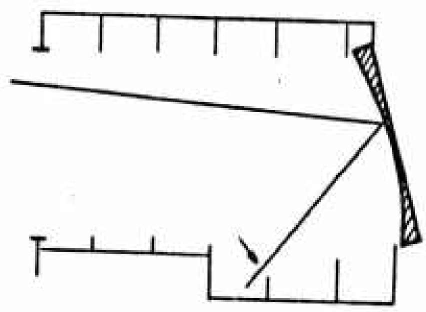
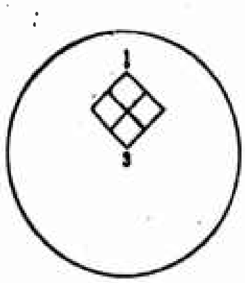
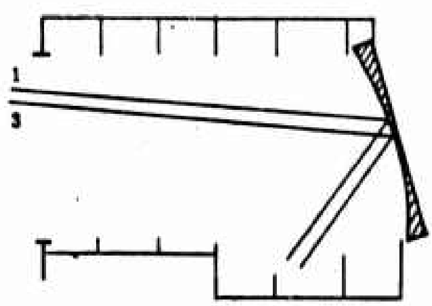
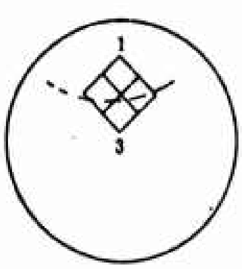
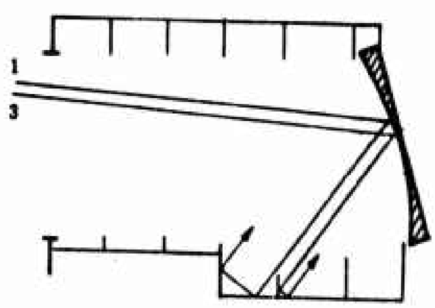
Step	Entrance Aperture	System	Comments
1			Initiate ray trace, find specular path through system
2			At each baffle plane, check to see if differential area is sliced by edge; if area containing central ray drops below threshold, return to entrance aperture
3			Re-initiate ray trace using 4 new differentials, each with new central ray (only 1 and 3 shown)
4			Check each new differential at each baffle plane; if any of the new ones are reduced, then that one is iterated; the others continue

Figure 3-3. Iterative Differential Ray Trace

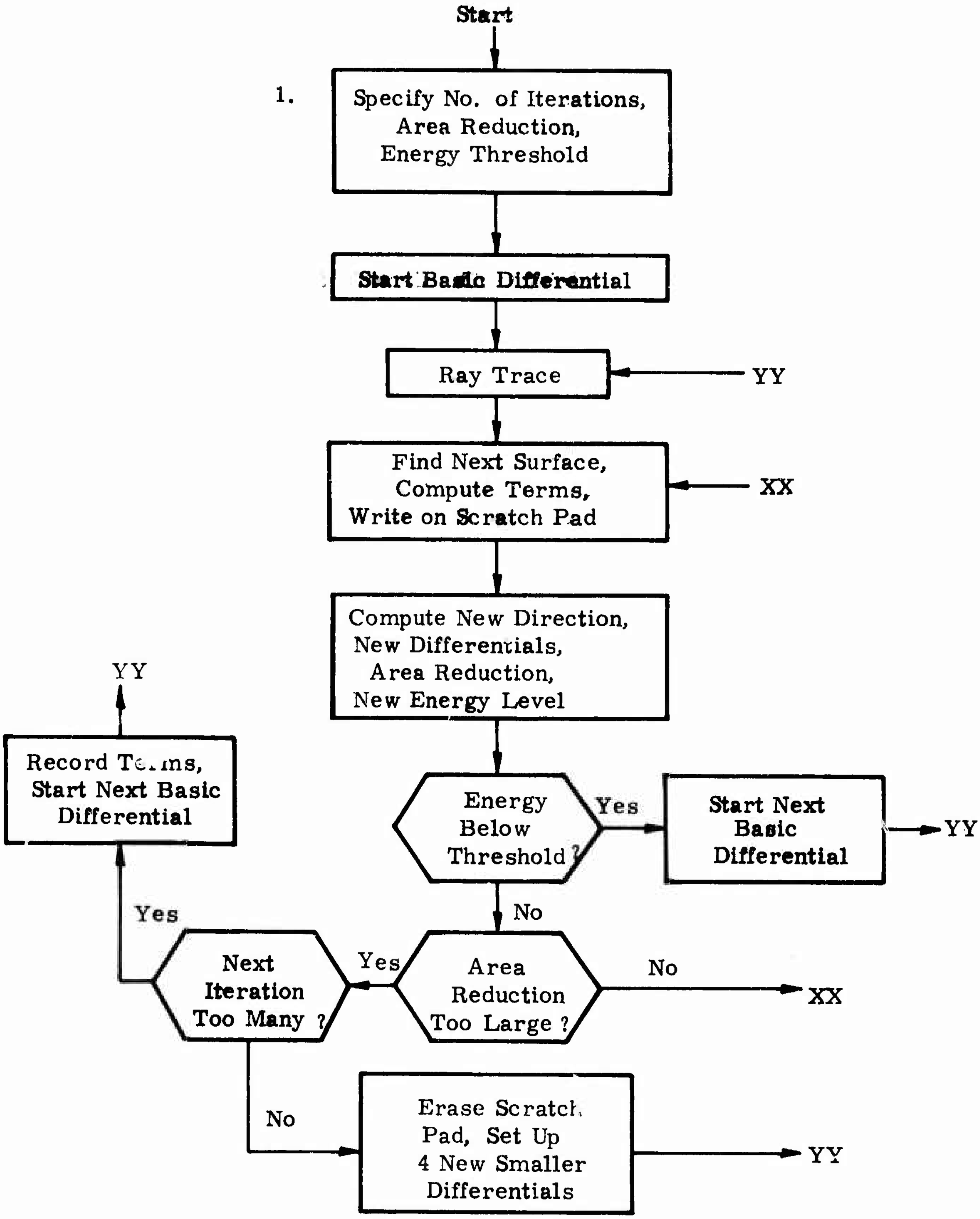


Figure 3-4. GUERAP II Iterative Differential Ray Trace Flow Diagram

differentials are set up, and the ray trace returned to the entrance aperture to begin with one of the new smaller differentials; or (3) the program returns to the entrance aperture to begin tracing the next basic (full sized) differential.

3.3.3 Selection of Parameters

As mentioned above, there are four basic parameters governing the use of the differential ray trace method in the GUERAP II computer program. Each of these is discussed briefly below.

3.3.3.1 Number of Initial Differentials

The initial number of differentials by itself does not strongly affect the final density of the rays because of the use of the iterative technique; it is the combination of the initial number of differentials and the number of iterations that largely determines the final maximum ray density.

A typical number of initial rays, about 20 for initial trial runs, and about 80 for final runs, has proven to be a reasonable choice for this parameter.

3.3.3.1 Number of Iterations

This parameter describes the number of times that the ray trace routine will return to the entrance aperture to further subdivide a differential that has been reduced by an edge below the area threshold; typical values for the number of iterations permitted is 3.

3.3.3.2 Area Threshold

Typical values of the area threshold that have been used in test examples are about 80%; results of varying the area threshold have demonstrated (for the cases run) that the sensitivity of the results on the value of the area threshold is low.

3.3.3.3 Energy Density Threshold

The energy density threshold to be specified must be low enough that the value of any anticipated stray radiation term, resulting from the incidence of a ray on a surface, be significantly less than the sensitivity goal of the particular run being performed. The purpose of specifying this value is to permit the program to bypass the calculation of terms that cannot be significant due to the low energy density of the ray being traced, thus enhancing program efficiency.

This condition is best expressed by the following equation:

$$\Delta F_k \cdot R_{k+1} = H_{fp} \ll H_{lim} \quad (3\text{-}8)$$

where

ΔF_k = flux in propagating differential area (equal to flux density resulting from k specular reflections times area of differential)

R_{k+1} = minimum assumed attenuation due to a scatter transfer from surface k+1 to detector (R is a ratio of flux densities)

H_{fp} = assumed focal plane flux density due to scattering at k + 1 surface of incident differential

H_{lim} = focal plane flux density limiting value; H is computed from the larger of either the accumulated stray radiation calculated in all previous calculations (the running total), or a specified system sensitivity limit.

If we use equation (3-8) above, we can compute the energy density threshold as follows. First, let

$$\Delta F_k = \Delta A_k \cdot H_k \quad (3\text{-}9)$$

where

ΔA_k = area of differential

H_k = flux density of differential

Substituting Eq. (3-9) into (3-8) yields

$$\Delta A_k \cdot H_k \cdot R_{k+1} << H_{lim} \quad . \tag{3-10}$$

Since

$$\Delta A_k << A_{ea} \tag{3-11}$$

where

A_{ea} = area of entrance aperture

Then we may write (3-10) as follows:

$$A_{ea} \cdot H_k \cdot R_{k+1} = H_{lim} \tag{3-12}$$

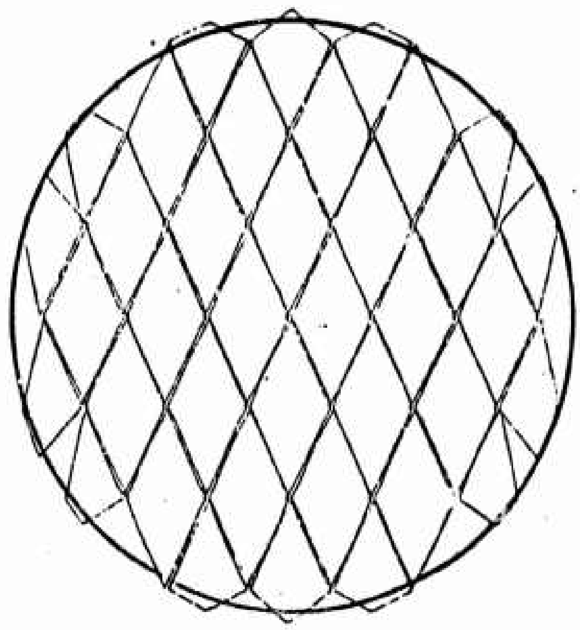
Solving for H_k yields the ray energy density threshold (equal to the ray energy density which satisfies the inequality of equation (3-10).

$$H_k = H_{\substack{\text{energy}\\ \text{density}\\ \text{threshold}}} = \frac{H_{lim}}{A_{ea} \cdot R_{k+1}} \tag{3-13}$$

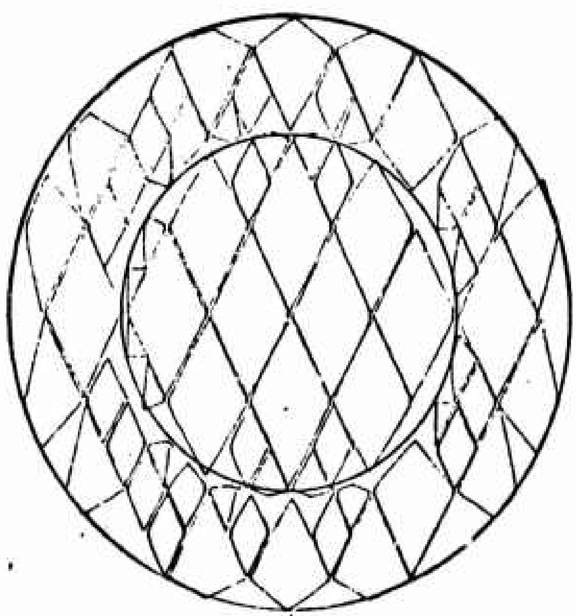
The values of the limiting flux density H_{lim} can be computed from the system BRDF goal, the values of the system f/no, and detector angular subtense.

3.3.4 Examples

Figure 3-5 illustrates a simple example of the use of a differential ray trace to fill the aperture of an optical system with area differentials. Figure 3-5, view a, illustrates the differentials that fill the entrance aperture for a source on-axis for a system in which no subsequent aperture reduces the effective aperture diameter. Figure 3-5, view b, illustrates the resultant differentials for the same system, for the case in which a Lyot stop has been inserted whose effective diameter is 60% of the diameter of the entrance aperture. Thus, the differentials propagating from the entrance aperture toward the focal plane have encountered an edge, and the iterative differential ray trace routine has generated smaller differentials that fill the aperture without cutting across the edge of the Lyot stop.



a. Lyot Stop Diameter = Entrance Aperture Image Diameter



b. Lyot Stop Diameter = 60% of Entrance Aperture Image Diameter

Figure 3-5. Entrance Aperture Filled with Differentials

Figure 3-6 illustrates a more complicated aperture filled with differentials. The case shown corresponds to a source located out of the field of view; thus, the complexity of the differential distribution resulted from the baffles and the edge of the mirrors encountered by the propagating differentials. In Figure 3-6, the initial number of differentials was ; the final number was about 1800 differentials. The number of permitted iterations was 3 for this case, and the area threshold was 80%.

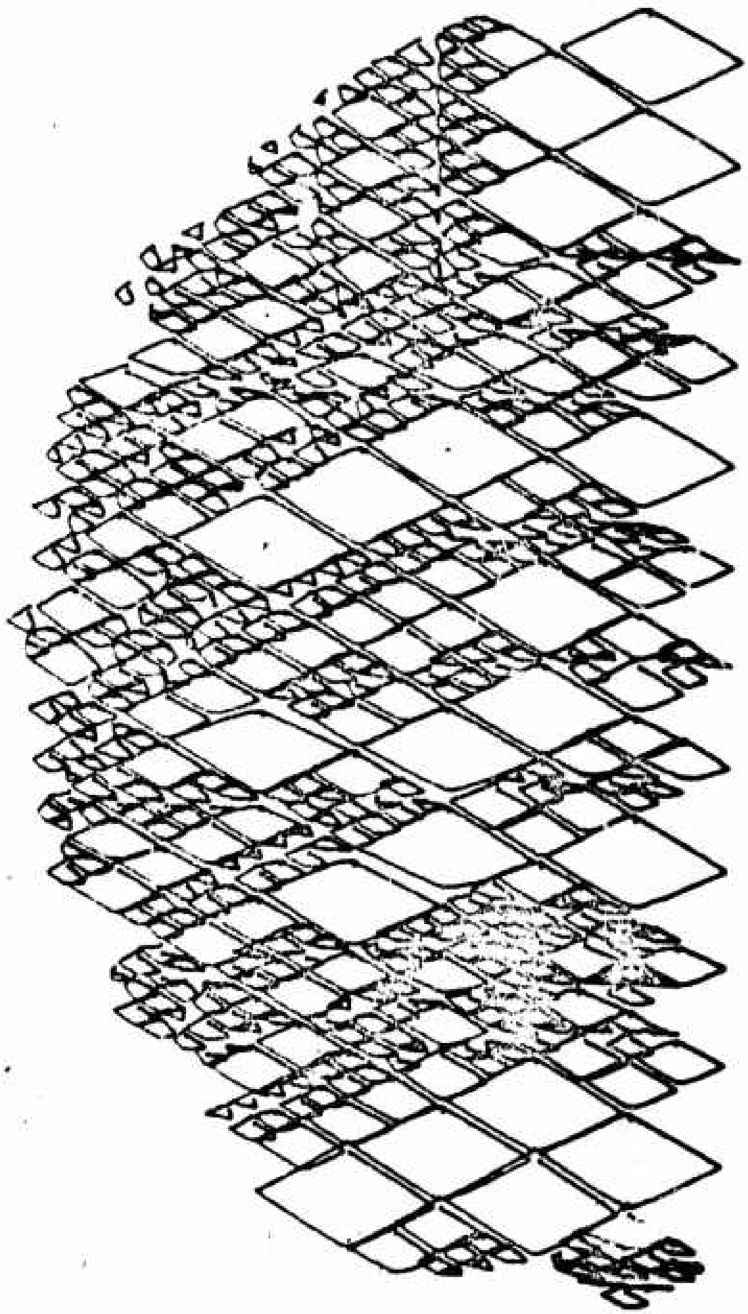


Figure 3-6. Results of Iterative Differential Ray Method (Upper Half of Aperture Shown Fitted)

SECTION IV

STRAY RADIATION CALCULATIONS

4.1 INTRODUCTION

In this section, the methods for performing the stray radiation calculations will be described in some detail. First, however, a few words need to be set forth about one of the basic objectives of the program, and the effect this objective had on the choice of methods employed for stray radiation calculation.

The objective of the program is the ability to analyze the capabilities of systems exhibiting very high off-axis rejection, thus it is of first importance to design a program that has no inherent performance (sensitivity) limitations. The method selected was to use deterministic calculations for the stray radiation terms, rather than a statistical approach.

This deterministic approach was made possible by two developments - the development of a general differential ray trace routine that provides much of the computational requirements for implementing a deterministic diffuse calculation method, and the development of a diffraction theory that describes diffraction in terms of rays originating at a point on an edge, and capable of rigorously handling multiple diffraction.

In the sections that follow, each of these methods will be described in some detail. It should be noted that the GUERAP II program, as presently configured, handles each of these two basic calculations in separate and distinct implementations, although the diffuse and diffract routines both depend upon the same optical form description and differential ray tracing routines.

4.2 DIFFUSE CALCULATIONS

4.2.1 Basic Method

The basic concept behind the diffuse calculations performed in GUERAP II is the propagation of energy through an optical system can be modeled by the existence of a specular component and a diffuse component each time a ray impinges on a surface; that the distribution of the diffusely scattered component is describable by a Bi-Directional Reflectance Distribution Function (BRDF); and that the propagation of the specular component can be handled by a ray trace routine capable of handling specular paths off all the surfaces in the system, including mirrors and baffles.

4.2.2 LEVEL 1 and LEVEL 2 Stray Radiation Terms

At each interaction between a differential and a system element, a number of stray light paths to the detector, either direct or off other system elements, are possible and must be computed if they are significant. These stray light components can be classified into stray light terms of various levels, depending upon the number of subsequent interactions that the scattered light must undergo in order to get to the detector. LEVEL 1 terms are those for which the stray light resulting from the interaction can directly impinge on the detector, while LEVEL 2 terms are those for which the scattered light must bounce off one intervening system element before impinging on the detector. Figure 4-1 illustrates schematically the LEVEL 1 and LEVEL 2 terms.

To perform the LEVEL 1 and LEVEL 2 interactions outlined above, two types of information are required about the system geometry:

(a) The edges and baffle surfaces that are visible to the detectors must be known, since it is only from these surfaces that a transfer of unwanted energy to the detectors can take place. These edges and surfaces are to be known as "critical" edges and surfaces.

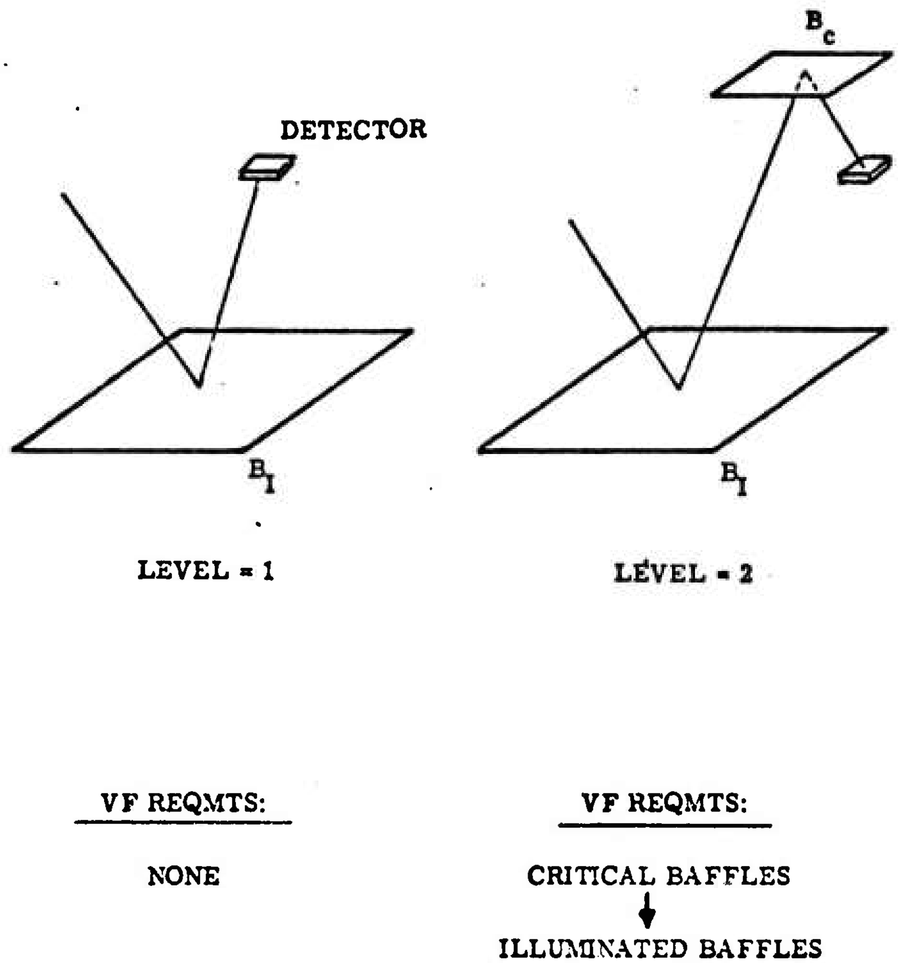


Figure 4-1. View Factor Requirements for Various Levels

(b) In order to identify the various interaction paths that exist within the system, knowledge on the visibility of of each baffle to other baffles is required; i.e., which baffles can baffle N see, since each baffle that baffle N can see represents a possible path for the transfer of unwanted energy. This visibility information is contained in a "view factor matrix".

4.2.3 Simplification of the View Factor Matrices

If the view factor matrix information were stored in one array, the array would be quite large; for example, for N identifiable system elements, the view factor matrix would require on the order of N^2 storage locations.

To reduce the size of the view factor array, the GUERAP II program will take advantage of the fact that the optical system is partitioned into sections as the optical system is entered into the program. Thus, the view factor information will be contained in two sets of information, as follows:

(a) Section-to-section view factors. The program user will be required to enter a simple binary (1 or 0) section-to-section view factor matrix that describes to the program what sections are directly visible and adjacent to what other sections.

(b) Baffle-to-baffle view factors. Based on the information in the section-to-section view factors, the baffle-to-baffle view factors will be internally generated by the computer program only between the baffles contained in sections that the section-to-section view factors indicate can possibly see each other. This avoids the necessity of storing a large number of entries in a view factor matrix between baffles that are located in sections of the optical system that cannot see each other.

4.2.4 Critical Matrix Pre-Processing

To determine the critical edges and surfaces, the GUERAP II program will "pre-process" the optical system prior to the actual differential ray trace by determining what edges and surfaces are visible to each of the detectors specified by the user. This operation will be performed by setting up an angle differential centered at each of the detectors specified; then the angle differential will be propagated, and the areas on each of the baffles within the system that the angle differentials intersect will be denoted and saved as the critical areas. In addition, the direction of the detector relative to the local normal of the baffle will be saved, along with the angular subtense of the detector from the critical surface. If the critical area is too close to the detector of interest, then the critical area will be broken down into a number of smaller areas. Each of the components of the critical matrix (the coordinates of 4 points defining the critical area, the detector subtense, and direction) will be used during the actual ray trace to compute the energy transferred to the detector.

4.2.5 Point-to-Point Routine and Additional Hand Entered Section View Factors

One of the key requirements of the program is that it be able to find paths of "lines of sight", from one system element to another via imaging paths off of one or more mirrors in addition to the simpler direct lines of sight that may exist. This is achieved by the implementation of a routine called PTP (point to point), which searches for and examines all possible mirror sequences from one specified system element to another.

To aid in the identification of all possible paths from one element of the system to another, the user is asked to read into the program two additional small binary matrices as follows:

(a) Section to aperture view factors. This matrix will identify what apertures can be seen from what sections directly (the aperture cannot be seen through another section).

(b) Aperture-to-aperture view factors. This matrix will identify what apertures can see what other apertures directly, without the line of sight passing through more than one section.

These view factors and the section-to-section view factors described in Section 4.2.2 are used to generate possible sequences from one system element to another. Once each sequence is set up, then an angular differential ray trace is used to see whether a line of sight does exist through that particular sequence of mirrors.

The use of these hand entered view factors greatly facilitates the computational efficiency of the program without placing any real burden on the user, as these three matrices are relatively small and require only binary (1 or 0) entries that can be determined rapidly by inspection from a sketch of the system being analyzed. The user is not being asked to identify a path sequence; only the answer to questions such as: "Can aperture A see aperture B directly?"

4.2.6 Computation of LEVEL 1 Terms

After the program has "preprocessed" the system, then the program performs a differential ray trace of the system, as described in Section III. During this ray trace, the LEVEL 1 diffuse computations are performed as follows:

(a) When a differential impinges upon a surface, the program checks to see whether the baffle being hit by the differential is marked as a critical baffle; it it is, then the program checks to see whether the central ray has hit inside the region marked as the critical area that can be seen directly by the detector. If the differential does not lie within this region, then the ray trace continues to the next surface. If the central ray does lie within the region, then step (b), below, is performed.

(b) The angle of incidence of the incident differential is computed and used in conjunction with the angular direction to the detector to compute the BRDF of the surface, which in turn is combined with the detector subtense to compute the fraction of the energy in the incident differential that is detected by the detector. This calculation is described by equation (4.1) below.

$$F_{det} = F_{diff} \cdot \text{BRDF}\ (\theta_{det}, \phi_i) \cdot \Omega_{det} \tag{4.1}$$

where F_{det} = flux incident on detector

F_{diff} = flux in differential incident on surface

θ_{det} = stored direction to detector

θ_i = angle of incidence of specular ray on surface

Ω_{det} = solid angle subtended by detector from critical area

Thus it can be seen that the use of "extended" critical matrix entries eliminates the requirements for any further ray tracing beyond the ray trace that determines that a given baffle is illuminated, i.e., all the calculations that are requried to perform the calculation of the transfer to the detector have been performed once on the preprocessing critical matrix determination.

4.2.7 <u>Preparation for LEVEL 2 Calculations</u>

As illustrated in Figure 4-1, the computations of the LEVEL 1 terms require only knowledge of th critical baffles, but do not require knowledge of baffle-to-baffle view factors. Thus, the GUERAP II program will initially perform the complete differential ray trace of the systems, compute the LEVEL 1 terms only, and will in the process determine which baffles are illuminated by differentials that have propagated by specular paths through the system.

The stray light totals arising from the LEVEL 1 will then be examined to determine whether the accumulated LEVEL 1 terms are so large that the LEVEL 2 terms would be insignificant. If that condition exists, the program will terminate, thus avoiding the unnecessary LEVEL 2 computations. However, if the test indicates that the LEVEL 2 terms could be significant, the program will then prepare for the LEVEL 2 computations by computing only those view factors that will be needed for the LEVEL 2 terms. As shown in Figure 4-1, the only view factors required for the LEVEL 2 terms are those from the critical baffles to the illuminated baffles. Since the set of view factors involving the critical and illuminated baffles is a relatively small set of all the possible view factors, the program remains relatively efficient by computing only those view factors that will actually be used in the LEVEL 2 computations.

4.2.8 Calculation of LEVEL 2 View Factors

Once the need for performing the LEVEL 2 calculations has been established, the program will compute the view factors as follows:

Each of the critical areas will be divided up into 9 separate points; for each of these points, an angle differential will be sent out to determine whether any portion of that differential intersects any part of any of the previously determined illuminated baffles. If any portion of the differential does intersect any part of an illuminated baffle, then the boundary of that region (which represents the part of the illuminated baffle that is visible to the specific point on the critical baffle) is saved and placed in the view factor matrix. Two additional pieces of data are also stored along with the coordinates of the 4 points that define the LEVEL 2 area; the distance to the critical baffle and the direction to the point on the critical baffle.

This matrix, which represents the largest storage requirements of the program and possibly the largest computational task in terms of time, nevertheless is a key feature of the efficiency of the program, as it eliminates the need during the LEVEL 2 computations for any ray tracing and path determination beyond the differential ray trace used to follow the propagation of the specular rays through the system. This point is explained further below.

4.2.9 Calculation of the LEVEL 2 Diffuse Terms

The computation of the LEVEL 2 terms is analogous to the LEVEL 1 computations; differential rays are traced through the system, and each time the differential ray hits a system element, the view factor matrices are searched for paths that exist to the detector. In this case, however, the search is for LEVEL 2 terms, since the LEVEL 1 terms were computed during the previous ray trace of the system.

The following simple example illustrates the method for determining all of the LEVEL 2 terms that exist from the specific illuminated baffle to the detector.

(1) Let the critical baffle matrix (baffles 2 and 4 are visible to the detector) be

$$C = \begin{bmatrix} 0 \\ 1 \\ 0 \\ 1 \end{bmatrix} \tag{4.2}$$

(2) Let the view factor matrix (baffle 3 can see baffle 4) be

$$V = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix} \tag{4.3}$$

(3) By using the differential ray trace routine, it is determined that baffle 3 is illuminated (the differential has hit baffle 3); thus set up illumination matrix.

$$I = [0 \; 0 \; 1 \; 0] \tag{4.4}$$

Now we can examine the possibility that there are LEVEL 2 stray radiation terms arising from the interaction of the differential with baffle 3, as follows:

<u>Is there a LEVEL 2 contribution?</u>

To determine if there is a LEVEL 2 contribution, the matrix product shown below must be examined:

$$I \cdot V \cdot C = [0 \; 0 \; 1 \; 0] \cdot \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix} \cdot \begin{bmatrix} 0 \\ 1 \\ 0 \\ 1 \end{bmatrix} > 0 \tag{4.5}$$

Since the matrix product is greater than zero, a LEVEL 2 term is indicated. Within the program, the matrix product will not be actually computed, but the view factor matrix will be examined to determine whether there is a non-zero term for the second and fourth element of the third row.

The actual computation of the LEVEL 2 term is defined below, in terms of the BRDF and the angles of the two surfaces involved.

$$F_{det} = F_{diff} \cdot BRDF_{IS}(\theta_{CS}, \phi_i) \cdot \Omega_{CS} \cdot BRDF_{CS}(\theta_{DET}, \phi_{CS}) \cdot \Omega_{det} \quad (4.6)$$

where

F_{det} = flux incident on detector

F_{diff} = flux in differential incident on surface

$BRDF_{IS}$ = BRDF function for illuminated surface

$BRDF_{CS}$ = BRDF function for critical surface

θ_{CS} = angle from illuminated surface to critical surface (contained in VFM)

ϕ_i = angle of incidence of differential ray

θ_{det} = angle from critical surface to detector (contained in CM)

ϕ_{CS} = angle from illuminated surface to critical surface (contained in VFM)

Ω_{CS} = solid angle of critical surface from illuminated surface (computed from distance contained in VFM)

Ω_{det} = solid angle of detector from critical surface (contained in CM)

Note that all of the information needed to perform the calculation of equation (4.6) is contained in either the Critical Matrix (CM) or the view factor matrix (VFM); thus, no further ray tracing is required to perform the actual LEVEL 2 computations, beyond the tracing of the specular rays through the system.

4.2.10 Efficiency Considerations and Overall Flow Chart

One of the problems inherent in writing a general program such as GUERAP II is that the total number of computational operations becomes quite large; it is of prime importance that the program be as efficient as possible to keep the running time down to a reasonable minimum. To this end, the GUERAP II diffuse calculations contain several features designed to increase efficiency, as follows:

(a) View factors are computed only as needed,

(b) View factors contain much pre-computed information, and

(c) The stray light terms are computed only if their expected values are large enough to be significant.

The first two of these features have been described previously; the third is described below.

Compute only significant stray light terms

As each term is computed during the performance of the ray trace for a given level, the expected value for each individual term is compared to both a user specified system accuracy limit, and the current running total of the stray light. The checking of each term before its computation will accomplish two goals, as follows:

(a) A particular LEVEL 2 term may be insignificant, due to the low energy density resulting a large number of baffle specular reflections before hitting the particular baffle of interest; only by testing the predicted value of each term, taking into account the differential's actual energy density, can such terms be eliminated; and

(b) As the terms of the particular level are accumulated, the recorded scattered light total for the system may significantly increase, thus raising the significance value used in the test described above, allowing the program to eliminate more and more computations as more and more stray light is accumulated.

The flow chart shown in Figure 4-2 illustrates the interaction of all of the methods and features of the diffuse calculations described in this section.

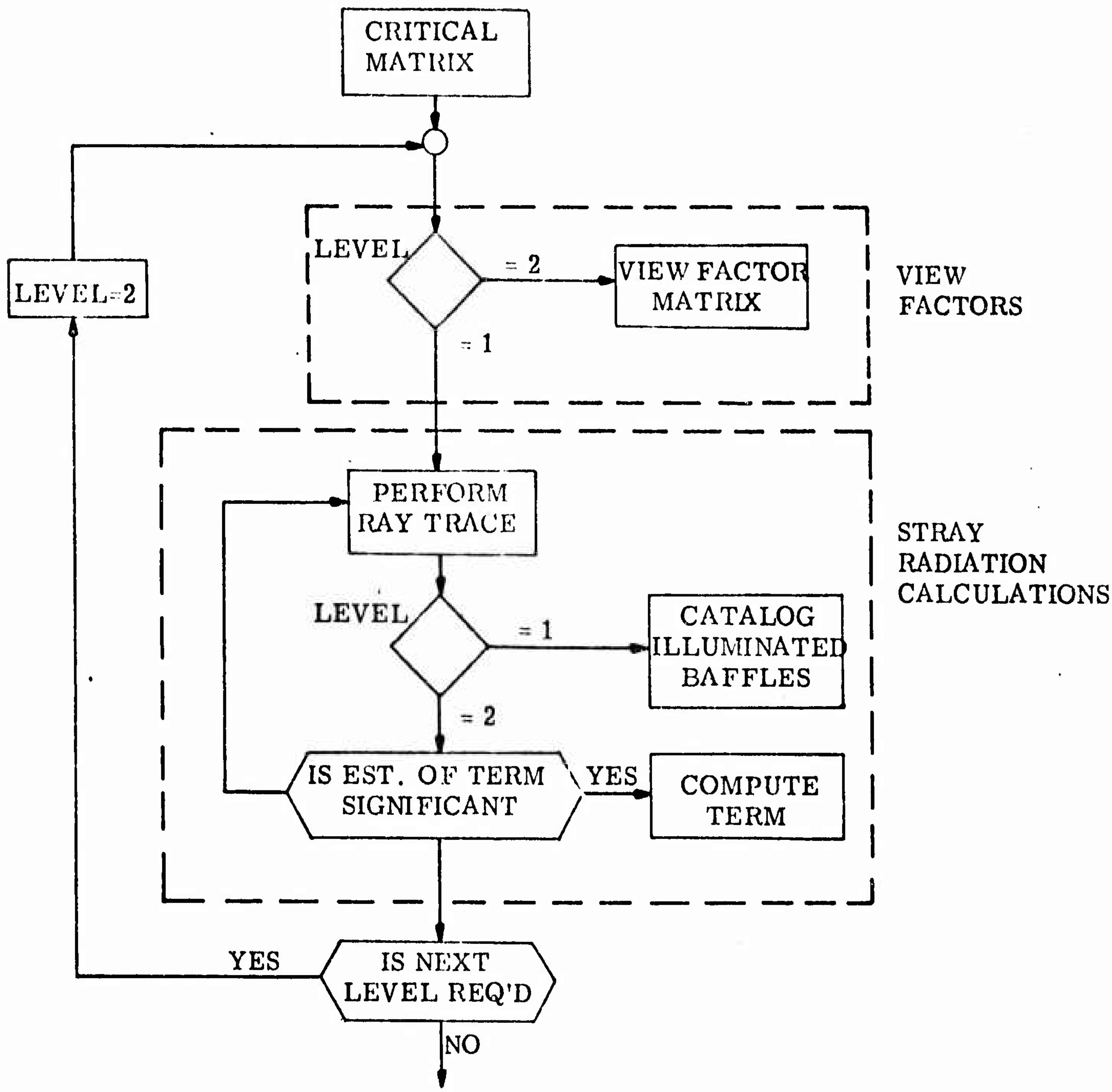


Figure 4-2. GUERAP II - Basic Flow Diagram

4.3 DIFFRACTION CALCULATIONS

4.3.1 Introduction

Conventional diffraction theory describes the phenomenon of diffraction as an area integral over an enclosed aperture, with the evaluation of multiple diffraction as a multi-variate integral over the apertures involved. However, this characterization of diffraction is not amenable to a program designed around the use of a ray trace technique. A more desirable characterization of the diffraction phenomenon would be one in which diffraction is described as a ray phenomenon, where the diffraction would occur at a point on an edge.

Such a characterization of diffraction has been developed at Perkin-Elmer, by extending the work of Keller,[1] Miyamoto and Wolf,[2] and others. The result of this work is a description of diffraction in terms of rays that can be traced by the differential ray trace routine described in Section III, and whose intensities can be similarly computed in terms of parameters that are easily derived from the use of the ray trace routine.

The characterization of diffraction has two parts; a vector existence condition that allows the determination of the direction in which the diffracted energy propagates, and a scalar intensity relationship that describes the intensity of the diffracted rays in terms of the propagation of a ray that is generally astigmatic.

One important feature of the diffraction characterization described in this section is that it is capable of handling multiple diffraction sequences with great accuracy.

4.3.2 Basic Theory

The basic theory gives the diffracted scalar electric field and hence can reproduce most of the fine fringes normally associated with diffraction. However, if the apertures are large and/or there is a range of wavelengths, only the general energy distribution will be of interest; in this case each ray is treated as a separate source of energy. The total energy diffracted is then the sum of the individual ray energies, ignoring their relative phases. This gives the local average or envelope of the basic diffracted energy.

4.3.2.1 Basic Equations

Let us now consider a diffracting aperture with a field incident from the left. The incident field varies slowly enough in phase and amplitude so that it can be satisfactorily represented by geometric rays if desired, although this will not be done at first. Miyamoto and Wolf write the field at the point S to the right of the aperture in the form:[2]

$$U\ (S) = U_g\ (S) + U_b\ (S) \qquad (4.7)$$

where $U_g(S)$ is the field in the bright region as determined by conventional geometric ray trajectories from the incident field through the aperture. $U_b(S)$ is the boundary edge diffracted contribution. This term is included in both the shadow and the directly illuminated region.

The edge diffracted component is given by Miyamoto and Wolf[2]

$$U_b\ (S) = \frac{1}{4\ell} \int A\ (\ell)\ \frac{\exp[ik(S+P_o)]}{S} \left[\frac{\hat{s} \times \hat{p} \cdot \hat{\ell}}{1 + \hat{s} \cdot \hat{p}}\right] d\ell \qquad (4.8)$$

where the integration is carried out along the edge of the aperture, A (ℓ) is the field strength along the edge of the aperture, k is the wave number, kP_o is the phase in radians of the incident wave at the edge of the aperture, S is the distance from the edge of the aperture to the point S, and (x) and (·) are the conventional cross and dot products for vectors.

There are three unit vectors indicated by (^). $\hat{s}$ is a vector from the edge of the aperture to the point S, $\hat{p}$ points back toward the source, and $\hat{\ell}$ is a unit vector tangent to the edge.

All of these variables are evaluated at the point ℓ on the aperture boundary. The point ℓ moves around the boundary as the integral is evaluated around the aperture as indicated by Equation (4.8).

Equations (4.7)and (4.8) give the field amplitude, normalized so that the irradiance (flux per unit area or watts per square meter) at the point S in a plane nominally normal to the incident rays is

$$I\ (S) = |U\ (S)|^2\ W\text{-}m^{-2} \qquad (4.9)$$

and likewise the incident irradiance along the edge is

$$I_{\ell} = |A\ (\ell)|^2\ \mathrm{W\text{-}m^{-2}} \qquad (4.10)$$

For the basic assumptions made, the field given by Equations (4.7) and (4.8) is as accurate as would be given directly by the more usual Kirchhoff diffraction integral. However, while Equation (4.8) is a line integral instead of the Kirchhoff surface integral, it is still not directly usable. Equation (4.8) can be converted into a more useful form by expanding the integral for its asymptotic behavior for large values of k by the method of stationary phase. The result of this expansion will be a representation for the edge diffracted field that is the equation of an ordinary geometric optical ray. Thus because of the initial assumptions, the entire field, which includes the incident field, the geometrically transmitted field and the diffracted field, will be represented by ordinary geometric rays.

The method of stationary phase shows that the significant contribution to the integral is given by those points along the aperture boundary ℓ for which

$$\frac{\partial (S+P_o)}{\partial \ell} = 0 \qquad (4.10)$$

In terms of unit vectors, this is identical to

$$(\hat{S} + \hat{p}) \cdot \hat{\ell} = 0 \qquad (4.11)$$

Using this method of solution, Equation (4.8) is approximated so that Equation (4.10) is given by

$$I\ (S) = B\ \frac{\lambda}{S\left|1 + \frac{S}{R}\right|}\ I_{\lambda n}\ \ \mathrm{W\text{-}m^{-2}} \qquad (4.12)$$

Where I (S) is the irradiance at a point S due to the incident illumination irradiance $I_{\ell n}$ at the point ℓ_n on the aperture edge, where

$$B = \left|\frac{\hat{\ell} \times \hat{p} \cdot \hat{S}}{4\pi\ |\hat{\ell} \times \hat{p}|\,(1 + \hat{p} \cdot \hat{S})}\right|^2 \qquad (4.13)$$

defines the angular variation of the diffracted flux density as a function of known unit vectors, and

$$\frac{1}{R} = \frac{1}{P} - \frac{1}{\rho} \frac{\hat{n} \cdot (\hat{p} + \hat{s})}{|\hat{\ell} \times \hat{p}|^2} \tag{4.14}$$

defines the distance R. P is the radius of curvature of the incident wavefront along $\hat{\ell}$ and p is the radius of curvature of the edge.

Equations (4.12) through (4.14) are the equations of a conventional astigmatic geometric ray propagating along the line from the diffraction point ℓ_n on the edge through the observation point S. The astigmatic ray has two foci along S. One is at the point of diffraction on the edge of the aperture in the plane of $\hat{n}$ and $\hat{s}$. The other focus is located a distance R behind the edge along $\hat{s}$ in the plane of $\hat{\ell}$ and s. It is interesting to note that although we have not explicitly used ray equations in deriving this result, the assumptions that have gone into it are analogous to the assumptions that allow the use of rays to represent optical fields in general. This allows us confidently to call this a "ray theory of diffraction" and to consider equation (4.12) as the equation of a ray.

4.3.2.2 Existence Condition

Equation (4.11) represents the condition for the existence of a diffracted ray. Interpret this equation in the following way: $\hat{p}$ is a unit vector in the negative direction of the incident ray to a point on the edge; $\hat{s}$ is the unit vector in the direction of a diffracted ray at the same point. Equation (4.11) says that for a given incident ray, the diffracted rays lie on the surface of a right circular cone centered on the edge tangent $\hat{\ell}$. The incident ray also lies on the surface of the cone. This is shown in Figure 4-3.

The diffracted field given by the preceding asymptotic ray expansion will be generally valid if the basic assumptions are satisfied and if the point S is not either on the geometric shadow edge or at a focus of one or both of the radii of curvature of the diffracted ray.

$$(\hat{S} + \hat{P}) \cdot \hat{L} = \emptyset$$

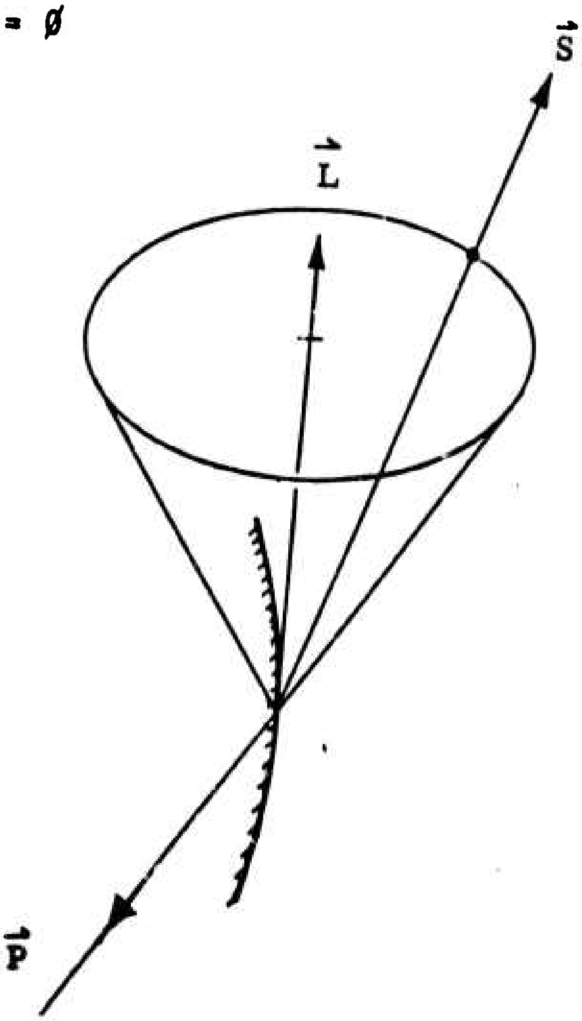


Figure 4-3. Condition for Diffraction

4.3.3 Implementation of Diffraction Theory in GUERAP II

Figure 4-4 illustrates the interesting case of a ray incident on an aperture at an angle almost normal to the plane of the aperture; this is the case of interest for most optical systems that are limited by bright sources near the field of view. As view a, Figure 4-4 illustrates, the cone describing the locus of diffracted energy for which the equations in Section 4.3.2 are valid is nearly flat, and the intersection of that cone with a plane positioned some distance away (not necessarily normal to the axis) is a hyperbola and very nearly a straight line.

The computation of the irradiance at some point along that hyperbola is a function of the distance from the diffracting edge to the point of observation, and is also a function of the apparent position of one of the astigmatic foci located at the point marked 1' on view b, Figure 4-4.

If the diffracting point is moved around the aperture (such as the sequence of points labeled 1-8 in Figure 4-4), the corresponding hyperbola in the plane of intersection also moves and changes shape.* Figure 4-5 illustrates the motion and the shape of the hyperbola as the diffraction point moves around the aperture. Note that all the hyperbolas intersect at the projection of the undiffracted ray $\hat{p}$ onto the plane of the observer.

Figure 4-5, view b, illustrates the distance between the hyperbola and the detector marked A in view a, as a function of the position of the diffracting point on the entrance aperture. As shown, there are two points for which the detector will be irradiated by the diffracted energy, as demonstrated by the fact that the distance between the diffraction hyperbola and the detector has gone to zero in view b, Figure 4-5.

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*The major axis is always parallel to the tangent to the diffracting edge, and the ratio of the major axis to the minor axis (the eccentricity) is a function of the angle between the tangent to the edge and the incident vector p.

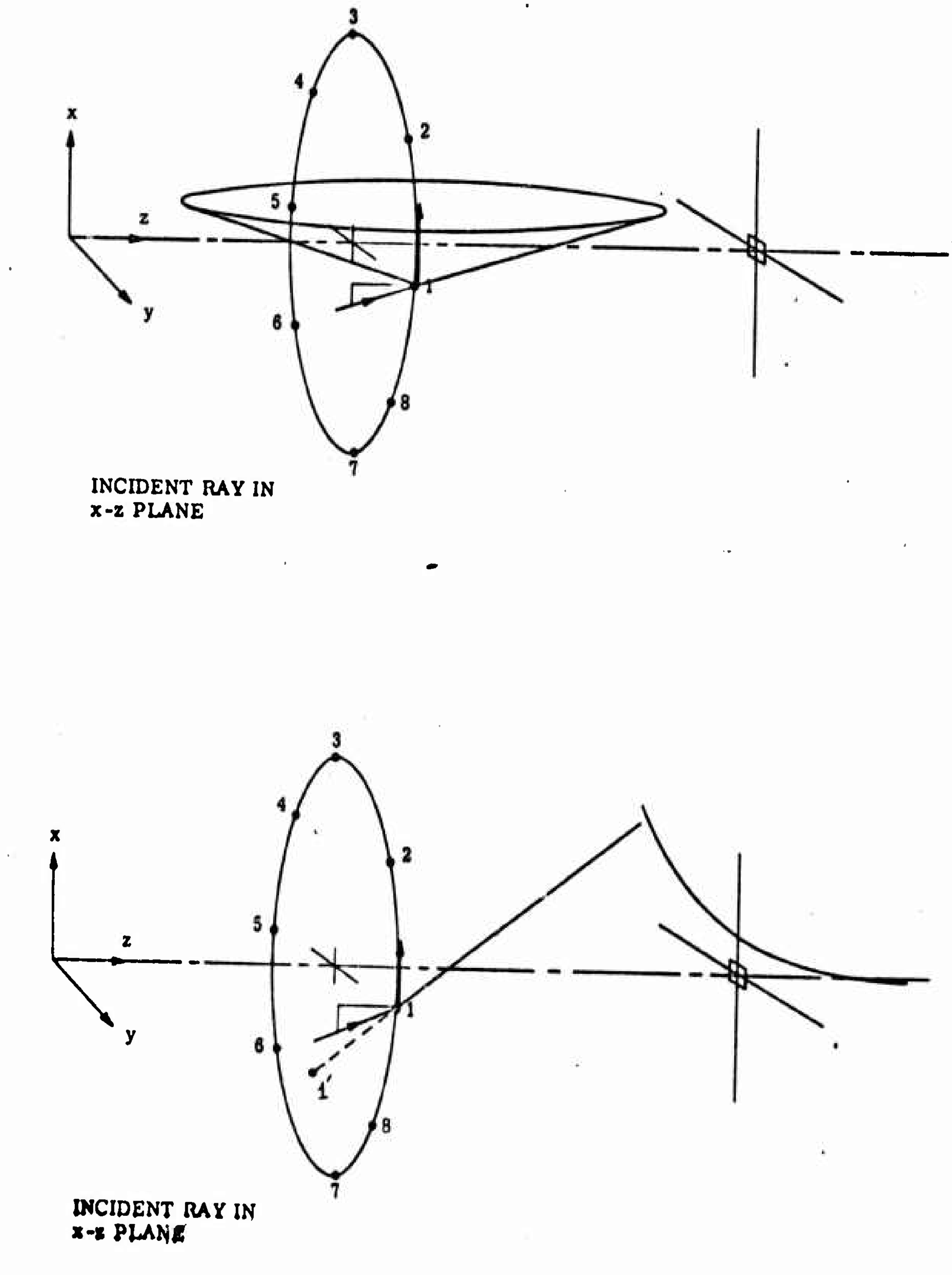


Figure 4-4. Diffraction at an Optical System Aperture

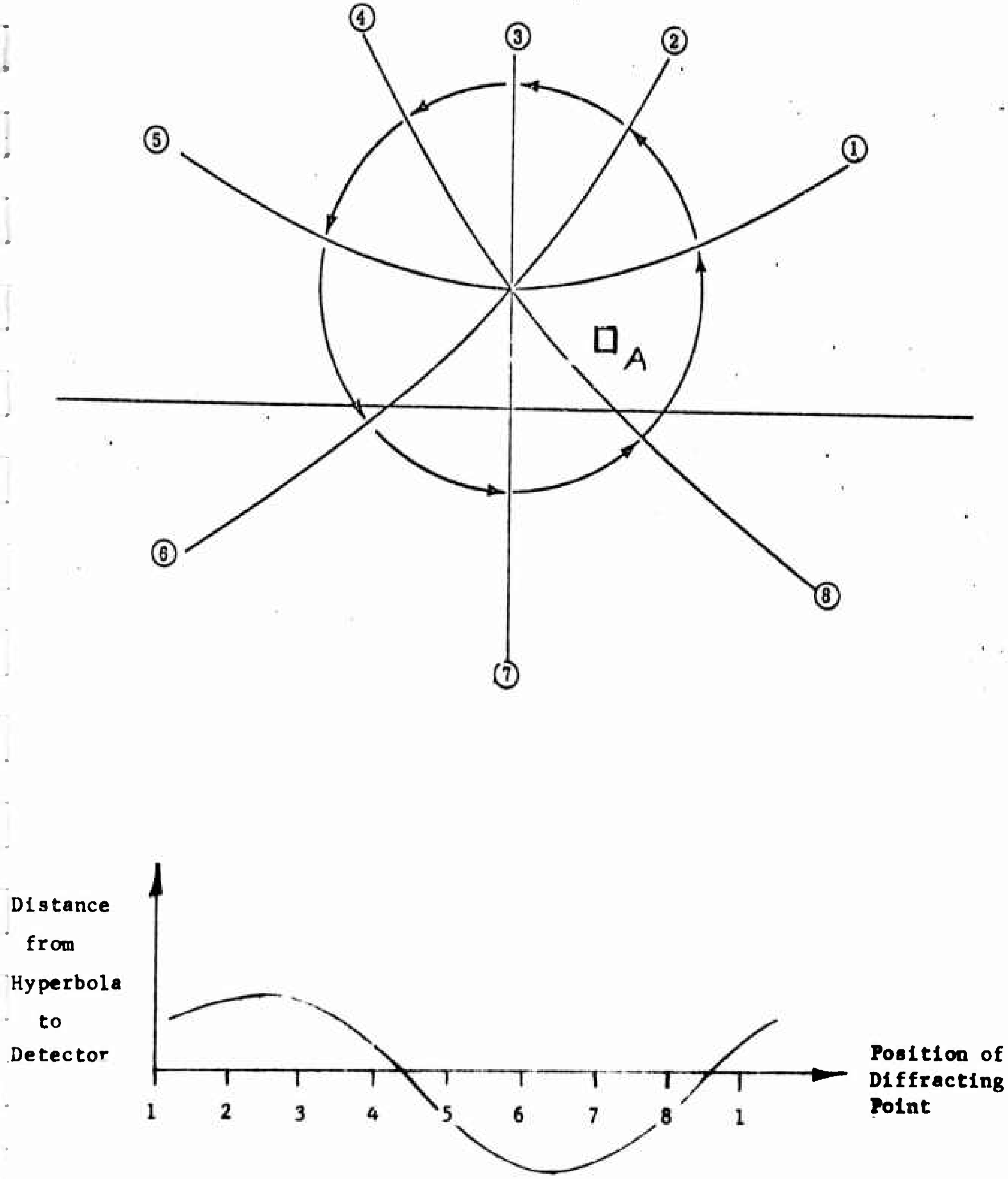


Figure 4-5. Diffraction Hyperbolas in Focal Plane for Simple Circular Aperture

4.3.4 Determination of Detection Condition

If one takes a small number of points around the entrance aperture and examines each or the resulting hyperbolas to see whether that hyperbola passes through the detector, it is unlikely that the hyperbola will pass directly through the detector. However, if the distance of the detector for each point in the entrance aperture is compared to the distance resulting from the previous point in the entrance aperture, then the detection condition will be flagged when the distance for one of the points has a different sign than for the other. Such a condition indicates that there was a cross-over between the two points, and the program will then iterate a new point in the entrance aperture between the two points in an effort to locate the diffracting point that results in a hyperbola passing through the detector.

One of the practical considerations to be made in implementing this method is the problem of drop-outs - i.e., the case where the hyperbola resulting from a given point on the illuminated aperture intersects the next aperture, but the hyperbola resulting from the previous point on the entrance aperture does not intersect the next aperture. In this case, there is no previous detector-to-hyperbola distance to which to compare the current distance; hence the program cannot make the comparison, and cannot detect a hyperbola cross-over between the two points.

The present solution for this problem is to let the sample density around the entrance aperture be high enough that the probability of a cross-over occurring at an entrance aperture point adjacent to a drop-out point is very low.

4.3.5 Multiple Diffraction

For multiple diffraction, an additional complication occurs, in that for each point in the entrance aperture, the resultant hyperbola can intersect a subsequent aperture such as the field stop in zero or two places (if the subsequent aperture is a closed convex figure, such as a circle), giving rise to zero or two hyperbolas at the next plane of interest, such as the Lyot stop plane. If that next plane contains another aperture (such as would occur if a triple diffraction sequence were being analyzed), then each of the two hyperbolas would result in zero or two hyperbolas in the next plane (such as the focal plane). Thus, one point in the entrance aperture results in a total of zero, two or four hyperbolas in the focal plane of a system suffering from triple diffraction, or zero or two hyperbolas for the case of double diffraction.*

The distance of each of these hyperbolas is measured relative to the detector as previously described under single diffraction and the detection process handled in the same way. Additional care must be made to keep track of the proper order of the multiple diffraction paths; as a consequence of the method used to keep track of the paths, the source must be outside the field stop, or the potential for errors exists.

4.3.6 Use of the Differential Ray Trace to Trace Diffracted Rays

One of the important consequences of using the ray diffraction theory based on the method of stationary phase is that it is possible to trace the diffracted rays through real optics, and examine the effect of the actual aberrations present in the optics on the intensity of the diffracted stray radiation.

To implement the ray trace of the diffracted energy, two separate functions must be performed by the differential ray trace routine:

(a) The direction of the diffracted rays, which initially lie on the diffraction cone, must be modified to account for the effect of the real optics; and

(b) The energy density, which depends upon the apparent location of the two astigmatic foci that are used to describe the intensity of the diffracted ray, must be computed after taking into account the effect of the aberrations on the ray energy density.

*The degenerate case of a hyperbola just grazing an aperture, resulting in a single hyperbola at the next plane, is ignored for the purpose of this discussion, but is not ignored in the program.

Each of these two functions is achieved by the use of the differential ray trace procedure; the details are given in Appendix I. The use of the differential ray trace method for the examination of the effect of real optics on system performance is given in the test system example (Section 7.2), which describes an analysis of the Baffle I test system that was assembled at Perkin-Elmer and subsequently tested for its off-axis rejection capabilities.

4.3.7 Illustrative Example of Diffraction Analysis: Triple Diffraction

In this section, the use of the method of stationary phase to derive the BRDF for triple diffraction, for both detectors on and off axis, will be described for the case of ideal (unaberrated) optics.

4.3.7.1 BRDF for Triple Diffraction - Detector On-Axis

The method of stationary phase can be used to derive an analytical expression for the BRDF for an ideal simple telescope for the case of a detector on-axis. The BRDF is

$$\mathrm{BRDF}_s = \frac{\lambda}{2\pi^3 c\phi^3} \quad sr^{-1} \text{ for } \phi \neq 0 \qquad (4.15)$$

at small angles. The wavelength is λ, the effective aperture radius is c and the light is incident at an angle of ϕ radians to the telescope axis.

By re-imaging the entrance aperture through a field stop onto a slightly smaller Lyot stop, diffracted energy cannot directly pass from the entrance aperture to the focal plane; consideration of the condition for a diffracted ray to be detected for a system containing a Lyot stop shows that diffracted energy can reach an on-axis detector only by the type of path shown in Figure 4-6. Each path contains three diffractions; there are no paths involving less than three diffractions that can result in an incident ray outside of the field of view hitting a detector within the field of view.

The equation of the BRDF for triple diffraction for an idealized system containing circular apertures, a Lyot stop, and a detector in the center of the field of view, is shown in equation (4.16) below,

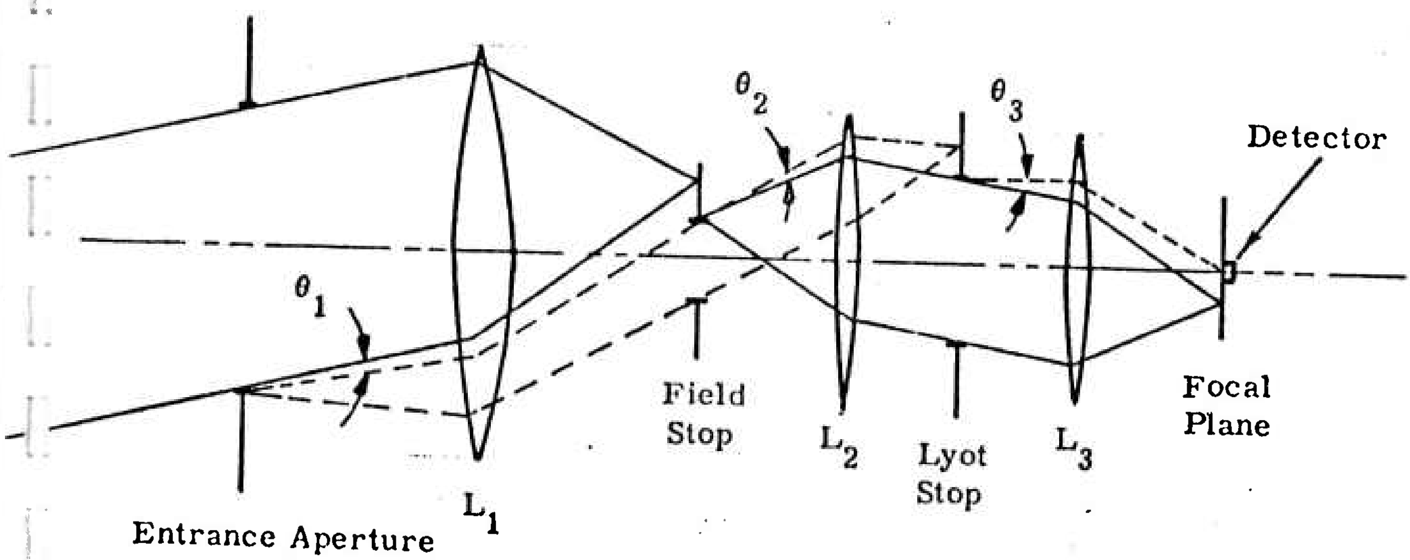


Figure 4-6. Triple Diffraction through a Re-imaging Telescope

$$BRDF_T = \frac{\lambda^3}{2^3 \pi^7 c\beta^2 a^2 \phi^3} \; F(c/a) \cdot F(\beta/\phi) \tag{4.16}$$

where

$$F(u) = \frac{1}{2} \left| \frac{1}{(1-u)^2} + \frac{1}{(1+u)^2} \right|$$

and λ = wavelength

a = radius of entrance aperture image at Lyot stop plane

c = Lyot stop radius

β = field stop radius (radians)

ϕ = source angular position (radians)

It is worth noting that the equation (4.16) can be written as the BRDF for single diffraction times a constant describing the attenuation resulting from the use of a Lyot stop. In this form, equation (4.16) becomes

$$BRDF_T = BRDF_S \; \frac{\lambda^2}{2^3 \pi^4 \beta^2 a^2} \cdot F\left(\frac{\beta}{\phi}\right) \cdot F\left(\frac{c}{a}\right) \quad \phi > \beta \tag{4.17}$$

The relationship shown in equation (4.17) above has the general shape shown in Figure 4-7. As the figure shows, there are three regions of interest in the above expression, as follows:

(a) If the source angular position is within the field stop, then the expression for single diffraction must be used, since single diffraction can reach the focal plane.

(b) If the source angular position is somewhat greater than the field stop, then the expression yields BRDF values that are in the transition region governed by the $F\left(\frac{\beta}{\phi}\right)$ term. In this region, the BRDF departs from the ϕ^{-3} law that holds for the other two regions.

(c) In the third region, the $F\left(\frac{\beta}{\phi}\right)$ transition term goes to its asymptotic value of unity, and the BRDF can be written as a function of the $F\left(\frac{c}{a}\right)$ term, which is a function of the c/a ratio of the system, as follows:

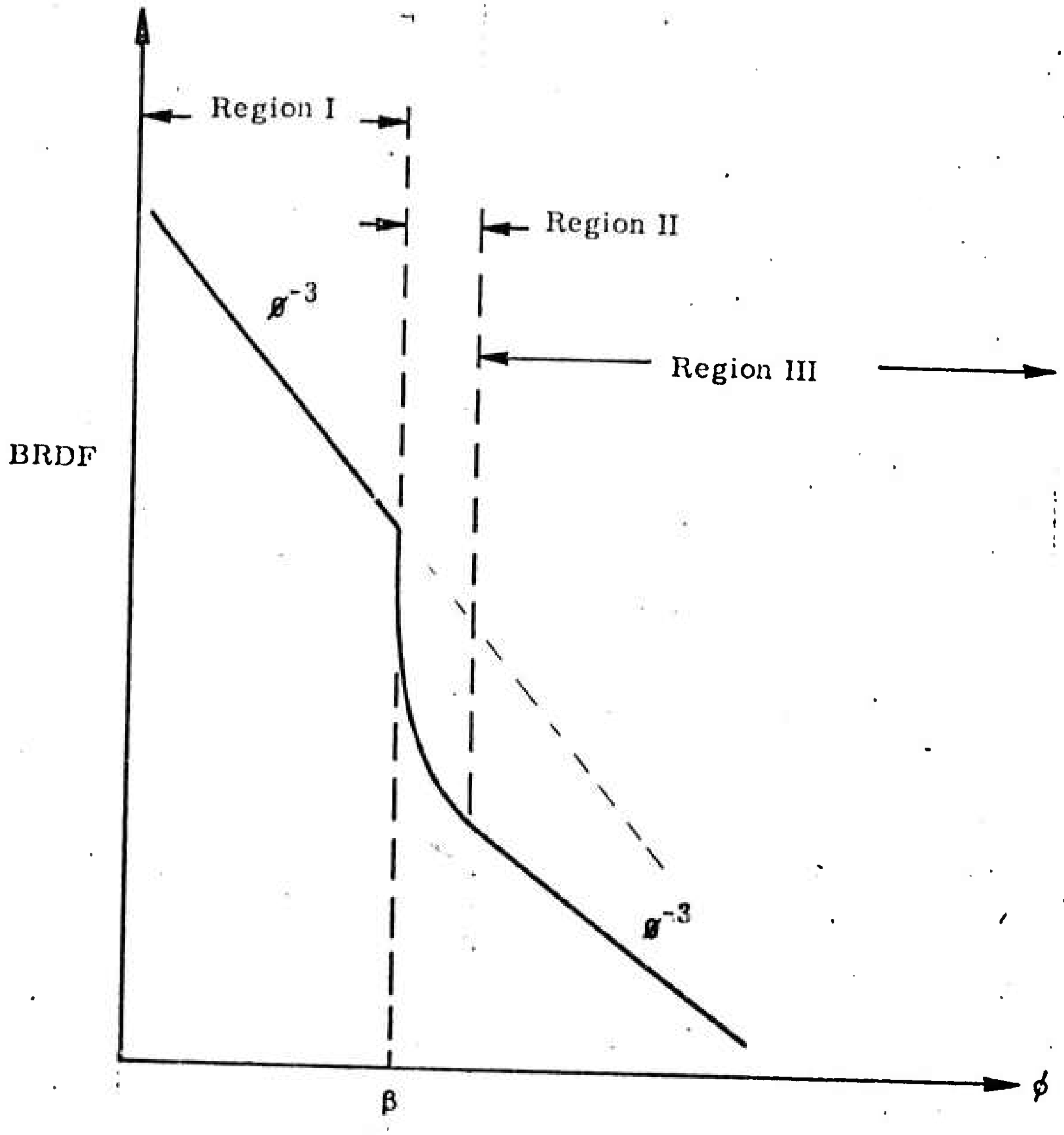


Figure 4-7. BRDF for Diffraction for System having Field Stop and Lyot Stop

4.3.7.2 BRDF for Triple Diffraction - Detector Off-Axis

For the on-axis case, the analysis of the diffraction is aided by the fact that the various paths of the diffracted energy from the entrance aperture to the focal plane lie on a plane containing the optical axis of the system. Equation (4.16) describing the net BRDF for the triple diffraction case, is derivable in the form shown only because of the **simplifications** permissible due to the fact that all the paths lie in a plane.

Once a detector is placed elsewhere in the focal plane, the geometry of diffraction becomes more difficult, and a computer solution to the problem of locating and evaluating the various paths to the detector becomes more practical than the derivation of a closed form expression; hence, the development of the GUERAP II computer program. Some results obtained with the diffraction portion of this program, for the case of a detector located off the optical axis, are included here.

Figure 4-8 illustrates a test case involving an off-axis detector that was evaluated using the computer program. The three arrows labeled A, B, and C indicate three directions in which a collimated source was used to compute the BRDF of the system, the results are plotted in Figure 4-9. The abscissa of Figure 4-9 is the angular separation between the source and the detector.

The test system parameters are as follows:

Entrance aperture	= 10.0 cm diameter
Field Stop	= 5.0° radius
c/a ratio	= 0.90
wavelength	= 10 microns

Figure 4-9 illustrates the expected anisotropic nature of the BRDF for a detector that is located off the optical axis - i.e., the BRDF curves for the three source tracks yield different values of the BRDF for the same displacement of the source from the detector position.

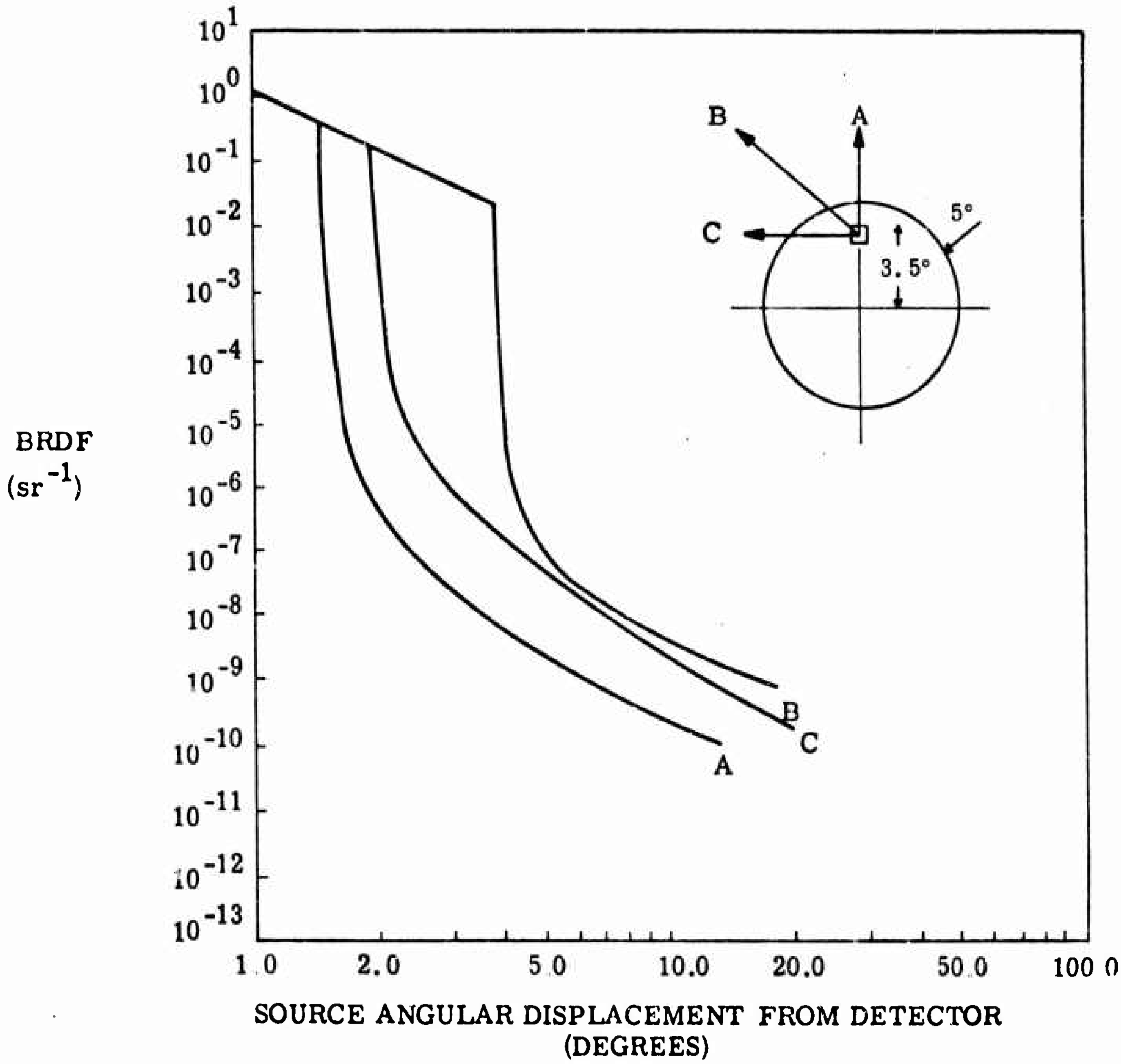


Figure 4-8. GUERAP II Triple Diffraction Analysis

SECTION V

PROGRAM EXECUTION

5.1 INTRODUCTION

The GUERAP-II program categorizes stray light terms according to whether the initial interaction with the system is diffuse scatter or diffraction. Diffuse terms are handled by first looking out from the detector and marking areas that can be seen. These areas are called (Level 1) critical areas. Then, the entrance aperture is filled with rays and any critical areas that are illuminated give rise to (single) diffuse scatter terms.

Similarly, by looking out from the Level 1 critical areas, Level 2 critical areas are marked. These Level 2 areas give rise to double diffuse scatter terms when they are illuminated. In principle, the method could be extended to any desired level, but the present implementation terminates at Level 2. Diffraction terms are computed by illuminating edges specified by the user and computing the diffracted energy reaching the detector by the methods described in Section III. Single, double, and triple diffraction terms can be handled as well as diffract-mirror diffuse terms.

One minor and three major main programs perform the computations described above. WRTABLE, the minor program, writes specular and diffuse BRDF tables described by the user onto a file for use with the other three programs, and is discussed in Section 5.2.1. TCRIT computes the critical areas and is described in Section 5.2.2. TDFUS, described in Section 5.2.3, computes diffuse terms using tables set up by TCRIT. Finally, diffraction terms are calculated by TDFR, which is discussed in Section 5.2.4. TDFR uses tables set up by TCRIT to compute diffract-mirror diffuse terms.

The normal procedure for doing an analysis is to generate the specular and diffuse reflectivity tables. Then a Level 1 critical analysis is performed and the critical tables are written on file. The Level 1 diffuse terms are computed next, which also causes the illuminated surfaces to be marked. Now, the critical program can be run again to compute the Level 2 view factor terms, after which the diffuse program can calculate the Level 2 diffuse terms. At any point after the Level 1 critical surfaces have been determined, a complete diffraction analysis, including pure single, double, and triple diffraction as well as diffract-mirror diffuse terms, can be accomplished.

Figure 5-1 is a block diagram which illustrates the above procedure.

Breaking up the analysis into four separate programs provides several advantages when running the program. Input errors, or possibly even design errors, may show up as early as the Level 1 critical analysis stage. Errors can be corrected at this stage (and subsequent stages) instead of running through a now useless analysis, thereby saving computer time. Also, since the critical tables do not depend on the source angle, a few source angles can be run first, then more can be run without redoing the critical analysis. Also, an examination of the critical tables themselves may show a problem for certain source angles that otherwise would not be tried.

5.2 SUGGESTED PROGRAM EXECUTION PROCEDURE

Details concerning the running of each program are provided in the following paragraphs.

5.2.1 Generating Reflectivity Tables

The reflectivity tables used in GUERAP-II are functions of two angles: the angle of incidence and the angle between the desired direction and the direction of specular reflectance, called the scatter angle. The tables are ordered first with respect to angle of incidence, then with respect to the scatter angle. For each angle of incidence, we have first the specular reflectivity at that angle, then a set of scatter angles and their associated BRDF

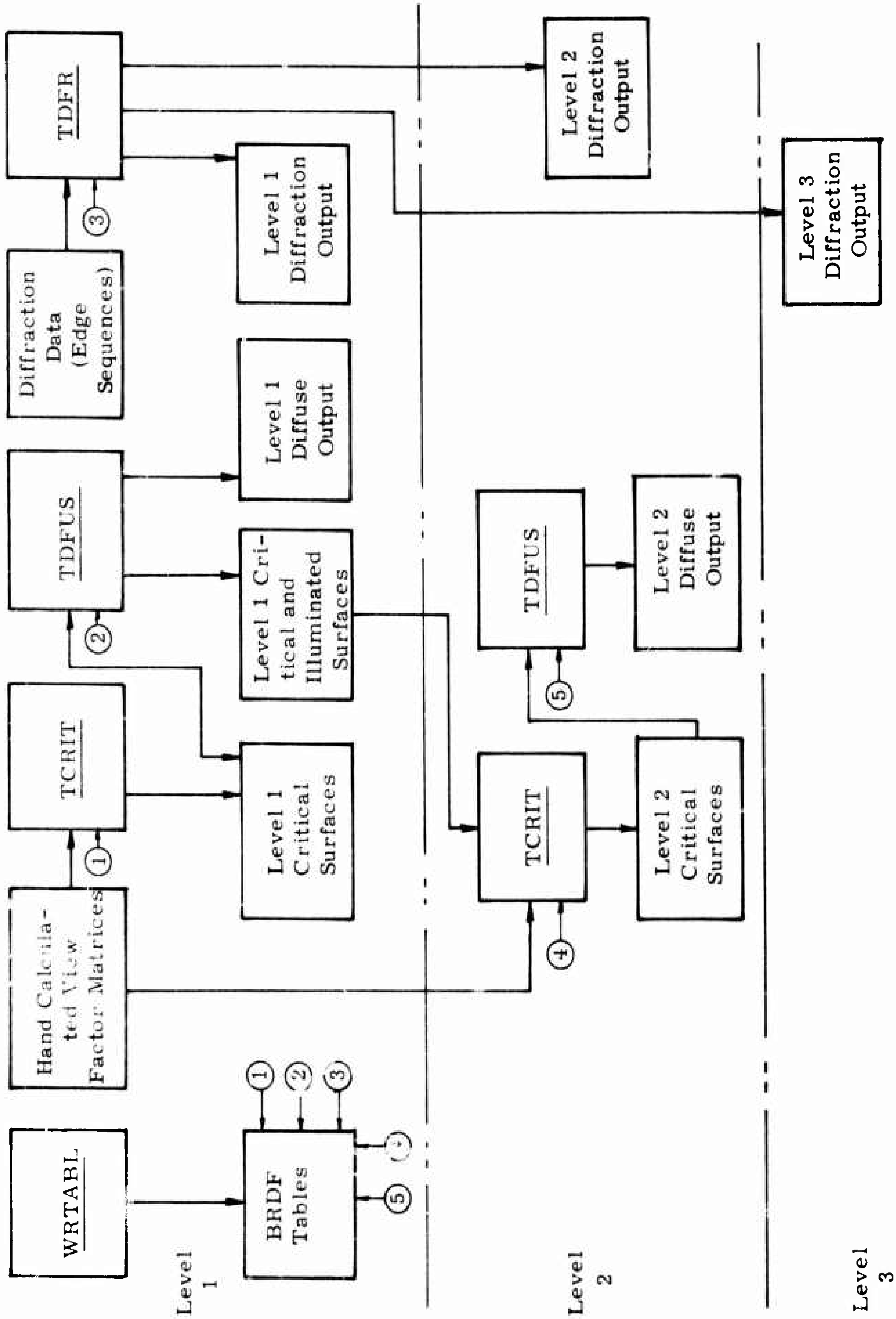


Figure 5-1. GUERAP II Block Diagram

values. The program assumes a step-function with the constant value holding between the previous angle and the angle given.

Table values are entered as data to the program WRTABL. (Refer to Section 6.2.18 for details of how the tables are to be entered.) This program writes out, on FORTRAN units 1 and 2, the specular reflectivity and diffuse BRDF tables, respectively. These tables are then read back in and used by the other GUERAP programs.

Figure 5-2 shows the arrangement of a typical BRDF table.

5.2.2 Generating Critical and View Factor Tables

The GUERAP-II program calculates first-order diffuse stray radiation terms by computing and marking all areas, called critical areas, that can be seen by a detector, either directly or specularly off one or more mirrors. Higher-order terms are calculated similarly, with lower-order critical areas playing the role of a detector. Three matrices input by the user guide the TCRIT program in finding these critical areas. These matrices, called the hand-calculated view factor matrices, consist of an aperture-to-aperture matrix, and aperture-to-section matrix, and a section-to-section matrix. The first two matrices are used to compute all mirror paths to the critical areas, while the third matrix is used to compute the direct paths.

The user begins by selecting a subset of the apertures in the system, called the set of critical apertures. These critical apertures describe how the imaging rays get through the system. The set of critical apertures must include the limiting aperture for each mirror in the system. In addition, each aperture that limits or obscures what one mirror can see of another must also be included in the set of critical apertures. Thus, in a typical system, the critical apertures include field stops, Lyot stops, and obscuring apertures, if any or all of these exist in the system. Once the critical apertures have been selected, they are described to the system by two parameters: the ordinary aperture number, and the mirror number of the associated mirror (0 if there is no associated mirror, as in the case of a field stop, etc.).

ANGLE OF INCIDENCE	SPECULAR REFLECTIVITY COEFFICIENT	SCATTER ANGLE	BRDF	SCATTER ANGLE	BRDF	SCATTER ANGLE	BRDF	SCATTER ANGLE	BRDF	SCATTER ANGLE	BRDF
1°	0.03	10°	0.1	180°	0.05						
2°	0.04	5°	0.1	20°	0.05	180°	0.02				
5°	0.05	4°	0.15	15°	0.1	40°	0.05	180°	0.03		
10°	0.07	3°	0.18	10°	0.12	30°	0.08	180°	0.04		
20°	0.1	3°	0.23	7°	0.15	23°	0.09	180°	0.05		
90°	0.4	2°	0.5	5°	0.25	15°	0.15	30°	0.09	180°	0.05

Figure 5-2. BRDF Table Example

The next step is to construct the aperture-to-aperture matrix. This matrix describes which critical apertures see which other critical apertures. A critical aperture is said to see another critical aperture if, and only if, a direct path <u>through no intervening critical aperture</u> exists. The user is never required to specify mirror paths, because mirror apertures must be critical apertures. By definition, critical apertures do not see themselves.

To complete the description of possible mirror paths, the aperture-to-section matrix is specified next. This matrix describes which critical apertures directly see which sections. If there is an aperture that limits or partially obscures this view, it is also specified. (If there is more than one such aperture, the most appropriate one is chosen.)

The program builds a list of trial mirror paths as follows: (It is assumed that the starting point for all paths is in section A, while the target surface is in section B.)

(a) The aperture-to-section matrix is checked for the next critical aperture seen from section A. This critical aperture is placed first on the critical aperture sequence. When there are no more critical apertures, the list is complete.

(b) The aperture-to-section matrix is checked to see whether section B sees the last critical aperture in the sequence. If so, the sequence is added to the list.

(c) Regardless of the outcome of step (b), the aperture-to-aperture matrix is checked in order to find out whether the last critical aperture sees any other critical aperture not yet checked and <u>not already in the present aperture sequence.</u> (The above restriction is invoked to prevent the generation of an infinite number of possible paths, and requires care (and possible trickery) in the choice of critical apertures, as no critical aperture is allowed to appear more than once on any given mirror path.) If there is another aperture, it is added to the sequence and then step (b) is repeated.

(d) Otherwise the last aperture on the sequence is deleted. If there still is an aperture in the sequence, step (c) is repeated. Otherwise step (a) is repeated.

Differential ray trace techniques (described in Section III) are then used to check these potential paths to find out whether any other paths actually exist in the system.

Finally, to allow the computation of direct paths, the section-to section matrix is specified. This matrix describes which sections can directly see which other sections (limiting or obscuring apertures are also specified as in the aperture-to-section matrix described above). Unlike the critical apertures, sections can always see themselves. These paths are then checked by the differential ray trace method.

Thus, by simply stating the direct paths possible in the system, the program is able to pick out the direct and mirror paths that actually exist in an optical system.

There are two possible modes of operation to consider when running the TCRIT program. The first mode generates a new Level 1 table. No previous critical tables are required, and the new table will be output (in binary format) on FORTRAN unit 12. The second mode uses a previously generated critical (Level 1) table as well as illumination information generated during a Level 1 TDFUS run (paragraph 5.2.3) to generate a new set of Level 2 view factors. Note that Level 2 terms are only computed from critical surfaces of Level 1 to illuminated surfaces, thus saving computer time and storage. This can be done because only illuminated Level 2 surfaces can give rise to double diffuse terms. For the Level 2 case, the previous critical and illumination tables are read in on FORTRAN unit 11 and new tables are output on FORTRAN unit 12. Data input details are given in Section VI. Note that the data in paragraph 6.2.14 are an exception to this case; BRDF data are read in on FORTRAN units 1 and 2.

5.2.3 Computing Diffuse Terms

Once the critical and view factor tables of the appropriate level have been computed, the calculation of diffuse terms becomes straightforward.

The critical and view factor tables are read in on FORTRAN unit 11; the diffuse analysis is performed for the set of input angles; and, if desired, the critical, view factor, and illumination tables are written out on FORTRAN unit 12. This method of operation means that the user can run a diffuse analysis for only a few source angles, look at the data, and then run new source angles without re-computing the critical and view factor tables.

Data input details are given in Section VI. BRDF data files are read in on FORTRAN units 1 and 2.

5.2.4 Computing Diffraction Terms

In computing diffraction terms, unlike the diffuse case, the user must specify the edge sequences at which the program is to look. The user begins by specifying the number of edges at each of Levels 1, 2 and 3. If the user specifies I edges at Level 1, J edges at Level 2 and K edges at Level 3, then the first (I) edges specified are Level 1 edges, the next (J) are Level 2 and the last (K) are Level 3 edges. An edge is specified by giving its aperture or baffle number, the number of aperture or aperture-mirror pairs between that edge and its destination (the detector plane for a Level 1 edge, or a Level n-1 edge for a Level n edge), the section number of the edge if it is illuminated (otherwise 0), and its destination edge number if the edge is Level 2 or higher (the destination edge number is the position of that destination edge which has been previously defined in this list). Aperture and aperture-mirror pair sequences are defined as in the critical aperture sequences. Note that the level of an edge is the number of diffractions that occur, starting at the edge and reaching the detector.

Level 2 diffraction terms include both double diffraction and diffraction-mirror diffuse terms. Therefore, is is necessary to have previously run a critical analysis of the system, and to read the critical tables in through FORTRAN unit 11. (BRDF tables must also be read in on units 1 and 2.)

Data input details are given in Section VI. Paragraph 6.2.14 describes the special diffraction input data described above. Note that this data is read in on FORTRAN unit 3.

5.3 PROGRAM OUTPUT REPORTS

There are four input and output reports which can be generated by the GUERAP II program. The selection of the reports to be generated for any given run is specified by the input parameter INMOD.

5.3.1 Input Report

The report is used by the program user to verify the correctness of the information given to the program on the data cards. For each of the input data cards, the program first prints a line indicating what information was expected on the succeeding card, followed by a line giving the actual data that was read in on that card. An example of this report is shown in Section II of Appendices I and II.

5.3.2 Optical Form Report

The optical form report is a summary of the information given by the input data describing the physical system. This report is used primarily for a quick check to describe the system that was analyzed and also for insertion in reports for future reference. The optical form report was designed to be easily readable by people unfamiliar with the specific operation of the program and the parameters needed by it. An example of the optical form report for the Baffle II system is given in Figure 5-1.

The following is an explanation of the various parts of this report. Cross referencing is used in various cases to assist the readers in understanding the details of the entered system.

5.3.2.1 Coordinate Systems

Coordinate systems are specified by the user in terms of a translation and rotation from any previously defined coordinate system. In this output section, all coordinate systems are expressed as a translation and rotation from coordinate system 1. In all succeeding output, all coordinate systems are treated as a rotation from coordinate system 1 (i.e., the coordinate systems are translated back to the origin of coordinate system 1).

5.3.2.2 Sections

The first parameter given for each section is the type. The section type is given by the specific type used in the input data. A value of 0-99 represents a standard baffled section; 100-199 represents an end section, 200-299 represents a concave mirror, and 300-399 represents a convex mirror. The values for Z1 and Z2 represent the Z coordinates of center of the aperture which defines the ends of the section. In sections that contain an unobscurred concave mirror at one end, there are not two ends. In these cases, a value of 0.0 is given for the Z-value. The section axis number refers to the coordinate system which is the axis for that section. The values of Z1 and Z2 given are with respect to the section axis. The section contents gives the numbers of the specific mirrors, apertures, and tubes which define that section.

5.3.2.3 Mirrors

Each mirror is described here. The column labeled section refers to the section in which the mirror is located. The aperture numbers give the numbers of the apertures that define each of the mirrors. In the case of a convex mirror two apertures are necessary; one behind the mirror to cut off the section of the sphere to be used, and a second one in front of the mirror to define from what points in space the mirror may be seen. The mirror type is +1 for a concave spherical mirror, and -1 for a convex one.

The aperture numbers are followed by the mirror center of curvature and the vertex of the mirror. The mirror axis is the number of the coordinate system which serves as the axis of the mirror. The mirror dimensions are the radii of curvature of the mirrors.

5.3.2.4 Apertures

The aperture data given are the numbers of the two sections which this aperture separates; next is the aperture type which, like the mirror type, defines the geometric shape. The geometric shapes for the apertures are defined in Section 6.2.8. The z-axis position gives the z-coordinate in the system given as the aperture axis. The dimensions of the aperture are those measured along the X and Y axes.

5.3.2.5 Tubes

The tube type gives the shape of the tube and follows the same codes as those for apertures, while Z1 and Z2 give the Z-coordinates of the centers of the tube at its extreme ends. The coordinate system to which all measurements and coordinates refer is given by the tube axis. The real tube dimensions refer to those along the X and Y axes of the physical tube. When the tube has baffles, an imaginary tube is specified with dimensions given that describe the exposed baffle edges.

The number of the baffle group which is contained in the tube is the last parameter given.

5.3.2.6 Baffle Groups

The baffle group gives the section in which this group is contained, followed by the baffle type which gives the shape made by the exposed baffle edges. This follows the key to the shapes which has already been given in the previous paragraphs; Z1 and Z2 give the Z-coordinates of the first and last baffle in the plane of their exposed edges. The number of baffles in this baffle group is the final figure.

5.3.2.7 Baffle Group Summary

Since so much data is involved in describing the baffles, a further section of the report gives more complete information about each of the baffle groups mentioned in the previous paragraph.

For this report, specific information is given for each baffle according to baffle groups. The first parameter is the type which refers to the shape of the baffle. The Z value given is the Z coordinate at the exposed baffle along the X and Y axes.

5.3.3 Final Report

5.3.3.1 Unwanted Energy Summary

In this report (IOPTN=1 or IOPTN=3) a separate report is generated for each source and detector specified in the input data. Values are given for the specular throughput of the system analyzed. In addition, if the user specified that the program calculate baffle diffraction, baffle diffuse, baffle specular or baffle diffuse terms, then values are given for them. Additionally, a composite value for all the terms plus the value for the total system has two values from this report; one value for the system BRDF, and a second value for the Point Source Rejection Ratio.

5.3.3.2 Specular Irradiance Matrix (Detector Plane Report)

This report is selected by giving a value of 2 or 3 to IOPTN. The values printed out represent the specular throughput to each bin of the detector plane. The bins are printed out in 8 columns, column 1 containing the energy for bins 1 to nbins, column 2 having the values for bins nbins + 1 to nbins + nbins, etc. This information is followed by the assumed detector subtense and other information that was included at the end of the Unwanted Energy Summary.

5.3.4 Hand Calculated View Factor Report

The report generated by subroutine OHCVF gives a printout of the three view factor matrices. A 1 in the matrix indicates that some portions of the two surfaces in question can probably see each other. A negative number indicates that the view is limited by an intermediate aperture. The three view factor matrices are the critical aperture-to-critical aperture matrix, the critical aperture-to-section matrix, and the section-to-section matrix. Also given is a table of the critical apertures and the numbers of the mirrors associated with these apertures to identify which critical apertures correspond to which of the actual system apertures.

5.3.5 Incoming Ray and Detector Plane Report

The report, generated by subroutine ORAYS, gives a summary of the source data and detector data that were input. The source is identified as one of the eight possible source types. For the first four source types, values are given for the radii of the inner and outer concentric circles and for the initial and final values of the angle THETA to define the area of the entrance aperture from which rays are to be traced. Also values are given for the number of concentric circles to be used and the number of angle divisions to define the density and starting positions for the incoming rays.

For the second four source types where a hexagonal grid is used instead of concentric circles, values are given for the minimum and maximum values on the X and Y axes to define the position of the grid of incoming rays in the entrance aperture, and the number of X and Y increments gives the density and position of the incoming rays on the grid. Since this source type uses differentials the input values for the maximum recursion level and fractional covering are given.

The input value of the source position is given for the finite conjugate cases. And, finally, for all eight types of source the attenuation cut-off value is reported.

The detector position is given by the number of the aperture which defines the detector plane, the X, Y, and Z coordinates of the center of the detector plane, and the coordinate system in which those coordinates lie. The detector plane is a grid with detectors at various positions on that grid. Values are given for the size of the whole grid and for the size of a small division on the grid. Also given are the X and Y coordinates for the positions of the detectors and the detector angular subtense.

5.3.6 Critical Surface Report

The report generated by OCRIT gives a summary of data identifying the critical surfaces (those surfaces which can see the detector directly or by interactions only with mirrors).*

If there are any critical areas on the tubes then the information reported for them is: the number of the system tube containing the critical area, the solid angle from the critical area on the tube wall to the detector plane, and the X or Y and Z coordinates of four points which define or place the critical area. For apertures the data given is the number of the aperture, the side of the aperture on which the critical area lies (1 = top, 2 = bottom), the solid angle the detector makes with the critical area,** and the X and Y

*These are actually Level 1 critical surfaces. Level 2 critical surfaces are those that see Level 1 surfaces.

**If the critical surface cannot see the mirror directly or specularly off mirrors, i.e., it is a Level 2 or higher critical surface, the solid angle is weighted by the solid angle to the critical area seen, times the BRDF of the diffuse interaction at that intermediate surface.

coordinates of three points in the critical area to mark the placement of the area. Similarly baffles which are critical are identified with the number of the baffle group, the number of the specific baffle unit in that group (where a baffle unit is a three-sided enclosure comprised of the upper side of the bottom baffle, the lower side of the top baffle, and the wall joining the two baffles). The unit number is the baffle number of the top baffle. The side indicates on which part of the unit the critical area lies, next is given the solid angle to the detector, and the X and Y coordinates of three points in the critical area.

Lastly the sizes of the critical tables and the execution time for this run are given.

SECTION VI

DATA ENTRY

6.1 INPUT DATA SUMMARY

In this section, the detailed input data format is called out for all of the data that is required by the GUERAP II computer program. Table 6-I is a compilation of all of the required data by type, and contains cross references to the appropriate subparagraph of Section 6.2 that contains the detailed input data definition and format required.

NOTE

The GUERAP II computer program, as presently configured, is executable in three separate modes; diffuse and diffract calculation modes, and BRDF table generation mode. (Refer to Section V for details.) The input data required for each of these modes is somewhat different, as listed below:

Program mode	Input data required
Diffuse analysis	1.0 Run data
	2.0 Optical form data
	3.0 Materials data
	4.0 Hand calculated view factors
	6.0 Computation level
	7.0 Redefined baffle data (optional)
Diffract mode	1.0 Run data
	2.0 Optical form data
	3.0 Materials data
	4.0 Hand calculated view factors
	5.0 Diffraction data
	6.0 Computation
	7.0 Redefined baffle data (optional)
BRDF Table Generation	8.0 BRDF Table Generation

TABLE 6-I. GUERAP INPUT DATA

1.0 RUN DATA			
1.1 INPUT/OUTPUT CONTROL	1.1.1	Input Unit No., Output Modes	6.2.1
	1.1.2	System Title	6.2.2
	1.1.3	Run Type and Desired Scattered Light Subsets	6.2.3
1.2 SOURCE DATA	1.2.1	Source Type	6.2.4
	1.2.2	Entrance Aperture Coverage, and Source Angles	
	1.2.3	Specular Cut-off, Number of Differential Iterations, Area Threshold	
1.3 DETECTOR DATA	1.3.1	Number of Detectors, and Detector Plane Axis	6.2.5
	1.3.2	Position of Detector Plane	
	1.3.3	Position of Each Detector	
	1.3.4	Subdivision of Detector Plane for Specular Irradiance Analysis	
	1.3.5	Detector Area, and System EFL	
2.0 OPTICAL FORM DATA			
2.1 COORDINATE SYSTEMS	2.1.1	Number of Coordinate Systems	6.2.6
	2.1.2	For Each Coordinate System, Enter:	
	2.1.2.1	Reference Axis Number of Reference Coordinate System	
	2.1.2.2	XYZ Coordinate of Origin	
	2.1.2.3	Euler Angles for Axis of New Coordinate System	
2.2 MIRRORS	2.2.1	Number of Mirrors	6.2.7
	2.2.2	For Each Mirror, Enter:	
	2.2.2.1	Number of Coordinate System that Defines Axis and that which Defines Center	
	2.2.2.2	Mirror Type and Center of Curvature Coordinates	
	2.2.2.3	BRDF Type and Scale Factor	
2.3 APERTURES	2.3.1	Number of Apertures	6.2.8
	2.3.2	For Each Aperture Enter:	
	2.3.2.1	Aperture Type (Circular, etc...)	
	2.3.2.2	Upper and Lower Section Numbers	
	2.3.2.3	Coordinate Systems Defining Axis and/or Center	
	2.3.2.4	XYZ Coordinates of Center	
	2.3.2.5	Aperture Radii Data	
	2.3.2.6	BRDF Type and Scale Factor	
2.4 TUBES	2.4.1	Number of Tubes	6.2.9
	2.4.2	For Each Tube, Enter	
	2.4.2.1	Tube Type (Circular, etc...)	
	2.4.2.2	Number and Type of Baffles Contained	
	2.4.2.3	Coordinate Systems Defining Axial and/or Center	
	2.4.2.4	XYZ Coordinates of Tube Center	
	2.4.2.5	Tube Radii Data, Tube Angle Data	
	2.4.2.6	BRDF Type and Scale Factor	

TABLE 6-I. GUERAP INPUT DATA (Continued)

2.5 STANDARD BAFFLE DATA	2.5.1 Number of Standard Baffles	6.2.9.1
	2.5.2 For each Standard Baffle, enter:	
	2.5.2.1 Type of Baffle	
	2.5.2.2 Z Coordinate of Intersection with Imaginary Tube	
	2.5.2.3 Slopes of Each Baffle	
	2.5.2.4 Number of Tube Containing Baffle - Numbers of Upper and Lower Apertures	
2.6 SECTIONS	2.6.1 Number of Sections	6.2.10
	2.6.2 For each Section, enter:	
	2.6.2.1 Type of Section (Standard Baffle, etc...)	
	2.6.2.2 Number of Tube containing Section	
	2.6.2.3 Upper and Lower Aperture Numbers	
	2.6.2.4 Holes and Wild Card Baffles	
2.7 WILD CARD BAFFLES	2.7.1 Number of Wild Cards	6.2.11
	2.7.2 For each Wild Card, enter:	
	2.7.2.1 Section Number and Wild Card Baffle Numbers	
	2.7.2.2 Z Axis Position and Baffle Type	
3.0 MATERIALS DATA		
3.1 MIRROR BRDF DATA	3.1.1 Number of BRDF Types	6.2.12
	3.1.2 For each type enter BRDF Data	
3.2 BAFFLE BRDF DATA	3.2.1 Number of BRDF Types	
	3.2.2 For each type enter BRDF Data	
4.0 HAND CALCULATED VIEW FACTOR MATRICES		
4.1 CRITICAL APERTURES	4.1.1 Number of Critical Apertures	6.2.13
	4.1.2 For each Critical Aperture, enter:	
	4.1.2.1 Number of System Aperture Corresponding to Critical Aperture Number	
	4.1.2.2 Number of Mirror that Aperture defines	
4.2 MATRICES	4.2.1 Numbers of Critical Apertures that can be seen by any Critical Aperture	
	4.2.2 Numbers of System Sections that can be seen by any Critical Aperture	
	4.2.3 Numbers of System Sections that can be seen by any System Section	
5.0 DIFFRACTION DATA		
5.1 GENERAL	5.1.1 Wavelength	6.2.14
	5.1.2 Number of points around edges	
5.2 CRITICAL EDGES	5.2.1 Number of Critical Edges at each Level	
	5.2.2 If edge is Aperture, input Aperture Number	
	5.2.3 If edge is baffle, enter Tube, Section, and Baffle Number	
	5.3.1 Number of Apertures in sequence to next edge or detector	
	5.3.2 Aperture Number and, if applicable, Mirror Number	

TABLE 6-I. GUERAP INPUT DATA (Continued)

6.0 COMPUTATION LEVEL		
6.1 LIMITS	6.1.1 Minimum Stray Light Level	
	6.1.2 Maximum Stray Light Level	
6.2 CRITICAL TABLES	6.2.1 Restore Previous Critical Tables?	
	6.2.2 Save New Critical Tables?	
7.0 REDEFINED BAFFLE SYSTEM DESIGN DATA		
7.1 SUMMARY	7.1.1 List of redefined Options wanted	6.2.17
7.2 MIRRORS	7.2.1 Number of Mirrors to be redefined	
	7.2.2 For each Mirror, give:	
	7.2.2.1 Mirror Number	
	7.2.2.2 Mirror Type and Dimensions	
	7.2.2.3 BRDF Type and Scale Factor	
7.3 APERTURES	7.3.1 Number of Apertures to be redefined	
	7.3.2 For each Aperture, give:	
	7.3.2.1 Aperture Number and Section Numbers	
	7.3.2.2 Aperture Type and Dimensions	
7.4 TUBES	7.4.1 Number of Tubes to be redefined	
	7.4.2 For each Tube, give:	
	7.4.2.1 Tube Number	
	7.4.2.2 Tube Type and Dimensions	
	7.4.2.3 BRDF Type and Scale Factor	
7.5 STANDARD BAFFLE DATA	7.5.1 Number of Standard Baffle to be redefined	
	7.5.2 For each Standard Baffle, give:	
	7.5.2.1 Standard Baffle Number and Tube Number	
	7.5.2.2 Type of Standard Baffle	
	7.5.2.3 BRDF Type and Scale Factor	
7.6 WILD CARD BAFFLES	7.6.1 Number of Wild Card Baffles to be redefined	
	7.6.2 For each Wild Card Baffle, give:	
	7.6.2.1 Number of Wild Card Baffle and Section Number	
	7.6.2.2 Type of Wild Card Baffle	
	7.6.2.3 BRDF Type and Scale Factor	
7.7 SECTIONS	7.7.1 Number of Sections to be redefined	
	7.7.2 For each Section, give:	
	7.7.2.1 Number of Section and Tube Number	
	7.7.2.2 Type of Section	
8.0 GENERATE BRDF TABLES		6.2.18

6.2 INPUT DATA FORMAT

6.2.1 Output Options

NOTE

Card 1 below is read in on FORTRAN unit 5. Subsequent cards, up to (but not including) section 6.2.14, are read in on the FORTRAN unit number specified in the first parameter below (KIN). Section 6.2.14 is read in on FORTRAN unit 3, sections 6.2.15 - 6.2.17 are read in on FORTRAN unit 5.

Card 1 Format = 3I6

(1)	KIN	= FORTRAN input unit number.
(2)	MODE	= 0 No ray trace diagnostic printout.
		= 1 Ray trace printout for trial and actual intersections.
		= -1 Ray trace printout for actual intersections only.

NOTE

A value of MODE = 0 is normally used.

(3)	MODIPR	= -2 No output.
		= -1 Optical form reports and final report.
		= 0 Optical form reports, final report, and input report.
(4)	MODOPR	= 0 No additional output.
		= 1 Detector plane report.

NOTE

Normal practice is to set MODIPR = 0 for the first run, to ensure that the input data has been entered as desired. Subsequently a value of MODIPR = -1 would be used. A value of MODIPR = 1 will produce a report showing the origin of all terms that get to the detector plane. A large quantity of output is likely to be produced in this case unless great care is taken with other input parameters.

Details of these reports are given in section 5.2.

6.2.2 System Title

Card 1 Format = 10A4

(1) ITITLE = System name

6.2.3 User Options

Card 1 Format = 6I6

(1)	IDIFFR	= 0 Do not perform baffle diffraction calculations.
		= 1 Perform baffle diffraction calculations.
(2)	IBSPEC	= 0 Do not perform baffle specular calculations.
		= 1 Perform baffle specular calculations.
(3)	IBDIFF	= 0 Do not perform baffle diffuse calculations.
		= 1 Perform baffle diffuse calculations.
(4)	IMSPEC	= 0 Do not perform mirror specular calculations.
		= 1 Perform mirror specular calculations.
(5)	IMDIFF	= 0 Do not perform mirror diffuse calculations.
		= 1 Perform mirror diffuse calculations.
(6)	IOPTN	= 1 Printout the scattered light subset report.
		= 2 Printout specular irradiance matrix.
		= 3 Printout both scattered light subset and specular irradiance reports.

NOTE

The IOPTN parameter allows the user to select the form of the final report he desires. A value of IOPTN = 1 is normal. These reports are described in section 5.2.3.

6.2.4 Source Data

The angular position of a source (and thus the direction(s) of entering rays) may be described to the program in either one of two distinct ways. Both methods describe, in terms of the standard coordinate system, the position of the center of the entrance aperture as seen from the source.

The first way describes the position of the entrance aperture in terms of angular cartesian coordinates. These coordinates are simply the arctangents of the ratios of the x direction cosine over the z direction cosine and the y direction cosine over the z direction cosine of the incoming ray, respectively. Thus, if C, D, E, are the x, y, z direction cosines, then ALPHA = arctan (C/E) and BETA = arctan (D/E). This is the usual way of specifying those angles to the program. See Figure 6-1.

An alternate way of specifying the source angles is in terms of elevation and azimuth. In this method, ALPHA is the angle between the incoming ray and the z-axis, while BETA is the angle the projection of the ray on the x-y plane makes with the x-axis. To specify this second method, the input variable INMOD should have a negative sign. See Figure 6-2.

NOTE

If the INMOD value given below is positive, the source angles ALPHA and BETA are angular cartesian coordinates. A negative value of INMOD indicates that ALPHA and BETA are elevation and azimuth source angles.

Card 1 Format = I6

(1)	INMOD	= 1 Diffuse light source, concentric circles of rays fill the aperture, no differentials.
		= 2 Collimated light (point source at infinity), concentric circle of rays fill the aperture, no differentials.
		= 3 Point source at a finite distance, concentric circle of rays fill the aperture, no differentials.
		= 4 Collimated light, rectangular grid, no differentials.
		= 5 Diffuse light source, hexagonal grid of rays fill the aperture, with differentials.
		= 6 Collimated light (point source at infinity) hexagonal grid of rays fill the aperture, with differentials.
		= 7 Point source at a finite distance, hexagonal grid of rays fill the aperture, with differentials.
		= 8 Collimated light, rectangular grid, with differentials.

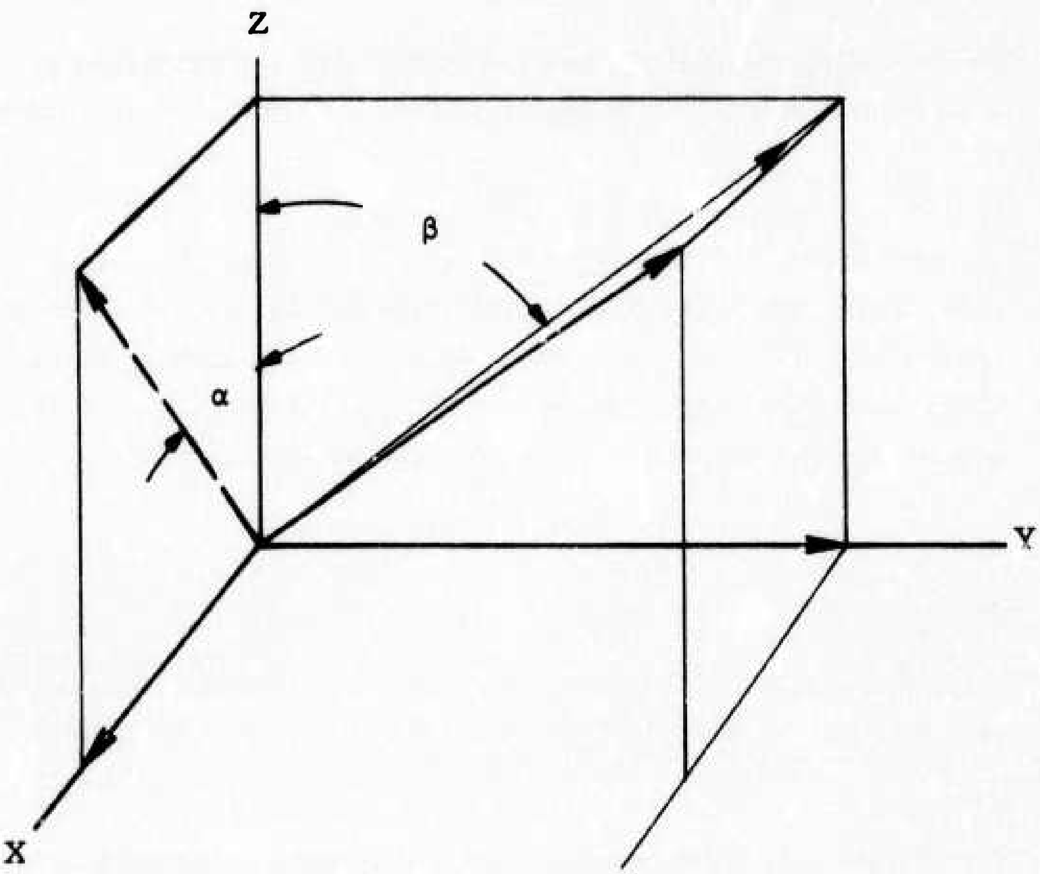


Figure 6-1. Angular Cartesian Coordinates

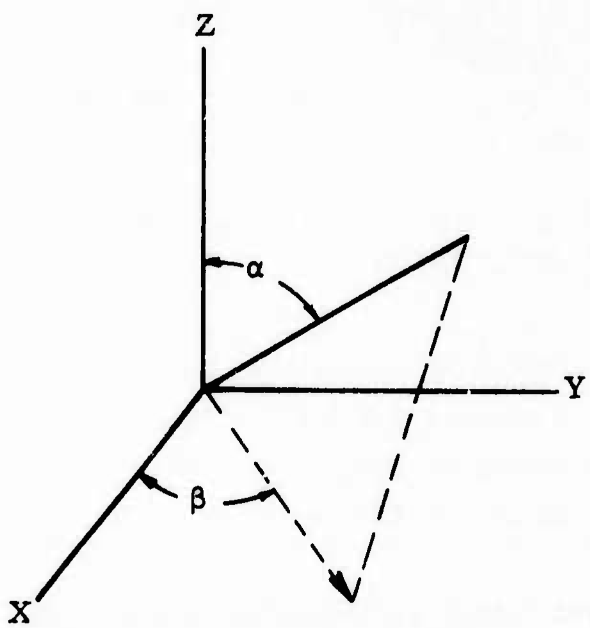


Figure 6-2. Elevation and Azimuth

NOTE

The remaining source data cards depend on the specification of a concentric circle or hexagonal grid of incident rays as follows.

NOTE

In cards 2 and 3 below (RMIN, RMAX, THETA1, THETA2, N, NN) or (XST, XFIN, YST, YFIN, N, NN) define the portion of the aperture to be filled with rays from each source; ALPHA1, ALPHA2, BETA1, BETA2, NNN, NNNN define the number and angular positions of each of the sources; the total number of sources is found as*:

N sources = NNN * NNNN

6.2.4.1 Concentric Circles (INMOD = 1, 2 or 3) See Figure 6-3.

Card 2 Format = 8F10.5

(1)	RMIN	= Radius of innermost concentric circle of rays in entrance aperture.
(2)	RMAX	= Radius of outermost concentric circle.
(3)	THETA1	= First angular polar coordinate describing sector of aperture to be filled with rays (in degrees).
(4)	THETA2	= Second value of angle THETA, in degrees.
(5)	ALPHA1	= Initial value of source position angle ALPHA, in degrees.
(6)	ALPHA2	= Final value of ALPHA, in degrees.
(7)	BETA1	= Initial value of the source position angle BETA, in degrees
(8)	BETA2	= Final value of the angle BETA, in degrees.

Card 3 Format = 4I6

(1)	N	= Number of R positions.
(2)	NN	= Number of THETA positions.
(3)	NNN	= Number of ALPHA positions.
(4)	NNNN	= Number of BETA positions.

*One exception: if (ALPHA, BETA) are elevation and azimuth (negative INMOD), and one value of ALPHA1 = 0., then:

Nsources = (NNN-1) * NNNN + 1

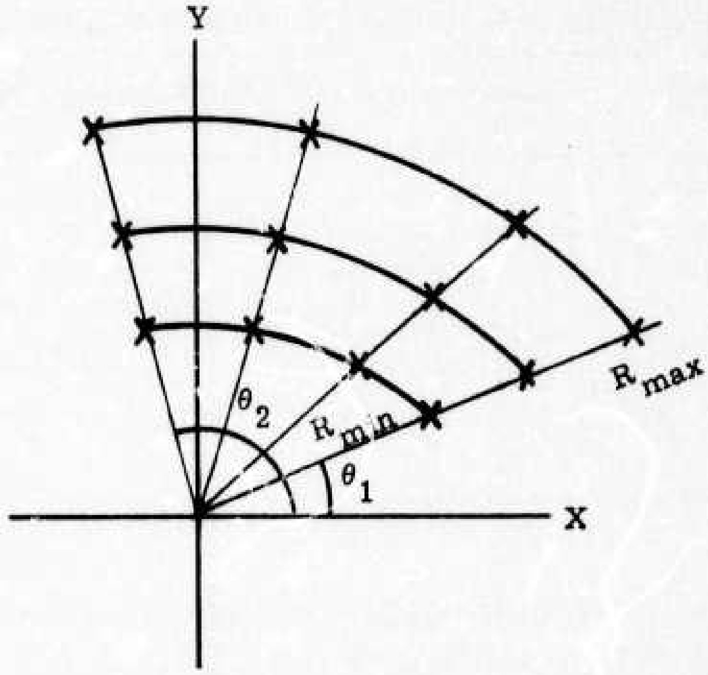


Figure 6-3. Concentric Circles

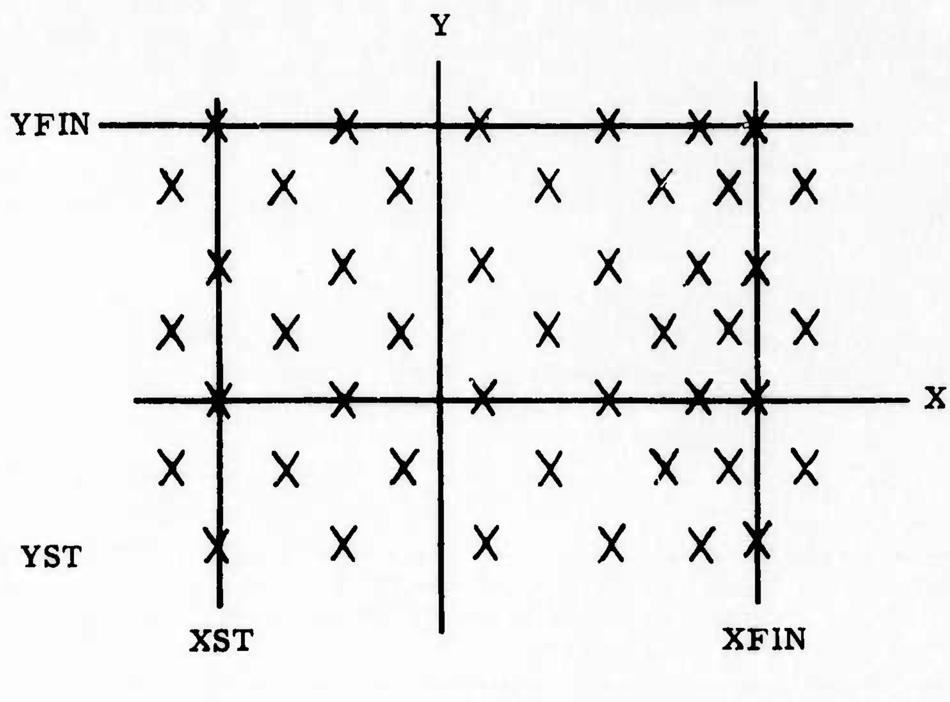


Figure 6-4. Hexagonal Grid

Card 4 (This card for the case INMOD = 3 only) Format = 8F10.5

(1)	TDIST	= Distance from the source to the entrance aperture.

Card 5

(1)	RCUT	= Energy density cutoff value for ray trace termination, relative to unity energy density of incident rays.

6.2.4.2 Hexagonal Grid (INMOD = 4, 5, 6, 7 or 8) See Figure 6-4.

Card 2 Format = 8F10.5

(1)	XST	= Initial value of X on grid (see drawing).
(2)	XFIN	= Final value of X on grid.
(3)	YST	= Initial value of Y on grid.
(4)	YFIN	= Final value of Y on grid.
(5)	ALPHA1	= Initial value of the angle ALPHA, in degrees.
(6)	ALPHA2	= Final value of the angle ALPHA, in degrees.
(7)	BETA1	= Initial value of the angle BETA, in degrees.
(8)	BETA2	= Final value of the angle BETA, in degrees.

Card 3 Format = 4I6

(1)	N	= Number of X positions.
(2)	NN	= Number of Y positions.
(3)	NNN	= Number of ALPHA positions.
(4)	NNNN	= Number of BETA positions.

Card 4 (This card for the case INMOD = 7 only) Format = F10.5

(1)	TDIST	= Distance from the source to the entrance aperture.

Card 5 Format = E12.4

(1)	RCUT	= Energy density cutoff value for ray trace termination, relative to unity energy density of incident rays.

Card 6 Format = I6

(1)	MAXLEV	= Maximum number of differential iterations to be permitted.

Card 7 Format = F10.5

(1)	RCOVER	= Iteration area threshold (differential routine will iterate a differential of its area drops below RCOVER fraction of its initial entrance aperture area; typical value = 0.80). This value is significant only if MAXLEV > 1.

6.2.5 Detector and Focal Plane Data

6.2.5.1 Detector Location Data

Card 1 Format = 3F10.5

(1)	XDET	= X coordinate of the center of the detector plane.
(2)	YDET	= Y coordinate of the center of the detector plane.
(3)	ZDET	= Z coordinate of the center of the detector plane.

Card 2 Format = 2I6

(1)	NDET	= Number of detectors (maximum of 10).
(2)	IDETAX	= Axes of detector plane. (Detector plane is X-Y plane of the axes specified.)

NOTE

Card 3 below is repeated with one card for each of the NDET detectors.

Card 3 Format = 2F10.5

(1)	DETPOS(1)	= X coordinate of center of detector within detector plane.
(2)	DETPOS(2)	= Y coordinate of center of detector within detector plane.

6.2.5.2 Focal Plane Bin Data (for recording specular throughput)

Card 1 Format = I6

(1)	NBINS	= The number of bins along an edge of the detector plane; must be an even number (maximum of 8).

Card 2 Format = F10.5

(1)	BINSIZ	= The length of an edge of a bin in the detector plane.

6.2.5.3 Detector Size Data

Card 1 Format = 2F10.5

(1)	DTAREA	= The area of a detector.
(2)	EFL	= Effective focal length of the optical system.

6.2.6 Coordinate Systems

In an off-axis optical system, the program requires each surface to be specified in a coordinate system natural to that surface. The following paragraphs show how these different coordinate systems can be specified.

The first step is to determine a reference coordinate system. For GUERAP the entrance aperture plane is usually defined to be the reference X-Y plane since source angles are given in this coordinate system. The Z axis is normal to this plane, positive Z-axis in the direction of propagation; the X and Y axes are defined in the X-Y plane to yield a right-handed coordinate system. This system is given the number 1 and is the reference coordinate system and is pre-defined. Other coordinate systems are defined with respect to the reference system or other coordinate systems previously defined and given the numbers 2, 3...etc., in sequence as they are defined. Thereafter, the coordinate systems can be referred to by number.

Coordinate systems are defined in terms of a previous coordinate system by the three angles, β, γ, δ called the Euler Angles of the coordinate system (ref: Synge and Griffith, Principles of Mechanics, McGraw-Hill 1959, pp. 259-261). The new coordinates can be obtained from the old ones by the following set of rotations performed in the order given: first rotate about the Z axis through the angle β; next rotate about the new Y axis through the angle γ; finally rotate about the new Z axis through the angle δ. Note that the first two rotations serve to bring the Z axis into position, and the final rotation brings the X and Y axes into position. See Figure 6-5.

The problem is greatly simplified if all rotations lie in the reference X-Z plane. Then β is 0° or 180°, depending on whether the rotation is toward the positive or negative X axis (note the X and Y axes are reversed for β = 180°), γ is then the angle of rotation in the X-Z plane, and δ is 0°.

Card 1 Format = I6

(1) NAXES = Number of coordinate systems (maximum of 20).

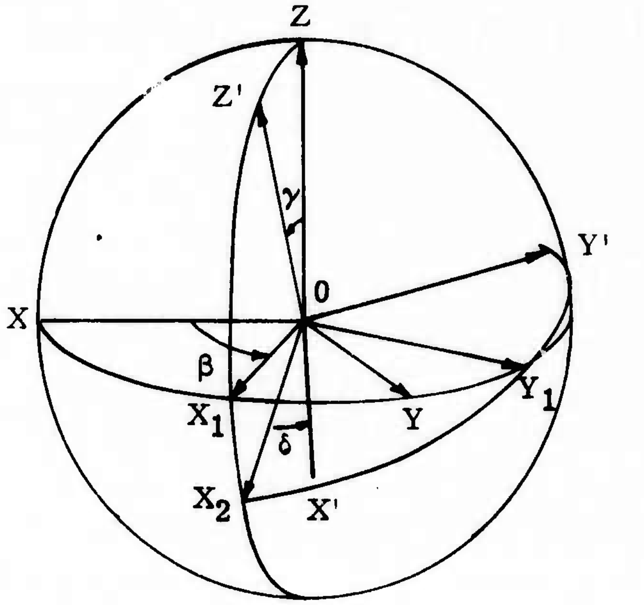
NOTE

Cards 2 - 4 below should be repeated for each coordinate system <u>except</u> the first coordinate system; the first coordinate system has an assumed reference axis number of one (IAXIS = 1), and an assumed origin of 0.,0.,0.). Thus, there should be (NAXES = 1) sets of cards 2 through 4.*

Card 2 Format = I6

(1) IAXIS = Reference axis number (the number of the coordinate system from which this system is derived).

*These sets of cards must be in order; the reference axis number for each coordinate system is implied from the position of its set of cards in the coordinate system stack.



(X_1, X_2, and Y_1 Are Intermediate Axes)

Figure 6-5. Euler Angles

Card 3 Format = 3F10.5

NOTE

XAX, YAX, ZAX below describe the position with respect to the IAXIS coordinate system.

(1)	XAX	= X coordinate with respect to the IAXIS system of the origin for the new coordinate system.
(2)	YAX	= Y coordinate with respect to the IAXIS system of the origin for the new coordinate system.
(3)	ZAX	= Z coordinate with respect to the IAXIS system of the origin for the new coordinate system.

Card 4 Format = 3F10.5

(1)	BETA	= Euler angle β
(2)	GAMMA	= Euler angle γ
(3)	DELTA	= Euler angle δ

6.2.7 Mirror Data

A mirror may be either a sphere or a flat plane. It is defined by giving the X, Y, Z position of the center of curvature and the radius of curvature or by giving the X, Y, and Z coordinates of the vertex and the radius of curvature. All the parameters necessary to define a mirror actually define two mirrors, one in either hemisphere. A positive value for the coordinate system identification number for the mirror axis indicates that the desired mirror is the one with the larger Z intercept, and a negative value indicates that the one with the smaller Z intercept should be used by the program.

Card 1 Format = I6

(1)	NMIRR	= Number of mirrors (maximum of 5)

The remaining mirror data cards consist of NMIRR sets of cards 2-6, as listed below, one set per mirror. For each mirror, cards 3-6 are either those described in 6.2.7.1 or those described in 6.2.7.2, depending upon the value of IAXIS found on card 2 for that mirror.

Card 2 Format = 3I6

(1)	MTYP	= 0 Flat mirror = 1 Concave spherical mirror = -1 Convex spherical mirror
(2)	MAXES	= The number of the coordinate system for which the Z axis is the axis of the mirror. (A positive value of MAXES indicates that the directed line from the vertex of the mirror to the center of curvature lies along the positive Z axis in the MAXES coordinate system. A negative value indicates the reverse.)
(3)	IAXIS	= ± the number of the coordinate system with respect to which the coordinates of the mirror are to be given. (A positive value of IAXIS indicates to the program that the coordinates of the vertex of the mirror will be given, while a negative value of IAXIS indicates that the coordinates of the center of curvature of the mirror will be given.)

6.2.7.1 Negative IAXIS

Card 3 Format = 3F10.5

(1)	AMIRR(1)	= X coordinate of the center of curvature of the mirror with respect to the IAXIS coordinate system.
(2)	AMIRR(2)	= Y coordinate of the center of curvature of the mirror with respect to the IAXIS coordinate system.
(3)	AMIRR(3)	= Z coordinate of the center of curvature of the mirror with respect to the IAXIS coordinate system.

Card 4 Format = F10.5

(1)	AMIRR(4)	= Radius of curvature of the mirror; must be positive.

Card 5 Format = F10.5

(1) REFMIR = A factor by which the BRDF value entered as the BRDF table data (6.2.12) will be multiplied. (This factor, usually unity, can be used to scale the BRDF data, if desired.)

Card 6 Format = I6

(1) IMRFT = BRDF surface type for the mirror, the number of the set of BRDF tables to be used for this mirror.

6.2.7.2 Positive IAXIS

Card 3 Format = 3F10.5

(1) XVERT = X coordinate of the vertex of the mirror, with respect to the IAXIS coordinate system.

(2) YVERT = Y coordinate of the vertex of the mirror, with respect to the IAXIS coordinate system.

(3) ZVERT = Z coordinate of the vertex of the mirror, with respect to the IAXIS coordinate system.

Card 4 Format = F10.5

(1) AMIRR(4) = Mirror radius, must be positive.

Card 5 Format = F10.5

(1) REFMIR = A number by which the BRDF value entered as the BRDF data (Section 6.2.12) will be multiplied. (This factor, usually unity, can be used to scale the BRDF data, if desired.)

Card 6 Format = I6

(1) IMRFT = BRDF surface type for the mirror, the number of the set of BRDF tables to be used for this mirror.

6.2.8 Aperture Data

An aperture is a hole cut in a plane allowing a ray to pass from one section to another. There are two types of apertures; a positive aperture is a hole surrounded by a plane, while a negative aperture is a solid central area surrounded by a clear region. Thus a positive aperture is opaque outside its boundary, while a negative aperture is opaque within the boundary (e.g., a disk).

An aperture may have one of four geometric shapes; a circle, an ellipse, a rectangle, or a circle convolved with a straight line. An aperture is always perpendicular to its Z-axis. Apertures may be used singly or in pairs, e.g., a ring with a clear aperture on either side would be a combination of a positive and negative aperture. (See Figure 6-6.)

Card 1 Format = I6

(1)	NAPER	= Number of apertures (maximum of 20).

The remaining aperture data cards consist of NAPER sets of cards 2-5, one per aperture.

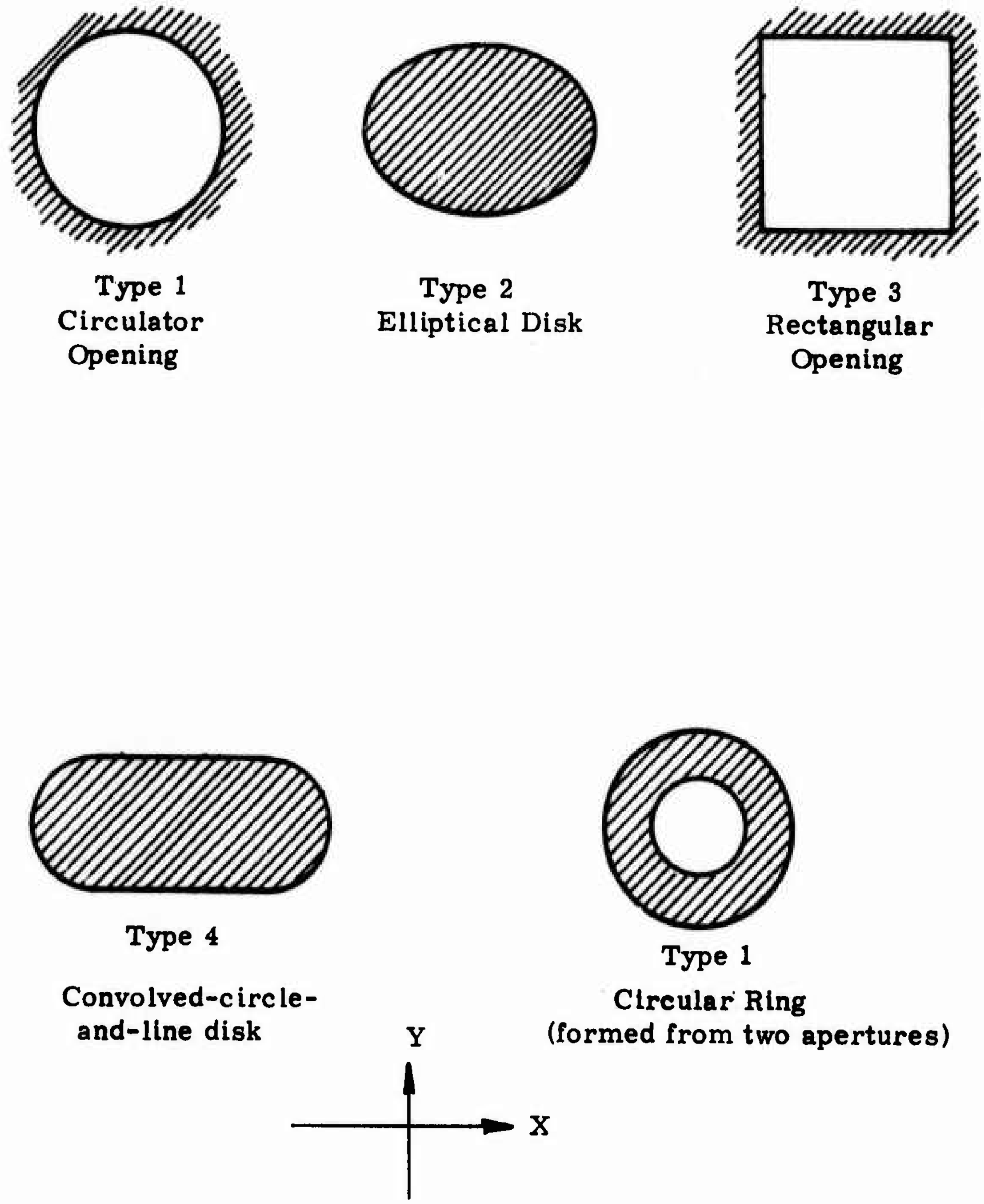


Figure 6-6 . Aperture Shapes

Card 2 Format = 6I6

(1) KATYP = ±1 Circular
= ±2 Elliptical
= ±3 Rectangular
= ±4 Convolved circle

NOTE

Positive value of KATYP indicates that the aperture is a "positive aperture" and a negative value indicates a "negative aperture" (as described above).

(2) KABACK = Number of the section in back of the aperture (back is toward smaller Z)

(3) KANEXT = Number of the section in front of the aperture (front is toward greater Z)

(4) KOTHER = The number of the aperture which lies inside this aperture if there is an inner aperture; a value of 0 indicates that there is no aperture within an aperture. See Figure 6-6.

(5) KAXES = The number of the coordinate system for which the Z axis is normal to the plane of the aperture. Thus the aperture must lie in the X-Y plane of this coordinate system.

(6) KREF = The number of the coordinate system with respect to which the center of the aperture will be specified.

Card 3 Format: 3F10.5

(1) ANAPER(1) = X coordinate of the center of the aperture with respect to the IAXIS coordinate system.

(2) ANAPER(2) = Y coordinate of the center of the aperture with respect to the IAXIS coordinate system.

(3) ANAPER(3) = Z coordinate of the center of the aperture with respect to the IAXIS coordinate system.

Card 4, below, describes the size of the aperture in terms of two parameters. The meaning of these parameters depends on the shape of the aperture as follows: (a) for a circle, ANAPER(4) defines the radius of the circle, ANAPER(5) is ignored; (b) for an ellipse, ANAPER(4) defines the semi-major axis of the ellipse (always assumed to lie along the X-axis), ANAPER(5) is the ratio of the semi-major to the semi-minor axis; (c) for a rectangle, ANAPER(4) defines the half-width in the X-direction, ANAPER(5) defines the half width along the y-direction; (d) for a convolved circle and line, ANAPER(4) and ANAPER(5) are given as above for the inscribed rectangle.

Card 4 Format = 2F10.5

(1) ANAPER(4) = First size parameter for the aperture.
(2) ANAPER(5) = Second size parameter for aperture.

Card 5 Format = F10.5

(1) RFAP = A factor by which the value from the BRDF table will be multiplied (for use when rays are incident on opaque portion of aperture). (This factor, usually unity, can be used to scale the BRDF data, if desired.)

Card 6 Format = I6

(1) IAPRFT = BRDF surface type.

6.2.9 Tube and Baffle Data

Card 1 Format = I6

(1) NTUBES = Number of tubes (maximum of 15).

NOTE

The remaining tube and baffle data cards consist of NTUBES sets of cards. Each set of cards consist of the following:

(1) Tube data (real and imaginary tube, or real tube data; see explanation 1, below) followed by

(2) Baffle data for that tube (standard and/or wild card baffle data; see explanation 2, below)

(a) Explanation 1: Tube Data

A tube is a two-dimensional surface which can be used as a wall (with or without baffles) or an imaginary surface to define baffle edges or holes in other surfaces. Allowed tube surfaces are circular and elliptical cones and cylinders, rectangular cones and cylinders, and convolved circle and line cones and cylinders.

A tube is defined in the program in the following manner: first the axis of the tube is selected. The axis of the tube must be parallel to the z-axis of one of the coordinate systems previously defined. The intersection of the tube with a plane perpendicular to the tube axis (called a tube cross-section) must be one of the four allowable shapes: circle, ellipse, rectangle, or convolved circle and line. Next a point of the tube axis is selected. This point is called the base point of the tube. Then the tube cross-section at this base point is described. Finally the variation of the tube cross-section along the tube axis is described in terms of slopes.

A real tube consists of a single surface; if that tube has baffles attached, then a second "imaginary" tube must be specified. This imaginary tube must have its axis parallel to the real tube. The baffles are defined to physically exist only in the volume between the real tube and the imaginary tube; thus, the edges of the baffles are coincident with the surface of the imaginary tube.

For a tube with baffles, the tube data consists of Cards 1-8 containing imaginary tube data (Cards 2 and 3 actually apply to the real tube), followed by a second sequence of Cards 4-7 containing real tube data. If there is no imaginary tube, then the tube data consists of Cards 1-8 containing the real tube data.

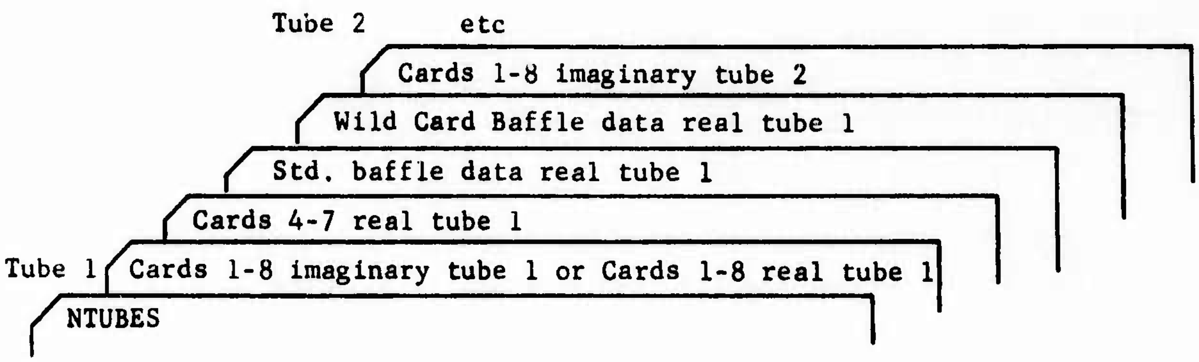
(b) Explanation 2: Baffle Data

The tube data given above are immediately followed by baffle data cards, if baffles are specified; first the standard baffle data is given, followed by the wild card baffle data, if there are any wild card baffles within the volume defined by the real and the imaginary tubes. (If that wild card baffle extends beyond the volume defined by the two tubes, then that wild card baffle must also be specified as a wild card baffle section in paragraph 6.2.10. If the wild card baffle specified here is wholly contained within the volume between the two tubes, then it should not be specified in paragraph 6.2.10.) The wild card baffle surfaces are described in paragraph 6.2.11.

Typically, standard baffles will consist of a number of similar baffles spaced along the tube; each of the data cards specified below for the standard baffles requires the values of a given parameter for all baffles, i.e., when the positions of the baffles are to be entered the user employs as many cards as necessary to include the positions of the N baffles in that tube, putting 8 positions on each card.

(c) Summary

The sketch below illustrates the sequence of tube and baffle data (the illustration reads from the bottom up).



6.2.9.1 Tube Data

Card 1 Format = 2I6

(1) LAXES = Number of the coordinate system which is the axis of the tube.

(2) IAXIS = Number of the coordinate system with respect to which the base point of the tube will be given.

Card 2

(1)	REFTUB	= A factor by which the BRDF value entered as the BRDF table data (6.2.12) will be multiplied. (This factor, usually unity, can be used to scale the BRDF data, if desired.)

Card 3 Format = I6

(1)	ITBRFT	= BRDF surface type for the tube: the number of the set of BRDF tables to be used for this tube.

Card 4 Format = 3F10.5

(1)	ATUBE(1)	= X coordinate of the base point of the tube (at which point the dimensions will be given).
(2)	ATUBE(2)	= Y coordinate of the base point of the tube.
(3)	ATUBE(3)	= Z coordinate of the base point of the tube.

Card 5 Format = I6

(1)	ITTUB	= 1 Circular tube
		= 2 Elliptical tube
		= 3 Rectangular tube
		= 4 Convolved circle

NOTE

In Card 6 below, the meanings of the first and second size parameters depend upon the shape of the tube analogous to aperture size parameters. Specifically for a circular tube, the first size parameter defines the radius at the base point, while the second size parameter is ignored. For an elliptical tube, the first size parameter defines the semi-minor axis, at the base point, while the second parameter defines the semi-major axis there. For a rectangular tube, the first and second size parameters define the half widths at the base point in the X and Y direction, respectively. For the convolved circle tube, the size parameters describe the inscribed rectangular tube, as above.

Card 6 Format = 2F10.5

(1)	ATUBE(4)	= First size parameter for the tube.
(2)	ATUBE(5)	= Second size parameter for tube.

Card 7 Format = F10.5

For the cases ITYPE = 1 or 2

(1)	ATUBE(6)	= Slope of the side of the tube. The slope is the ratio of the first size parameter change to the distance moved along the tube axis (a slope of 0, describes a cylinder).

For the case ITYPE = 3 or 4

(1)	ATUBE(6)	= Direction cosine in the X direction of the normal to the side of the tube parallel to the Y axis.
(2)	ATUBE(7)	= Direction cosine in the Z direction of the normal to the side of the tube parallel to the Y axis.
(3)	ATUBE(8)	= Direction cosine in the Y direction of the normal to the side of the tube parallel to the X axis.
(4)	ATUBE(9)	= Direction cosine in the Z direction of the normal to the side of the tube parallel to the X axis.

NOTE

Values at 1., 0., 1., 0., for ATUBE(6-9) define a cylinder.

Card 8 Format = 2I6

(1)	IBAFF	= 1 No standard baffles on this tube.
		= 2 Tube has standard baffles.
(2)	IWCBAF	= 0 No wild card baffles within the standard baffles on this tube.
		= 1 Wild card baffles within the standard baffles on this tube.

6.2.9.2 Standard Baffle Data

Card 1 Format = I6

(1)	MBAF	= Number of standard baffles within tube (maximum of 100 baffles in total).

Card 2 (more than one card may be required) Format = 8F10.5

(1)	ZB	= Z coordinates of the intersection of the edges of each of the MBAF annular baffles with the imaginary tube. (The coordinate system is the same as that used to specify the imaginary tube.)

NOTE

The remainder of the standard baffle data consists of cards specifying the slopes for each of the individual baffles. All of the baffles in a given tube must be of the same type; thus the data cards from either Section 6.2.9.2.1 or 6.2.9.2.2 must be used, depending upon the tube type specified by ITTUB on Card 5, Section 6.2.9.1

6.2.9.2.1 Circular and Elliptical Baffles

Card 3 (more than one card may be required) Format = 8F10.5

(1)	S	= Slopes of each of the MBAF annular baffles

6.2.9.2.2 Rectangular and Convolved Circle Baffles

Card 3 (more than one card may be required) Format = 8F10.5

(1)	SX	= Slopes in the X direction of each of the MBAF annular baffles.

Card 4 (more than one card may be required) Format = 8F10.5

(1)	SY	= Slopes in the Y direction of each of the MBAF annular baffles.

6.2.9.3 Wild Card Baffle Data (IWCBAF = 1)

If there are no wild card baffles located between the real and imaginary tube, these cards are not included and information about the next tube is the next set of cards.

Card 1 Format = 2I6

(1)	MINWCB	= Number of the standard baffle which precedes the first wild card baffle.
(2)	MAXWCB	= Number of the standard baffle which follows the last wild card baffle.

Wild card baffle surfaces are described in section 6.2.11. The order in which they are described to the program determines their <u>wild card baffle surface number</u>.

The following card (or cards) contains the wild card baffle surface numbers of all wild card baffle surfaces appearing between the real and imaginary tubes. The list of wild card baffle surface numbers is terminated with a zero, and the numbers are entered eight per card.

Card 2 (more than one card may be required) Format = 8I6

(1)	IWCBS	= Wild card baffle surface numbers of each wild card baffle surface between these baffles, eight per card, terminated with a zero.

6.2.10 Section Data

Sections are the means by which the various surfaces are linked together to form an optical system. Each section encompasses a local region of one of four types; standard baffled section, end section, concave mirror section, and convex mirror section (each section type is described below). A ray can pass from one section to another in three different ways; through an aperture; through a hole (described below) in the case where both sections are standard baffled sections; and by the wild card baffle mechanism.

Card 1 Format = I6

(1)	NSECT	= Number of sections (maximum of 20)

NOTE

The remaining section data cards consist of NSECT sets of one or more cards, as listed in Sections 6.2.10.1 to 6.2.10.4, with the type of set determined by the section type. The section data must be given in sequence (set 1 for Section 1, set 2 for Section 2, etc.)

Section data for a given section consists of at least one card giving section parameters. These parameters include all apertures of the section as well as flags indicating whether holes or wild card baffles are present. Hole card(s) (if any) come first, followed by wild card baffle cards (if any). Formats for each kind of card are described below.

6.2 10.1 Standard Baffled Section

A standard baffled section consists of one or two tubes delimited by a pair of apertures. If the region being described is inside a tube, that tube is called the outer tube. If the region being described lies outside a tube, that tube is called the inner tube. A standard baffled section consisting of both an outer and an inner tube lies between those tubes. All tubes and both apertures must lie in parallel (or the same) coordinate systems. The aperture intersecting the tube axis at a lower Z value is called the back aperture, the one intersection at the higher value is the front aperture.

A standard baffled section may have one or two holes to allow additional means for rays to pass from one section to another in off-axis systems. A hole is a semi-infinite tube bounded on one end by an aperture. Any part of the apertures and tubes described above which lie within the hole are non-existent. The aperture and tube describing the hole must have parallel (or the same) coordinate systems, but these coordinate systems will not, in general, be parallel to the section coordinate systems. Note that the section transferred to will also have a hole in it.

A standard baffled section may have wild card baffles also. Wild card baffles are described in section 6.2.9.3 and 6.2.11.

Examples of standard baffled sections are shown in Figure 6-7. An example of a hole is shown in Figure 6-8.

Card 1 Format = 5I6

(1)	JTYPE	= 0 No inner tube.
		≠ 0 Tube number of inner tube.
(2)	JSECT1	= 0 No outer tube.
		≠ 0 Number of outer tube.
(3)	JBACK	= Number of the end aperture of low Z value.
		Number of the end aperture of high Z value.
(4)	JNEXT	= Gives the number of the other end aperture.
(5)	JSECT2	= 0 There are no holes in the section other than the apertures.
		= 1 There are one or two holes in the section (see card 2).
(6)	JSECT3	= 0 No wild card baffle surfaces in the section.
		= 1 Wild card baffle surfaces exist in the section (see card 3).

NOTE

If there is a hole or wild card baffle surface in the section, then one or more cards are needed. They will be described below.

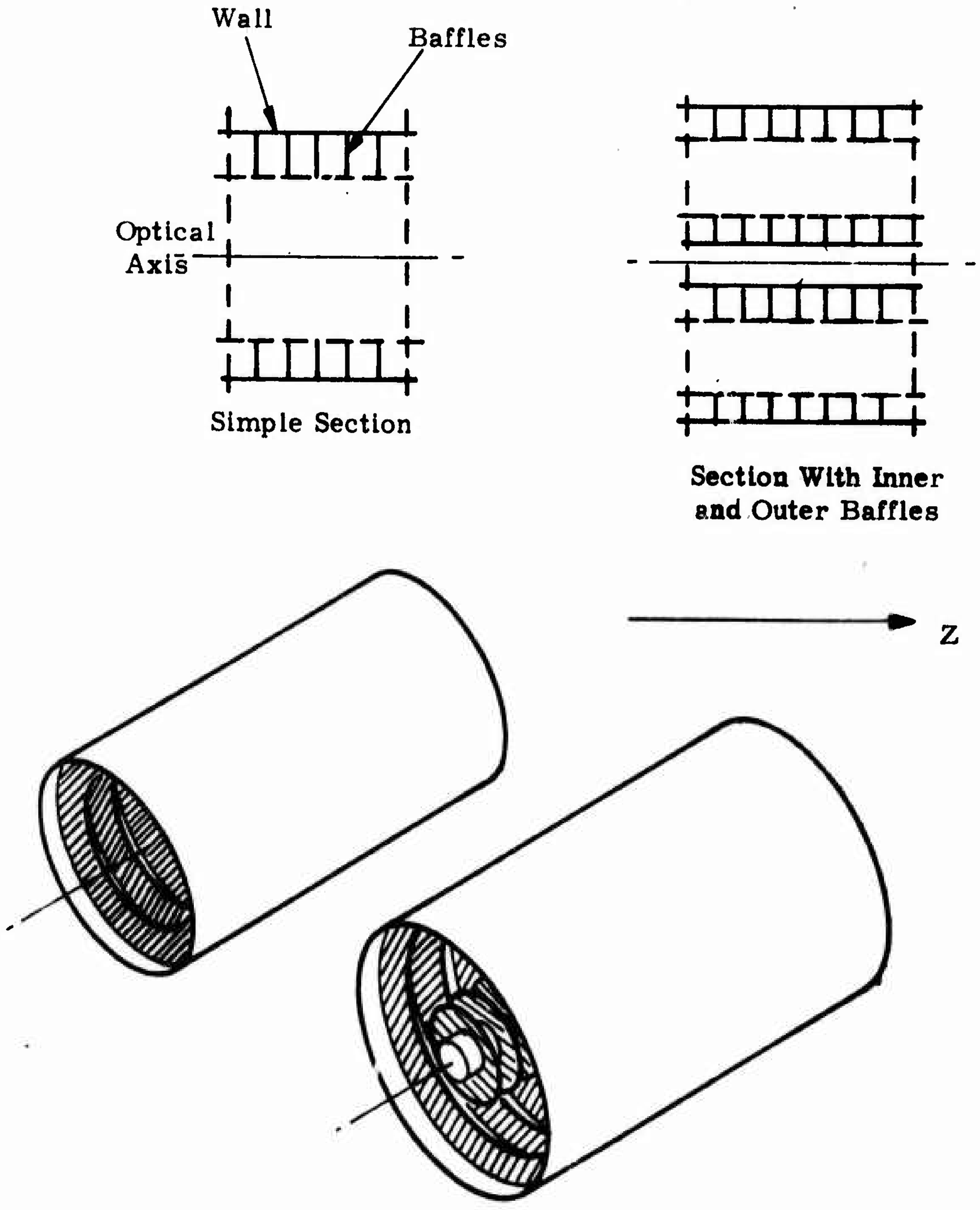


Figure 6-7. Standard Baffled Sections

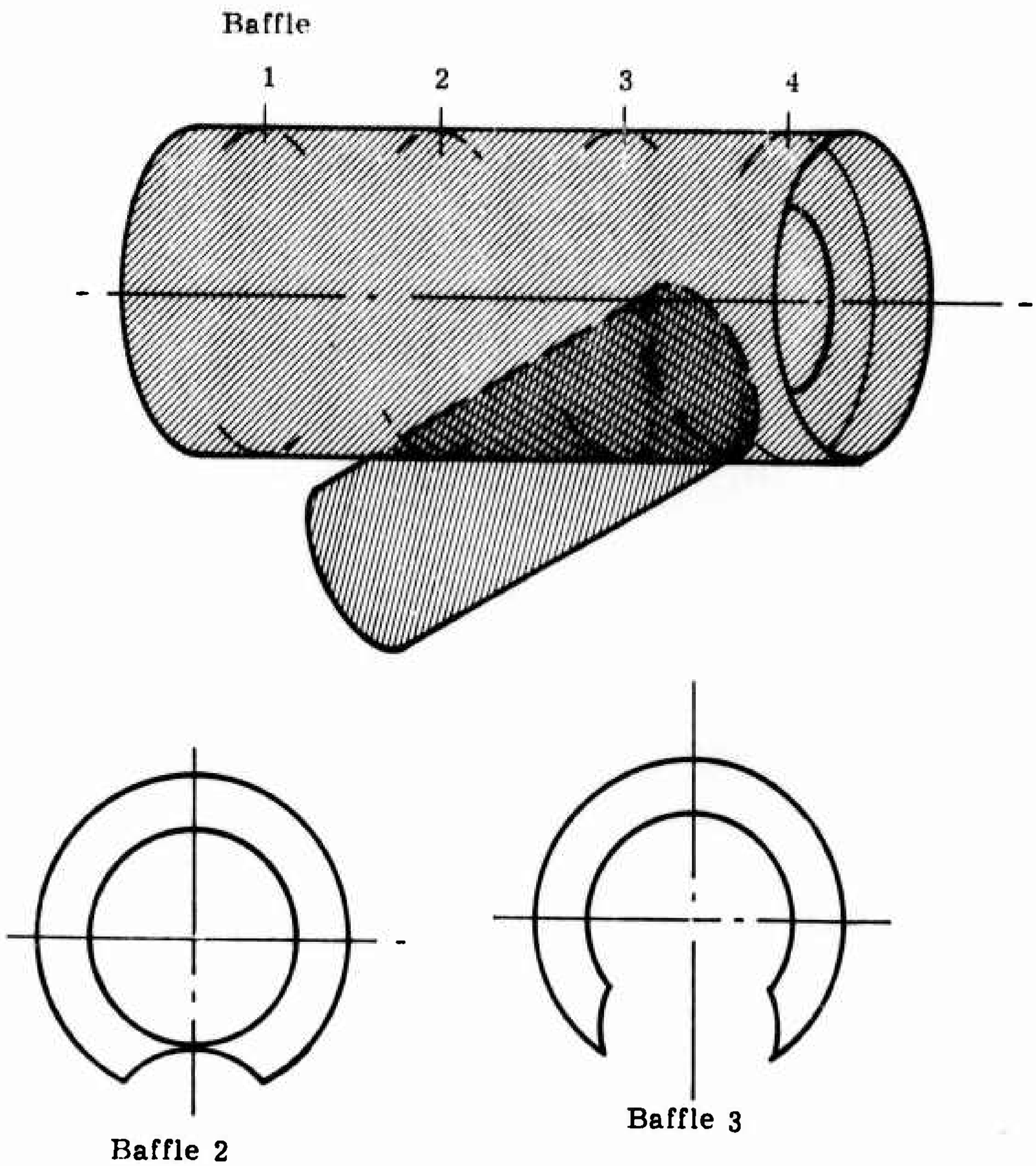


Figure 6-8. Holes

Card 2 (only entered for a standard baffled section with a hole) Format = 5I6

NOTE

A second hole card follows immediately if there is a second hole.

(1)	IHTUBE	= The number of the tube defining the hole.
(2)	IHAP	= The number of the aperture defining the end of the hole.
(3)	IHDIR	Since the tube is of infinite length, there would be a length of tube on either side of the aperture limiting the extent of the hole; the values of IHDIR indicate the hole as follows:
		= 1 The aperture is the bottom of the hole (it is less positive in Z than the hole).
		= 2 The aperture is the top of the hole (it is more positive in Z than the hole).
(4)	IHSECT	= The number of the section the ray enters when it passes through the hole.
(5)	IHNEXT	= 0 There are no more holes in this section.
		= 1 There is a second hole in the baffled section.

Card 3 Format = 8I6

NOTE

Card(s) 3 is required only if JSECT3 is non-zero. If more than seven wild card baffle surfaces exist in the section, additional cards are necessary. (If there are only eight surfaces, they can be put on a single card but a blank card must follow.) See also sections 6.2.9.3 and 6.2.11.

(1)	IWCBS(I)	= Wild card baffle surface number of each wild card baffle in the section.

6.2.10.2 End Section

End sections are used in off-axis systems to interface an aperture to a tube, where the normal to the aperture is not parallel to the axis of the tube. If desired, a second tube may also be interfaced. The aperture being interfaced is called the odd aperture. Each tube must also be bounded by an aperture whose normal is parallel to the axis of that tube. The end section then consists of the region in each tube between its normal aperture and the odd aperture. Portions of a tube or normal aperture lying inside the other tube (if there is one) are considered to be non-existent.

Examples of end sections are given in Figure 6-9.

Card 1 Format = 5I6

(1)	JTYPE	= 100 + Aperture Number of the odd aperture.
(2)	JSECT1	= Tube number of the first tube.
(3)	JBACK	= Aperture number of the aperture normal to the first tube.
(4)	JNEXT	= Aperture number of the aperture normal to the second tube (if any).
(5)	JSECT2	= Tube number of the second tube (if any).
(6)	JSECT3	= 0 No wild card baffle surfaces in the section.
		= 1 Wild card baffle surfaces exists in the section.

NOTE

If there is a wild card baffle surface in the section, then one or more cards are needed. They are described in Sections 6.2.9.3 and 6.2.11.

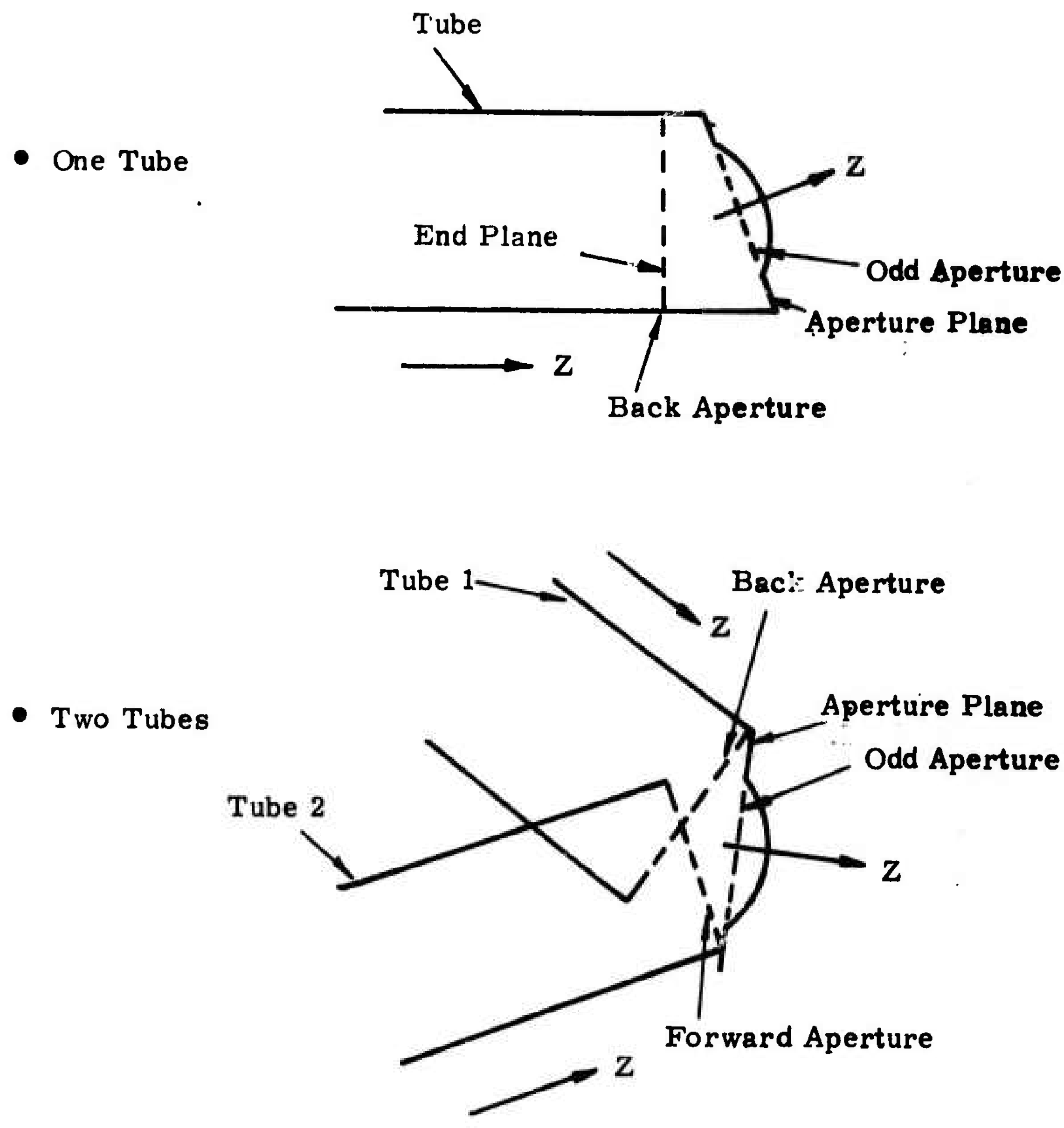


Figure 6-9. End Sections

6.2.10.3 Concave Mirror Sections

Concave mirror sections consist of a concave (or flat) mirror together with one or two limiting apertures and an optional central obscuration.

A concave mirror must be limited by an aperture describing the portion of the entire surface (sphere, conic, or plane) which is the mirror surface. The center of the mirror may be cut out or obscured. If so, the concave mirror section must be bounded by an aperture describing the plane of the hole or obscuration. Further, for an obscured mirror there can be a further obscuration in the form of a tube (with or without baffles).

If the concave mirror section is bounded by two apertures, the one that intersects the mirror axis at the lower Z value is called the back aperture, while the one that intersects the mirror axis at the higher Z value is called the front aperture.

In the one aperture case, the aperture is considered the front or back aperture with respect to an imaginary aperture behind the mirror.

Examples of concave mirror sections are given in Figure 6-10.

Card 1 Format = 6I6

(1)	JTYPE	= 200 unobscured mirror.
		200 + tube number of the tube obscuring the mirror.
(2)	JSECT1	= Mirror number of the concave (or flat) mirror.
(3)	JBACK	= Aperture number for the back aperture (lower Z value), if any.
(4)	JNEXT	= Aperture number for the front aperture (higher Z value), if any.
(5)	JSECT2	= A value of 0 should be entered.
(6)	JSECT3	= 0 No wild card baffle surfaces in the section.
		= 1 Wild card baffle surface exists in the section.

NOTE

If there is a wild card baffle surface in the section, then one or more cards are needed. They are described in Sections 6.2.9.3 and 6.2.11.

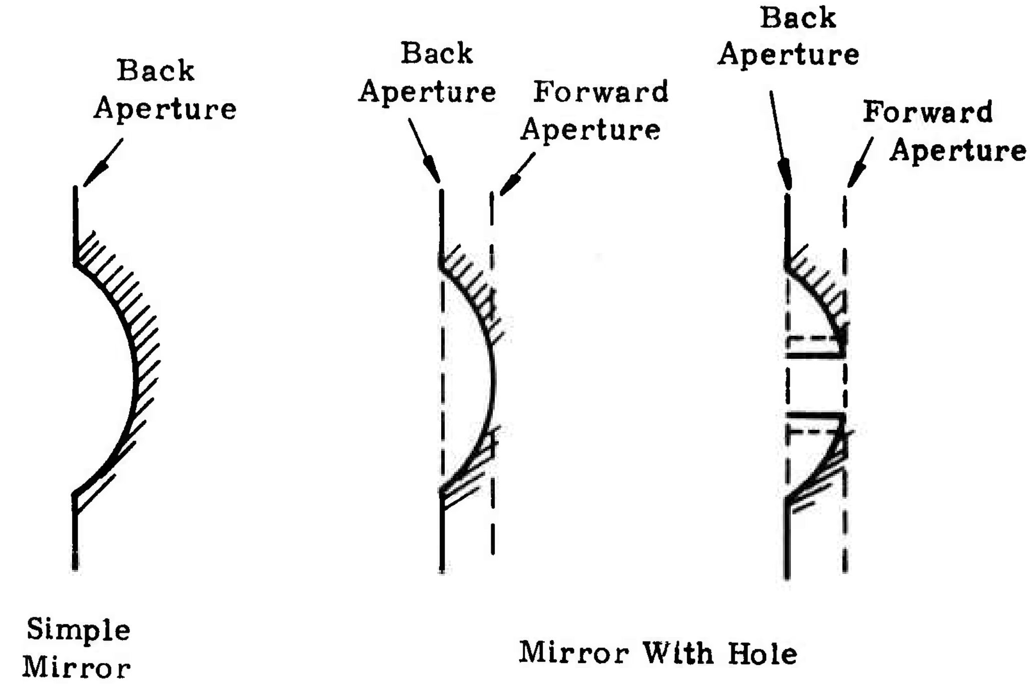


Figure 6-10. Concave Mirror Sections

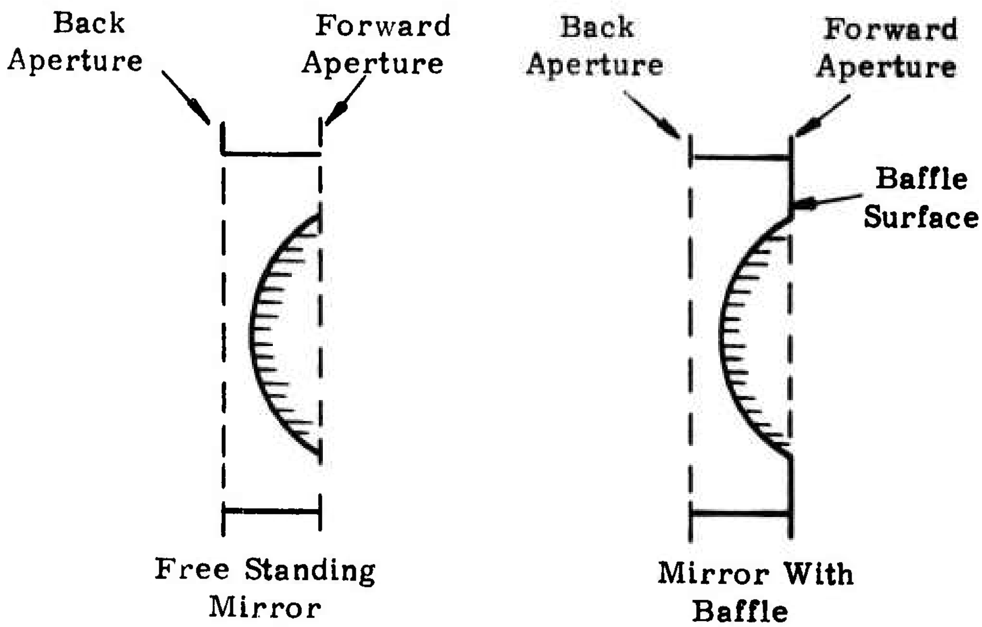


Figure 6-11. Convex Mirror Sections

6.2.10.4 Convex Mirror Sections

A convex mirror section consists of a convex mirror, two limiting apertures, and a surrounding tube. One aperture describes the portion of the sphere or conic which is the actual mirror, while the other aperture must be in front of the mirror to separate it from other sections. The aperture intersecting the mirror axis at the lower Z value is called the back aperture, while the one intersecting that axis at the higher Z value is called the front aperture.

Examples of convex mirror sections are given in Figure 6-11.

Card 1 Format = 6I6

(1)	JTYPE	= 300.
(2)	JSECT1	= Tube number of tube surrounding the convex mirror section.
(3)	JBACK	= The number of the back aperture (lower Z value).
(4)	JNEXT	= The number of the front aperture (greater Z value).
(5)	JSECT2	= Mirror number of the convex mirror.
(6)	JSECT3	= 0 No wild card baffle surfaces in the section.
		= 1 Wild card baffle surface exists in the section.

NOTE

If there is a wild card baffle surface in the section, then one or more cards are needed. They are described in Sections 6.2.9.3 and 6.2.11.

6.2.11 Wild Card Baffle Surfaces

Wild card baffle surfaces are distinguished from ordinary surfaces in that their placement in the optical system does not conform to the rules for ordinary baffles or standard sections, as described above. Sections 6.2.9.3 and 6.2.10 described how the wild card baffle surface is placed between ordinary baffles or inside standard sections, in terms of wild card baffle surface numbers. This section explains how to describe the actual surface corresponding to each wild card baffle surface number.

Wild card baffles consist of standard surfaces (mirrors, apertures, or tubes) formed into a wild card object which must be one of the standard section types described in 6.2.10. (It is the presence of this object in another section that causes it to be a wild card baffle.)

Each of the surfaces in a wild card baffle is a separate wild card baffle surface and is described by two parameters. The first parameter is the mirror (or aperture or tube) number increased by 0 (or 100 or 200, respectively) and the second is the section number of the complete wild card object. For example, a strut could consist of a tube bounded by two disk apertures. This would form a standard baffled section with an inner tube but no outer tube.

Card 1 Format = I6

(1)	NWCBS	= Number of wild card baffle surfaces to be specified for all wild card objects.

NOTE

A separate card 2 must appear for each of the NWCBS wild card baffle surfaces. The first one defines wild card baffle surface 1, etc. The wild card baffle surface numbers are the ones used in Sections 6.2.9.3 and 6.2.10 to show how these surfaces are contained between ordinary baffles or in standard sections.

Card 2 Format = 2I6

(1)	ITWCBS	= 0 to 99 for a mirror; with the specific value being the number of the mirror.
		= 100 to 199 for an aperture; with the specific value being the number of the aperture + 100.
		= 200 to 299 for a tube; with the specific value being the number of the tube + 200.
(2)	ISWCB	= Section number of the wild card object of which this wild card baffle surface is a part.

6.2.12 BRDF Tables

The BRDF tables must have been previously prepared and written out as two binary files by the WRTABL program described in Section 5.2.1. This section describes how they are read in on FORTRAN units 1 and 2, and methods by which all or parts of these tables can be modified by constant scale factors.

Card 1 Format = I6

(1)	NTAB	= Number of BRDF tables (maximum of 3)

6.2.12.1 Global BRDF Table Multipliers

NOTE

A separate card 1, below, must be included for each of the NTAB BRDF Tables.

Card 1 Format = 2F10.5

(1)	SM	= Multiply all the specular attenuation values in this set of BRDF tables by the value SM. A negative value indicates that the tables should be used as they were read in. In this case the value of DM is ignored.
(2)	DM	= Multiply all the diffuse attenuation values by DM.

6.2.12.2 Local BRDF Tube Multipliers

NOTE

These cards should be included for a particular table only if the value of SM (above) is negative.

Card 1 Format = 8I6

(1)	ITDM	= The numbers of the specific rows, corresponding to different incident angles within that set, whose values are to be multiplied by some coefficient before they are used. An input of all zeroes indicates that all the tables in that set should be used as they were read in, and is the normal mode of operation. In this case, cards 2 and 3 should be omitted.

NOTE

Cards 2 and 3 should be included for a particular table only if card 1 has at least one non-zero entry.

Card 2 Format = 8F10.5

(1)	TSM	= The coefficients by which all of the specular values in each of the rows specified in card 1 are to be multiplied. Each row has its own multiplier. There should be as many entries on this card as non-zero indices specified on card 1.

Card 3 Format = 8F10.5

(1)	TDM	= The coefficients by which all of the diffuse values in each of the rows specified in card 1 are to be multiplied. There should be as many entries on this card as non-zero indices specified on card 1.

6.2.13 Hand Calculated View Factor Matrices

The GUERAP-II program calculates first-order diffuse stray radiation terms by computing and marking all areas, called critical areas, which can be seen by a detector, either directly or specularly off one or more mirrors. Higher order terms are calculated similarly, with lower order critical areas playing the role of a detector. Three matrices are input by the user to guide the program in finding these critical areas. These matrices, called the hand-calculated view factor matrices, consist of an aperture-to-aperture matrix, an aperture-to-section matrix, and a section-to-section matrix. The first two matrices are used to compute all mirror paths to the critical areas, while the third matrix is used to compute the direct paths.

The user begins by selecting a subset of the apertures in the system, called the set of critical apertures. These critical apertures describe how the imaging rays get through the system. The set of critical apertures must include the limiting aperture for each mirror in the system. In addition, each aperture that limits or obscures what one mirror can see of another must also be included in the set of critical apertures. Thus, in a typical system, the critical apertures include field stops, Lyot stops, and obscuring apertures, if any or all of these exist in the system. Once the critical apertures have been selected, they are described to the system by two parameters: the ordinary aperture number, and the mirror number of the associated mirror (0 if there is no associated mirror, as in the case of a field stop, etc.).

The next step is to construct the aperture-to-aperture matrix. This matrix describes which critical apertures see which others. A critical aperture is said to see another critical aperture if, and only if, a direct path through no intervening critical aperture exists. The user is never required to specify mirror paths, as the program can calculate these paths once the direct path from a point to a mirror and the direct mirror-to-mirror paths have been specified. By definition, critical apertures do not see themselves.

To complete the description of possible mirror paths, the aperture-to-section matrix is specified next. This matrix describes which critical apertures directly see which sections. If there is an aperture that limits or partially obscures this view, it is also specified. (If there is more than one such aperture, the most appropriate one is chosen.)

Finally, to allow the computation of direct paths, the section-to-section matrix is specified. This matrix describes which sections can directly see which other sections. (Limiting or obscuring apertures are also specified as in the aperture-to-section matrix described above.) Unlike the critical apertures, sections can always see themselves.

Thus, by simply stating the direct paths possible in the system, the program is able to pick out the direct and mirror paths that actually exist in an optical system.

Card 1 Format = I6

(1) NCAP = Number of critical apertures in the system (maximum of 10).

Card 2 Format = 2I6

NOTE

Card 2 should be repeated for each critical aperture 1 to NCAP with one card for each critical aperture.

(1) ISEQAM(1) = The number of the system aperture that corresponds to this critical aperture (critical aperture 2 might actually be system aperture 10).

(2) ISEQAM(2) = The number of the mirror that this aperture defines. If the critical aperture is a stop, then this should have a value of 0.

Card 3 Aperture-to-Aperture Format = 8I6

NOTE

Card 3 should be repeated for each critical aperture 1 to NCAP with as many cards as needed for each aperture and at least 1 card for each critical aperture.

(1) IAP2VF = The numbers of the other critical apertures that can be seen by each particular critical aperture. Since only eight aperture numbers may be input on one card, more than one card may be needed to cover all the apertures seen by any one of the others. If a critical aperture sees only eight other critical apertures, then a blank card must follow before going on to the next aperture.

Card 4 Aperture-to-Section Format = 8I6

NOTE

Card 4 should be repeated for each critical aperture 1 to NCAP with as many cards as needed for each aperture and at least 1 card for each critical aperture.

(1) ISAPVF = The numbers of the system sections that can be seen by each particular critical aperture. As with Card 3, more than one card may be needed for an aperture and a blank card should follow the data card for an aperture that sees exactly eight sections. If the critical aperture looks through aperture N to see a particular section, that section number should be increased by 100 x N. Thus, if critical aperture 2 sees section 6 through aperture 9, the second set of cards should contain the entry 906.

Card 5 Section-to-Section Format = 8I6

NOTE

Card 5 should be repeated for each system section 1 to NSECT with as many cards as needed for each section and at least one card for each section.

(1) IS2VF = The numbers of the system sections that can be seen by each particular system section. As with the previous two matrices, more than one card may be needed for a section and a blank card should follow the data card for a section that sees exactly eight other sections. If a section views another section through aperture N, the section seen should be increased by 100 x N. Thus, if section 3 sees section 6 through aperture 11, the third set of cards should contain the entry 1106.

6.2.14 Diffraction Data

NOTE

This section is omitted entirely except when diffraction terms are being computed. Also refer to Section 5.2.4.

In computing diffraction terms, unlike the diffuse case, the user must specify the edge sequences at which the program is to look. The user begins by specifying the number of edges at each of Levels 1, 2 and 3.

A level 1 edge is an edge from which a diffracted ray could reach the detector (either directly or by a specular path off one or more mirrors). Thus a level 1 edge may give rise to a single diffraction term, or be the last edge in a multiple diffraction term. A higher level edge is one from which a diffracted ray could reach a lower level edge. Thus a level 2 edge could give rise to a double diffraction term, be the middle edge in a triple diffraction term, etc.

If the user specifies I edges at Level 1, J edges at Level 2, and K edges at Level 3, then the first I edges specified are Level 1 edges, the next J are Level 2 and the last K are Level 3 edges. An edge is specified by giving its aperture or baffle number; the number of aperture or aperture-mirror pairs between that edge and its destination (the detector plane for a Level 1 edge, or a Level n-1 edge for a Level n edge); the section number of the edge if it is illuminated (otherwise 0); and its destination edge number if the edge is Level 2 or higher (the destination edge number is the position of that destination edge which has been previously defined in this list). Aperture and aperture-mirror pair sequences are defined as in the critical aperture sequences. Note that the level of an edge is the number of diffractions that occur, starting at that edge and reaching the detector.

NOTE

All data cards in Section 6.2.14 are read in on FORTRAN unit 3.

Card 1 Format = F15.5

(1) W = Wavelength (in the same units as the length units used earlier).

Card 2 Format = I6

(1) NPTS = Number of points to be taken around an edge. (The program checks points equally spaced around each edge to see whether diffraction from the edge at that point can reach the detector.)

Card 3 (Diagnostic outputs, not for production use) Format = I6

(1) MDIAG = 0

(2) NDIAG = 0

(3) NP1 = 0

(4) NP2 = 0

Card 4 Format = 2I6

(1) NSW1 = 1

(2) NSW2 = 0 No diffraction path summary report

= 1 Output diffraction path summary

Card 5 Format = 3I6

(1) NCREG(1) = The number of critical edges at Level 1

(2) NCREG(2) = The number of critical edges at Level 2

(3) NCREG(3) = The number of critical edges at Level 3

Card 6 Format = 4I6

NOTE

Card 6 should be repeated for each edge at each of the three levels (all cards for Level 1 edges must be input before Level 2 and all Level 2 before Level 3). These should be NCREG(1) + NCREG(2) + NCREG(3). Card 6 cards in total are interspersed with Card 7 cards for each edge.

(1)	IEGPR(1)	= If edge is an aperture, then input the aperture number.
		= If edge is a baffle, then input the following: 100 times the tube number which contains the baffle plus baffle number.
(2)	IEGPR(2)	= The number of apertures in the sequence to the next edge or to the detector, whichever is applicable.
(3)	IEGPR(3)	= 0 The edge is not illuminated.
		= Section number of the edge if the program should check to see whether the edge is illuminated.
(4)	IEGPR(4)	= 0 For single diffraction. 1 The number of the next edge in the sequence to the detector.

Card 7 Format 2I6

NOTE

Card 7 should be repeated for each aperture in the sequence to the next edge or detector; there should be one set of IEGPR(2) cards for each edge.

(1)	ISQS(1)	= Aperture number.
(2)	ISQS(2)	= Mirror number if there is a mirror associated with aperture ISQS(1).

6.2.15 Computation Level

NOTE

This data is read in on FORTRAN unit 5.

Card 1 Format = 2I6

(1)	MNSTRL	= Beginning level of stray light terms to be computed for this run.
(2)	MSTRLV	= Final level of stray light terms to be computed for this run.

6.2.16 Critical and View Factor Tables

NOTE

This data is read in on FORTRAN unit 5.

Card 1 Format = I6

(1)	IOLD	= 0 No previously existing critical table will be used.
		= 1 A copy of an existing critical table will be used for this analysis; the previously created matrix will be read in on FORTRAN unit .

Card 2 Format = I6

(2)	INEW	= 0 The new critical table will not be written out.
		= 1 The new critical table will be written out on FORTRAN unit 12.

6.2.17 Updates

The update procedure allows the user to make several runs in succession, changing a few parameters each time.

6.2.17.1 Mode Data

NOTE

The data in this section is read in on FORTRAN unit 5.

Card 1 Format = 3I6

(1)	KIN	= The FORTRAN input unit number from which the updates are read. A value of 0 indicates that there will not be any updates. A value of -5 indicates a fresh start. Go back to Section 6.2.1.
(2)	MODE	= Refer to Section 6.2.1 for explanation (mode data).
(3)	MODIPR	= Refer to Section 6.2.1 for explanation (mode data).
(4)	MODOPR	= Refer to Section 6.2.1 for explanation (mode data).

Card 2, below, describes the update codes used to describe which type of data is being updated. Updating will continue until an update code of 0 is entered.

Card 2 Format = I6

(1)	IUPDAT	= 0 Updating is complete = 1 Update User Options = 2 Update Source Data = 3 Update Detector Data = 10 Update Coordinate Systems = 11 Update Mirrors = 12 Update Apertures = 13 Update Tubes = 14 Update Sections = 15 Update Wild Card Baffles = 21 Update BRDF Data

6.2.17.2 User Options

Input format for succeeding cards is the same as that for User Options given in Input Data Format (Section 6.2.1).

6.2.17.3 Source Data

Input format for succeeding cards is the same as that for Source Data given in Input Data Format (Section 6.2.1).

6.2.17.4 Detector Data

Input format for succeeding cards is the same as that for Detector Data given in Input Data Format (Section 6.2.1).

6.2.17.5 Coordinate Systems

Card 1A Format = I6

(1)	ISYS	= The number of the coordinate system to be updated. A 0 indicates that no more coordinate systems are to be altered and other updates are to be done.

The succeeding mirror update cards carry a new set of mirror data for mirror IMIRR as described in Mirror Data, Input Data Format (Section 6.2.1).

6.2.17.6 Apertures

Card 1A Format = I6

(1)	IAPER	= The number of the aperture to be updated. A 0 indicates that the aperature updates have been completed.

The succeeding aperture update cards carry a new set of aperture data for aperture IAPER as described in Aperture Data, Input Data Format (Section 6.2.1).

6.2.17.7 Tubes

Card 1A Format = I6

(1)	ITUBE	= The number of the tube to be updated. A 0 indicates that the tube updates have been completed.

The succeeding tube update cards carry a new set of the tube and baffle data for tube ITUBE as described in Tube Data, Input Data Format (Section 6.2.1).

6.2.17.8 Sections

Card 1A Format = I6

(1)	ISECT	= The number of the section to be updated. A 0 indicates that the section updates have been completed.

The succeeding section update cards carry a new set of section data for section ISECT as described in Section Data, Input Data Format (Section 6.2.1).

6.2.17.9 Wild Card Baffles

Card 1A Format = I6

(1)	IWCBAF	= The number of the wild card baffle to be updated. A 0 indicates that the wild card baffle updates have been completed. The succeeding wild card baffle update cards carry a new set of wild card baffle data for wild card baffle IWCBAF as described in Wild Card Baffle Data, Input Data Format (Section 6.2.1).

NOTE

Updates 10 through 15 should not beused to add additional pieces of information, but only to alter existing values; that is changing the position of a baffle but not adding a new baffle.

6.2.17.10 BRDF Data

Card 1A Format = I6

(1)	ISET	= The number of the set of BRDF tables to be updated. A 0 indicates that the BRDF updates have been completed.

The succeeding BRDF update cards carry a new set of surface type and individual table multipliers for BRDF surface type ISET as described in BRDF Data, Input Data Format (Section 6.2.1). These multipliers are applied to the original table values that were read in.

6.2.18 Constructing BRDF Disk Files

This section describes input parameters to the WRTABL program which writes BRDF tables out on two disk files (FORTRAN units 1 and 2), which are read in by the TCRIT, TDFUS and TDFR programs as described in Section 6.2.12. (Also see Section 5.1.1.)

NOTE

The data is read in on FORTRAN unit 5.

Card 1 Format = I6

(1) NTAB = Number of BRDF tables (minimum of 3). A separate table is required for each kind of surface with a different BRDF profile.

Cards 2-6 below should be repeated eight times for each of the NTAB tables, except as modified by Card 2.

Card 2 Format = 2F10.5

(1) ANGI = Angle of incidence for this row of the table.

NOTE

If ANGI < 0, terminate reading rows for this table.

(2) SPECCF = Specular reflectivity coefficient for this angle of incidence.

Cards 3-4

(1) ANGS = Up to 15 scatter angles for the above angle of incidence, 8 per card; two cards are required.

Cards 5-6 Format = 8F10.5

(1) BRDF = Up to 15 BRDF values, corresponding to scatter angles given above, 8 per card; two cards are required.

SECTION VII

TEST EXAMPLES

7.1 INTRODUCTION

In this section, two test examples are given in detail, in the hopes that the reader will be able to find in the examples the answer to questions that arise in the reading of the preceding sections of this report.

Emphasis is given in the examples to the entry of the systems into the computer. A complete description of all the data cards for the analysis of these systems is given in appendices, along with further explanations, where required, elaborating on the instructions found in Section V.

7.2 BAFFLE I TEST EXAMPLE

7.2.1 General

The Baffle I system, shown in Figure 7-1, is a simple system consisting of two spherical mirrors. This system was used to generated laboratory measurements to aid in the initial development of GUERAP II. The system was designed to operate with a finite source, thus avoiding the necessity for an additional collimator, which would introduce another scattering surface.

The baffles in the system (B1 - B5) were such that their inner radii were coincident with a cone formed by the finite source and B1. The mirror aperture had a radius smaller than the projected cone radius so that it serves as the entrance pupil for the system.

The reimaging secondary is oriented so that the final source image is located out of the plane of Figure 7-1. This served to reduce some of the off-axis aberrations in forming the image of the primary aperture where the Lyot stop was to be employed.

Figure 7-2 illustrates the sections and the coordinate systems used to describe the system to the GUERAP II computer program, while Figure 7-3 illustrates the apertures that were used.

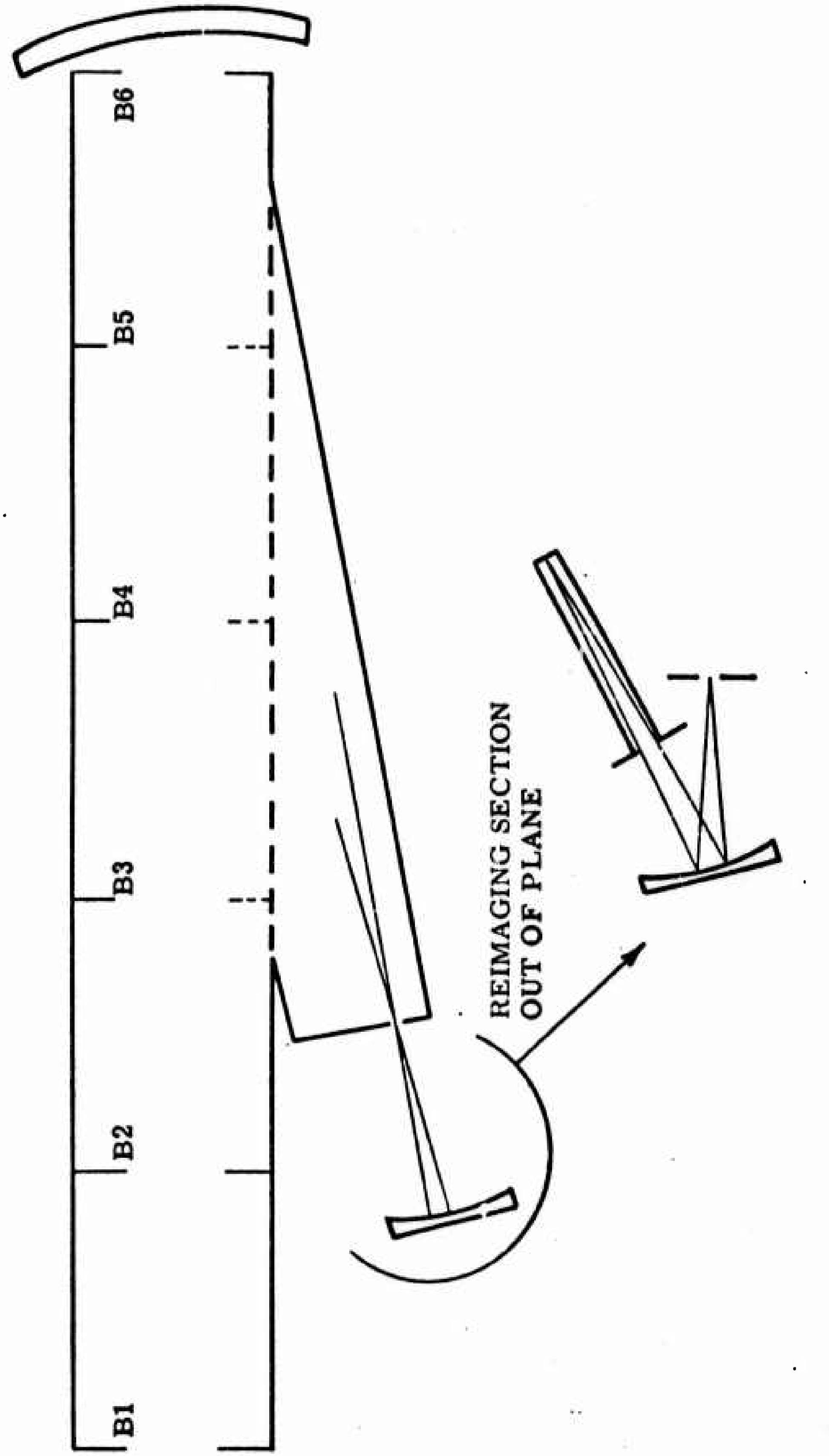
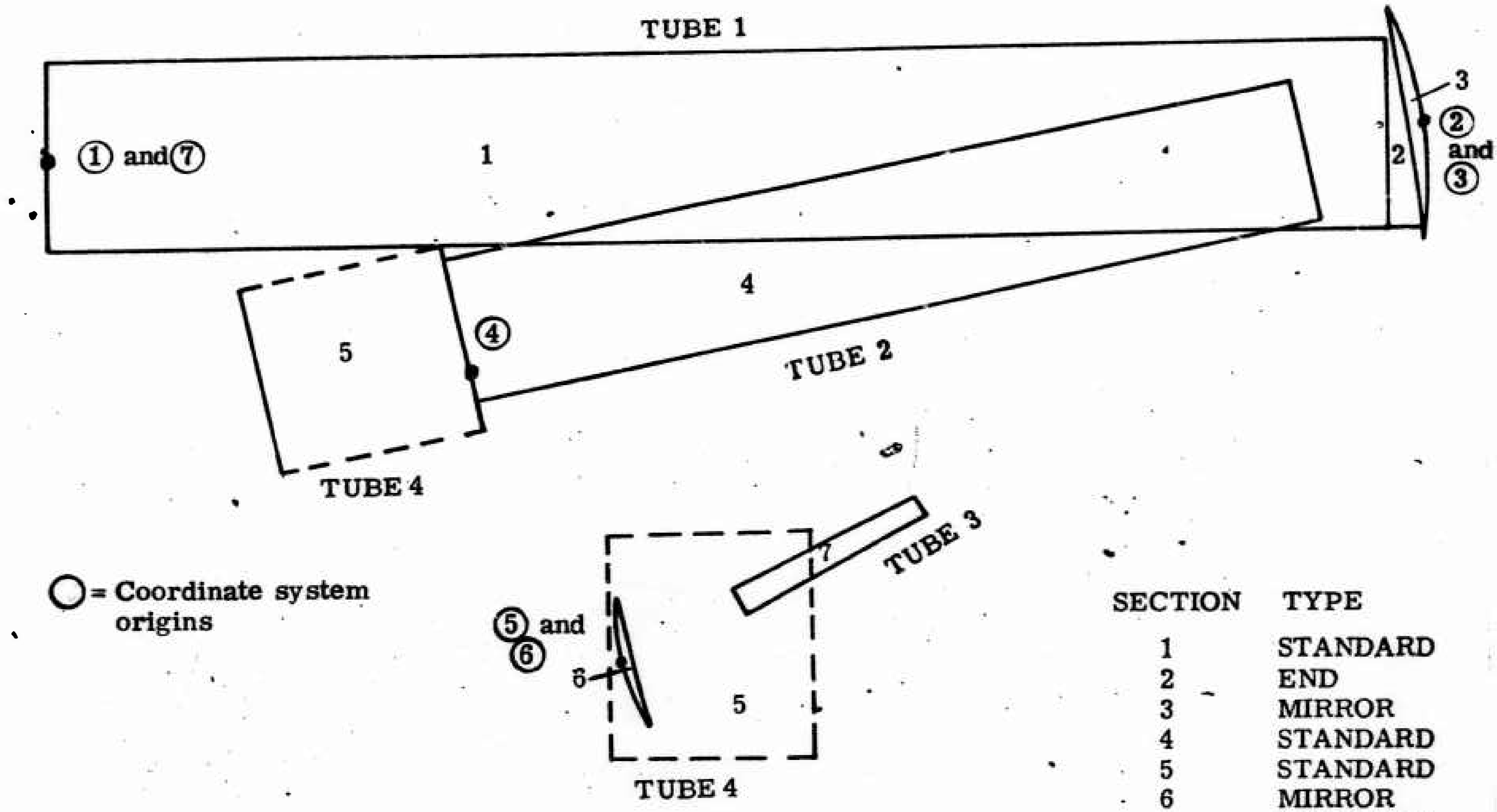


Figure 7-1. Baffle I System



SECTION	TYPE
1	STANDARD
2	END
3	MIRROR
4	STANDARD
5	STANDARD
6	MIRROR
7	STANDARD

Figure 7-2. Sections, Tubes, and Coordinate Systems for Baffle I

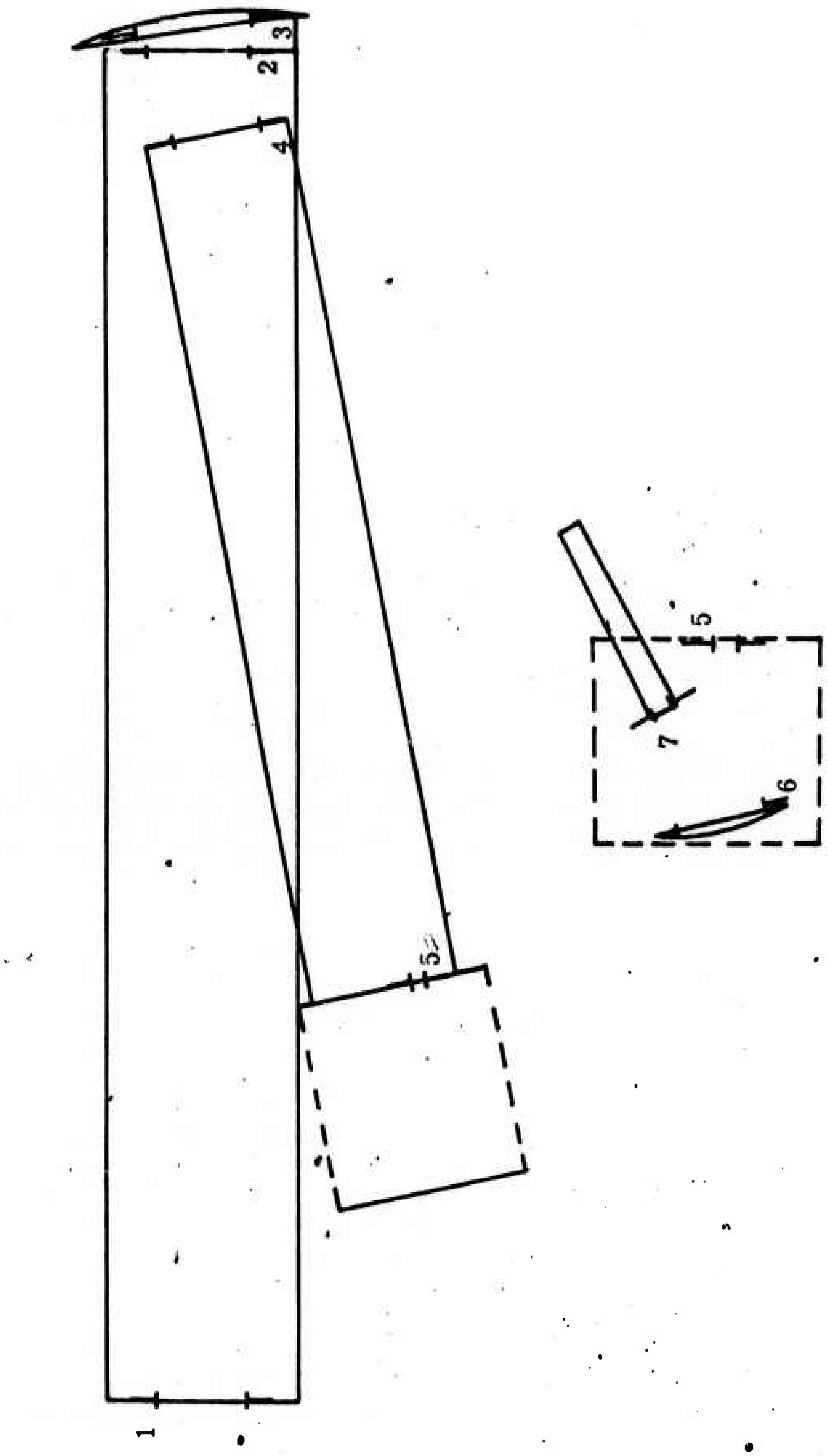


Figure 7-3. Apertures for Baffle I System

7.2.2 Input Data Details

Appendix A contains the detailed input data used to analyze BAFFLE I system, along with detailed explanations. The contents of Appendix I are as follows:

Section	Contents
A-1	Copy of input data cards as read into program
A-2	Input data, with labels, as printed out by GUERAP II; useful for scanning input data before performing analysis to check for obvious errors
A-3	Input data explanation
A-4	Sample program outputs

7.2.3 Stray Light Computations for Baffle I

A laboratory evaluation of the off-axis rejection characteristics of the Baffle I system was performed with and without a Lyot stop. The data generated during that laboratory evaluation provides a means for evaluating the GUERAP II program's analysis of the off-axis rejection capabilities of Baffle I.

7.2.3.1 Diffuse

The major contribution of the diffuse terms is the primary mirror when it is directly illuminated. When the Lyot stop is not in place, the baffle and wall areas surrounding the primary mirror are directly irradiated and serve as critical I surfaces. When the mirror is no longer irradiated (as the source moves further off axis) these become the major diffuse terms. Figure 7-4, which illustrates the results of the diffuse analysis of the Baffle I system, also demonstrates the ability of the program to categorize the stray radiation contributions, allowing one to identify the dominant term at any source angle.

When a Lyot stop is used in conjunction with a re-imaging section, the primary mirror surface diffuse term is unaltered. However, all the critical

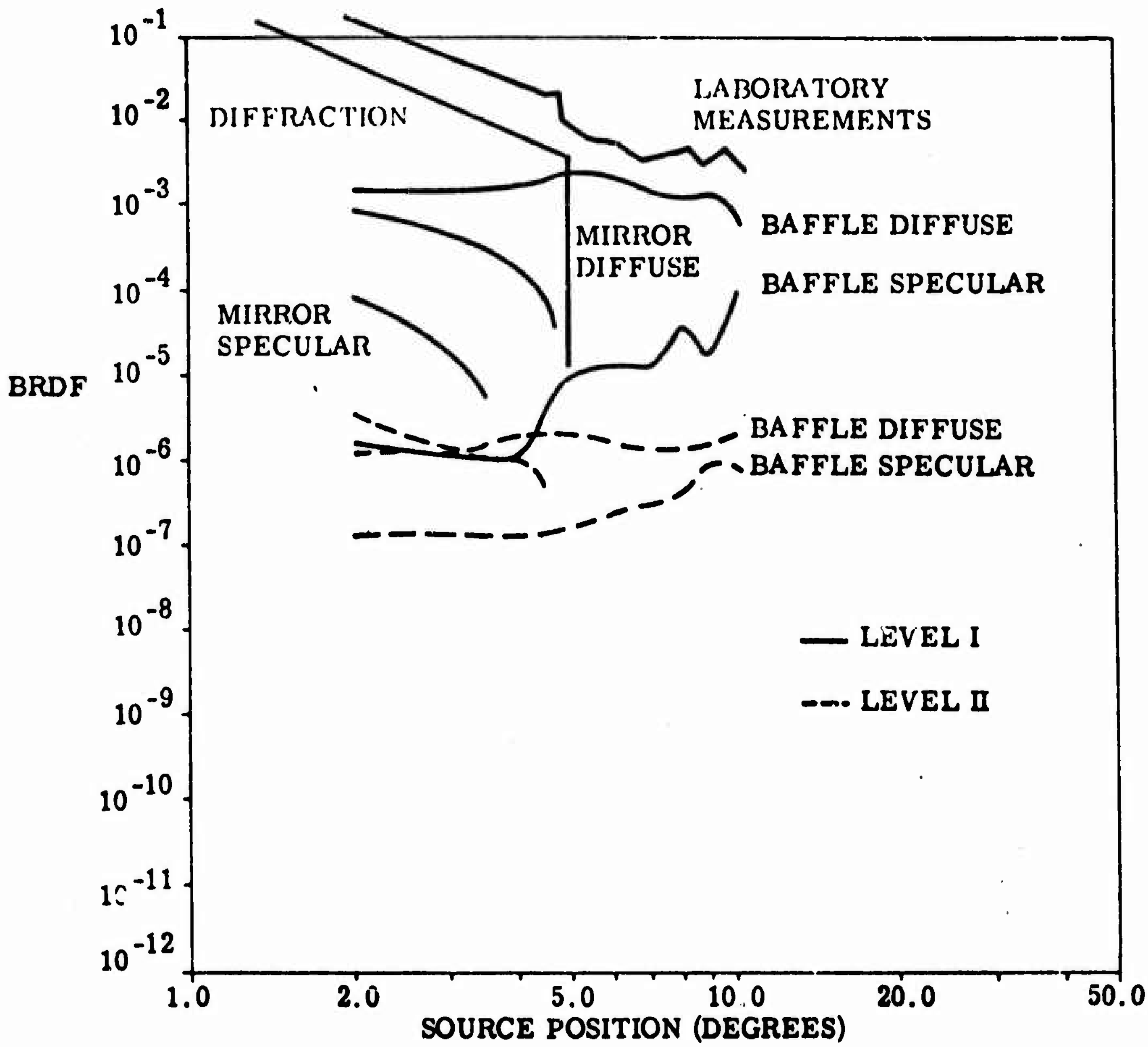


Figure 7-4. GUERAP II Diffuse Analysis; Baffle I, No Relay Optics

I surfaces are eliminated. The higher-order terms (diffuse-diffuse) are the next level, but are well below the critical I levels. Program results for the Lyot-stopped Baffle I are shown in Figure 7-5.

7.2.3.2 Diffraction

The single diffraction from the primary mirror aperture (entrance pupil) serves as the largest off-axis contribution for small angles, if no Lyot stop is used. If a Lyot stop is used, then a triple diffraction path is the dominant diffraction term. Each of these terms is illustrated on Figures 7-4 and 7-5.

7.2.3.3 Lyot Stop Variation

As shown, the off-axis rejection features of an optical system suffering from single diffraction can be dramatically improved by the use of a Lyot stop, if mirror diffuse is not the dominant term. As the radius of the Lyot stop is reduced, the off-axis rejection can be further improved.

This experiment was performed with the laboratory Baffle I system, with an off-axis angle of approximately 1/2° (plane of Figure 7-1). An analogous radii variation prediction was performed using the GUERAP II computer program for both the single and triple diffraction paths. The experimental results showed a large reduction in the diffraction level for a Lyot stop diameter of approximately 10 mm. As previously stated, the system was mirror limited so that the reduction in system BRDF was limited by the mirror scatter. The GUERAP II predicted single and triple diffraction terms are shown in Figure 7-6.

The GUERAP II was also used to compute the BRDF with Lyot stop variation for a 1/2° source position in a direction orthogonal to the plane of Figure 7-1. The results, which revealed that the Lyot stop diameter for this direction is slightly smaller than in the plane rotation discussed previously, showed that the single diffraction reduced to zero for a Lyot stop of approximately 10.5 mm diameter, as opposed to a Lyot stop diameter of approximately 11.5 mm diameter for the source located in the plane of Figure 7-1. This is a real optics phenomenon characteristic of Baffle I, resulting from the

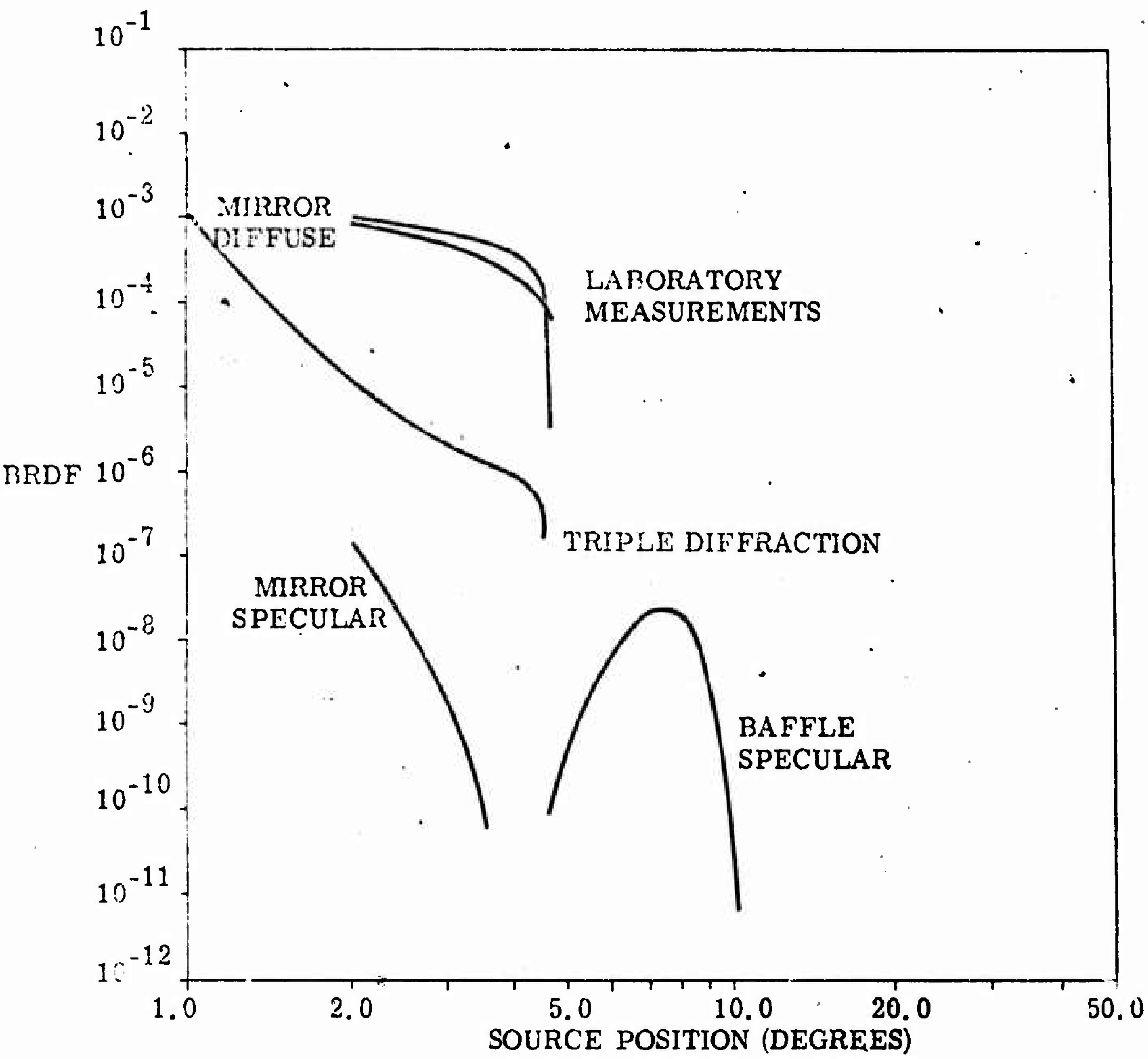


Figure 7-5. GUERAP II Diffuse Analysis; Baffle I with Relay Optics and Lyot Stop

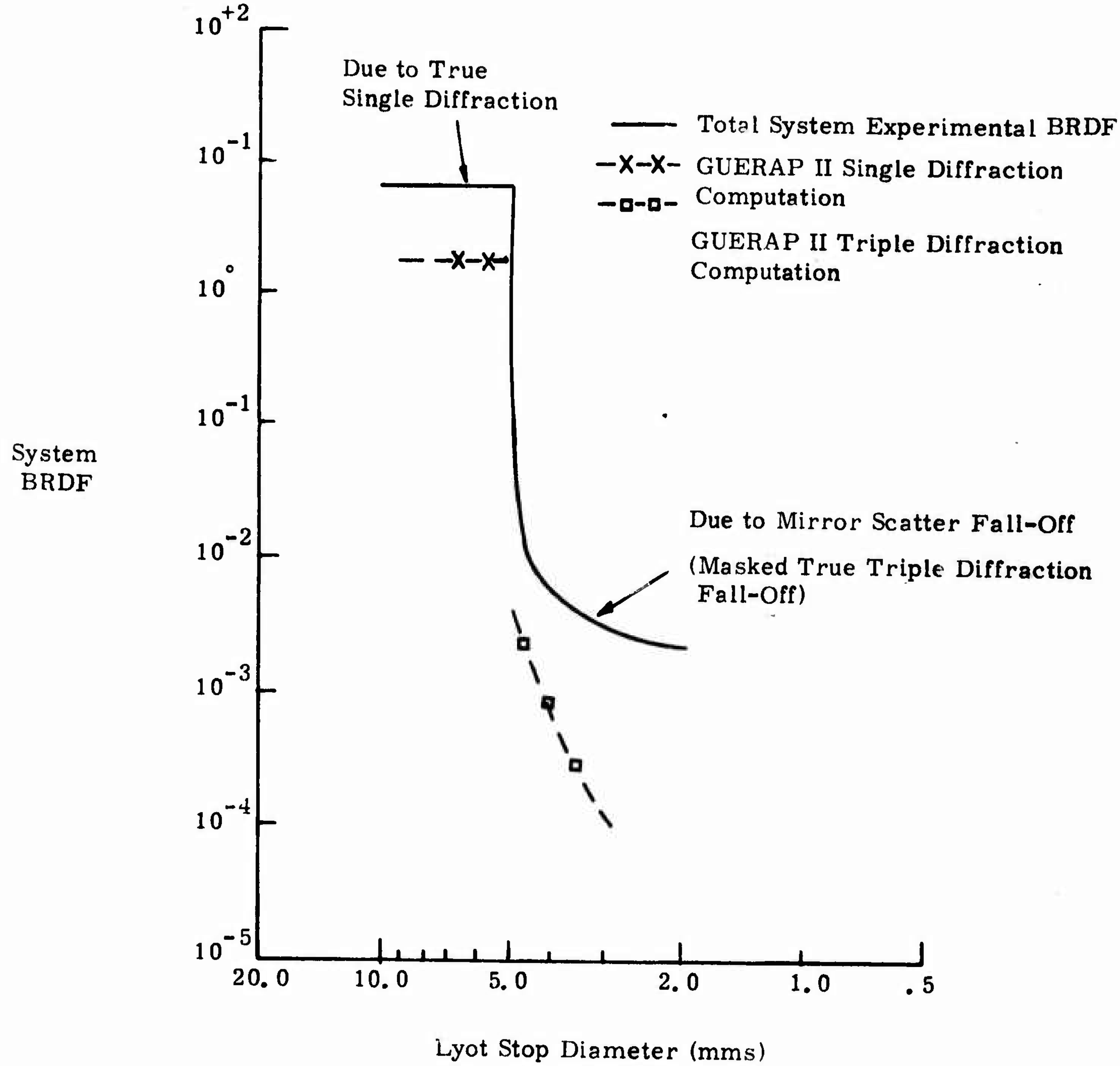


Figure 7-6. Diffraction Analysis of Baffle I system with Varying Lyot Stop Diameter

non-circular image of the primary aperture as formed by the secondary (this non-circular image was observed in the course of the experimental program). The off-axis tilting of the secondary, as well as the aberrations of the overall off-axis system produces the asymmetric aberrated image.

7.3 MARK VII TEST EXAMPLE

7.3.1 General

The Mark VII offers an example of an on-axis optical system which has different stray light characteristics from the Baffle I system. The following sections briefly describe the system, its modeling into GUERAP II, and some off-axis energy rejection features as provided by both experiment and theory.

The Mark VII optical sensor is shown in Figure 7-7. It is a 15 inch aperture f/2.2 modified folded Gregorian system with approximately a 1° field of view. The systems contain four reflecting elements; a spherical primary, aspheric secondary and tertiary, and a planar quaternary. The secondary is supported by four struts. The entrance aperture and the other baffles positioned between the entrance aperture and the primary aperture lie on a cone of sufficient radius to prevent single diffraction from getting to the detector plane. The prevention of single diffraction from the primary aperture or the secondary mount can be prevented by positioning a Lyot stop between the tertiary and the quaternary. The detector can see the field stop and therefore double diffraction is inherent in the design and becomes the limiting diffraction level.

7.3.2 Input Data Details

The modeling of the Mark VII in GUERAP II requires similar procedures as that used for Baffle I, the basic difference being that Mark VII is an on-axis system. Whereas the Baffle I system required seven coordinate systems, Mark VII requires a single coordinate system centered at the entrance aperture. The remainder of the modeling consists of fourteen apertures, seven tubes, and twelve sections. The complete placement of the elements is shown in Figure 7-8. The input data and the system optical form printout are given in Appendix II.

7.3.3 Stray Light Computations for Mark VII

The Mark VII Sensor off-axis rejection features were measured experimentally using techniques analogous to those used for the Baffle I system. A point source was located a large distance from the entrance aperture (~ 100 ft) avoiding the additional scatter from a collimator. The detector plane was adjusted so as to be conjugate with the finite source. The experimental BRDF is shown in Figure 7-9.

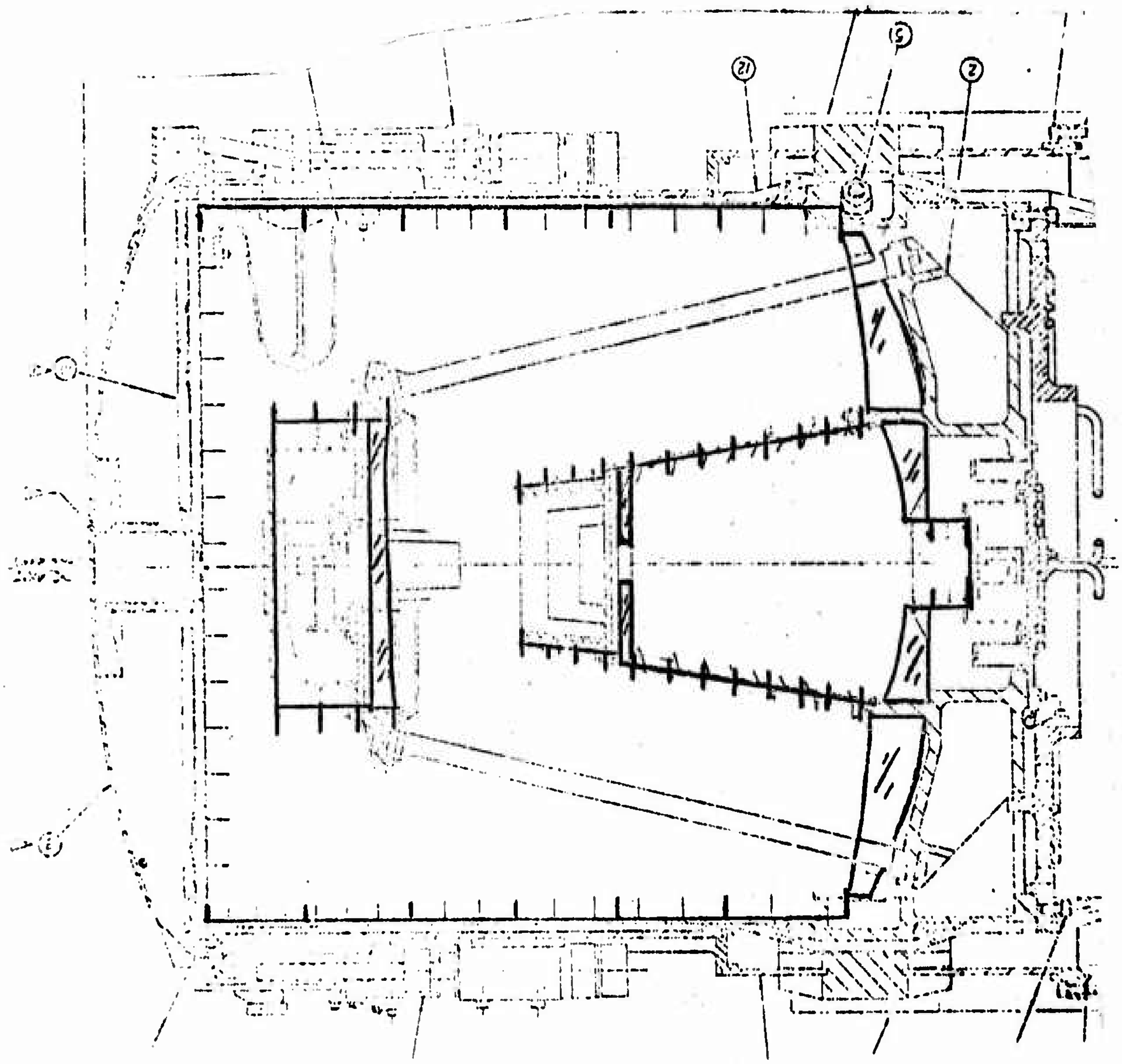


Figure 7-7. Mark VII Sensor

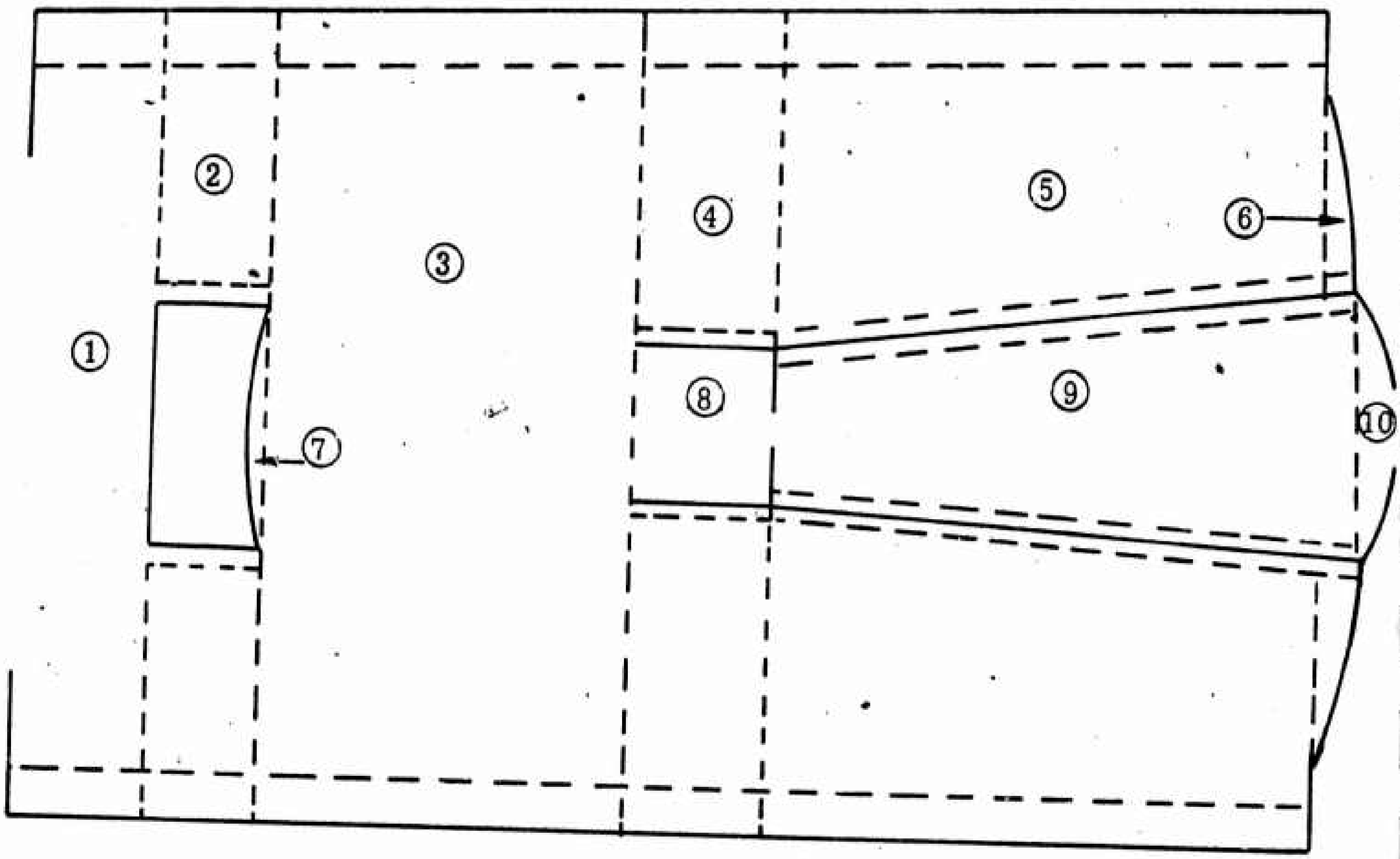


Figure 7-8. GUERAP Description of Mark VII Sensor

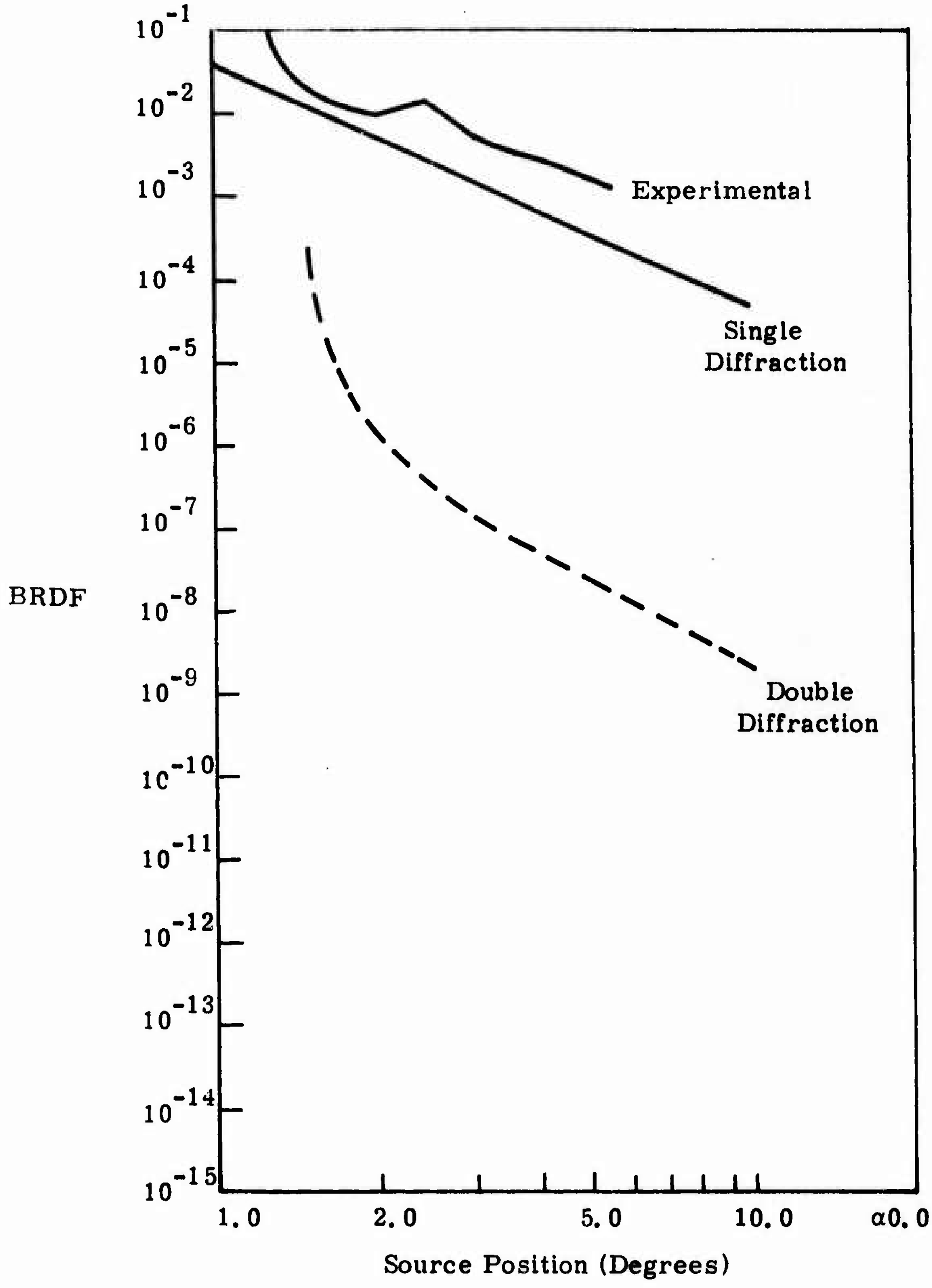


Figure 7-9. Experimental and Calculated BRDF's for Diffraction

The program computations were concerned with verifying the various diffraction paths characteristic of the system. As stated previously, various levels of diffraction are permitted depending upon the degree of Lyot stop usage. The diffractions paths are as follows:

(a) Where no Lyot Stop is employed:

(1) Single diffraction from primary aperture

(2) Single diffraction from secondary tube baffle

(3) Since the detector has an unobstructed view of the field stop, (1) and (2) also play a role in double diffraction paths in which the 2nd diffraction occurs off the field stop.

(b) When a Lyot stop is employed:

The single diffraction paths, (1) and (2), are eliminated and become triple diffraction paths, so that the double diffraction path, (3), would dominate.

The entrance aperture provided no single diffraction paths in agreement with the design objectives. However a slight misplacement of the field stop so as to provide a larger angle subtense was initially entered erroneously in the program model. The misplacement (approximately 3.5% of primary-secondary focus) was sufficient to permit single diffraction paths emanating from the entrance aperture. This is an interesting example of the GUERAP II providing real optics characteristics.

APPENDIX I

BAFFLE I INPUT DATA AND PROGRAM RESULT EXAMPLES

I.1 COPY OF INPUT DATA CARDS FOR BAFFLE I EXAMPLE

```
B-I          GUERAP                05/30/73     14:32:47                PAGE      1

BAFFLE I TEST, WITH TWO DETECTORS
1,1,1,1,0,1,
6,
-5.,5.,-5.,5.,6.,7.,0.,0.,
6,6,2,1,
1.E-10,
2,
.8,
0.,0.,0.,
2,6,
0.,0.,
0.1,0.1,
8,
.2,
.01,91.,
7,
1,
0.,0.,127.,
0.,7.,0.,
2,
0.,0.,0.,
0.,7.,0.,
3,
4.35,0.,-91.,
0.,-3.5,0.,
3,
0.,0.,-108.1,
90.,14.,-90.,
3,
0.,0.,-108.1,
90.,28.,-90.,
1,
0.,0.,0.,
0.,90.,0.,
2,
1,-2,2,
0.,0.,0.,
152.,
1.,
2,
1,5,5,
0.,0.,0.,
22.4,
1.,
2,
8,
1,0,1,0,1,1,
0.,0.,0.,
4.45,
1.,
1,
1,1,2,0,1,1,
0.,0.,125.,
4.57,
1.,
```

```
 56: 1,
 57: 1,2,3,0,2,1,
 58: 0.,0.,126.9,
 59: 6.35,
 60: 1.,
 61: 1,
 62: 1,1,4,0,4,4,
 63: 0.,0.,87.,
 64: 6.35,
 65: 1.,
 66: 1,
 67: 1,4,5,0,4,4,
 68: -4.35,0.,0.,
 69: .5,
 70: 1.,
 71: 1,
 72: 1,5,6,0,5,5,
 73: 0.,0.,1.,
 74: 4.5,
 75: 1.,
 76: 1,
 77: 1,5,7,0,6,6,
 78: 0.,0.,12.3,
 79: 1.,0.,
 80: 1.,
 81: 1,
 82: 1,7,-1,0,6,6,
 83: 0.,0.,31.8,
 84: 1.,
 85: 1.,
 86: 1,
 87: 4,
 88: 1,1,
 89: 1.,
 90: 1,
 91: 0.,0.,0.,
 92: 1,
 93: 4.45,
 94: .0182,
 95: 2,
 96: 0.,0.,0.,
 97: 1,
 98: 8.9,
 99: 0.,
100: 6,
101: 0.,25.,50.,75.,100.,125.,
102: 0.,0.,0.,0.,0.,0.,
103: 4,3,
104: 1.,
105: 1,
106: 0.,0.,0.,
107: 1,
108: 6.35,
109: 0.,
110: 1,
```

```
111: 6,6,
112: 1.,
113: 1,
114: 0.,0.,12.3,
115: 1,
116: 1.,
117: 0.,
118: 1,
119: 4,3,
120: 1.,
121: 1,
122: 0.,0.,0.,
123: 1,
124: 10.,
125: 0.,
126: 1,
127: 7,
128: 0,1,1,2,1,
129: 2,4,2,4,0,
130: 103,1,2,0,0,
131: 200,1,3,0,
132: 0,2,5,4,1,
133: 1,2,2,1,
134: 106,4,5,7,3,
135: 200,2,0,6,
136: 0,3,7,8,0,
137: 2,
138: -1.,-1.,
139: 0,
140: -1.,-1.,
141: 0,
142: 4,
143: 3,1,
144: 5,0,
145: 6,2,
146: 7,0,
147: 2,
148: 1,3,
149: 2,4,
150: 3,
151: 1,2,3,104,
152: 101,2,4,5,
153: 5,6,
154: 5,7,
155: 1,2,104,
156: 1,2,104,
157: 3,
158: 101,102,4,
159: 5,
160: 6,
161: 7,
162: 1,
163: 3,7,
164: -75.,0.,-8.9,
165: 25.,7.,
```

I.2 INPUT DATA, WITH LABELS, AS PRINTED OUT BY GUERAP II

```
^P67USERID  SCHREYER    05/30/73    14.35.47


INPUT TITLE
BAFFLE I TEST, WITH TWO DETECTORS
INPUT IDIFFR,IBSPEC,IBDIFF,IMSPEC,IMDIFF,IOPTN
     1      1      1      1      C      1
INPUT INMOD
     6
INPUT XST,XFIN,YST,YFIN,ALPHA1,ALPHA2,BETA1,BETA2,
 -5.00000   5.00000  -5.00000   5.00000   6.00000   7.00000   0.0        0.0
INPUT N,NN,NNN,NNNN
     6      6      2      1
INPUT INTENSITY CUTOFF VALUE
 0.10000D-09
INPUT MAXIMUM RECURSION LEVEL
     2
INPUT FRACTIONAL COVERING DESIRED
  0.80000
INPUT XDET,YDET,ZDET
  0.0        0.0        0.0
INPUT NUMBER OF DETECTORS AND AXES OF DETECTOR PLANE
     2      6
INPUT X,Y POSITION OF DETECTOR
  0.0        0.0
 .PUT X,Y POSITION OF DETECTOR
  0.10000   0.10000
INPUT NBINS
     8
INPUT BINSIZ
  0.20000
INPUT DTAREA,EFL
  0.01000  91.00000
```

```
INPUT NUMBER OF LOCAL COORDINATE SYSTEMS
    7
INPUT REFERENCE AXIS NUMBER
    1
INPUT ORIGIN FOR THIS COORDINATE SYSTEM
  0.0         0.0       127.00000
INPUT EULER ANGLES FOR AXES BETA,GAMMA,DELTA
  0.0         7.00000    0.0
INPUT REFERENCE AXIS NUMBER
    2
INPUT ORIGIN FOR THIS COORDINATE SYSTEM
  0.0         0.0         0.0
INPUT EULER ANGLES FOR AXES BETA,GAMMA,DELTA
  0.0         7.00000    0.0
INPUT REFERENCE AXIS NUMBER
    3
INPUT ORIGIN FOR THIS COORDINATE SYSTEM
  4.35000    0.0       -91.00000
INPUT EULER ANGLES FOR AXES BETA,GAMMA,DELTA
  0.0        -3.50000    0.0
INPUT REFERENCE AXIS NUMBER
    3
INPUT ORIGIN FOR THIS COORDINATE SYSTEM
  0.0         0.0      -108.10000
INPUT EULER ANGLES FOR AXES BETA,GAMMA,DELTA
 90.00000   14.00000 -90.00000
INPUT REFERENCE AXIS NUMBER
    3
INPUT ORIGIN FOR THIS COORDINATE SYSTEM
  0.0         0.0      -108.10000
  PUT EULER ANGLES FOR AXES BETA,GAMMA,DELTA
 90.00000   28.00000 -90.00000
INPUT REFERENCE AXIS NUMBER
    1
INPUT ORIGIN FOR THIS COORDINATE SYSTEM
  0.0         0.0         0.0
INPUT EULER ANGLES FOR AXES BETA,GAMMA,DELTA
  0.0        90.00000    0.0
```

```
INPUT NUMBER OF MIRRORS
    2
INPUT MIRROR TYPE, MIRROR AND REFERENCE AXES NUMBERS
    1     -2     2
INPUT XVERT,YVERT,ZVERT OF MIRROR
  0.0        0.0        0.0
INPUT MIRROR RADIUS
152.00000
INPUT MIRROR REFLECTIVITY
  1.00000
INPUT BRDF TYPE
    2
INPUT MIRROR TYPE, MIRROR AND REFERENCE AXES NUMBERS
    1      5     5
INPUT XVERT,YVERT,ZVERT OF MIRROR
  0.0        0.0        0.0
INPUT MIRROR RADIUS
 22.40000
INPUT MIRROR REFLECTIVITY
  1.00000
INPUT BRDF TYPE
    2
```

```
INPUT NUMBER OF APERTURES
   8
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
    1     0     1     0     1     1
INPUT CENTER POSITION
  0.0         0.0         0.0
INPUT APERTURE DIMENSIONS
  4.45000   0.0
INPUT APERTURE REFLECTIVITY
  1.00000
INPUT BRDF TYPE
    1
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
    1     1     2     0     1     1
INPUT CENTER POSITION
  0.0         0.0       125.00000
INPUT APERTURE DIMENSIONS
  4.57000   0.0
INPUT APERTURE REFLECTIVITY
  1.00000
INPUT BRDF TYPE
    1
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
    1     2     3     0     2     1
INPUT CENTER POSITION
  0.0         0.0       126.90000
INPUT APERTURE DIMENSIONS
  6.35000   0.0
INPUT APERTURE REFLECTIVITY
  1.00000
  PUT BRDF TYPE
    1
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
    1     1     4     0     4     4
INPUT CENTER POSITION
  0.0         0.0        87.00000
INPUT APERTURE DIMENSIONS
  6.35000   0.0
INPUT APERTURE REFLECTIVITY
  1.00000
INPUT BRDF TYPE
    1
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
    1     4     5     0     4     4
INPUT CENTER POSITION
 -4.35000   0.0         0.0
INPUT APERTURE DIMENSIONS
  0.50000   0.0
INPUT APERTURE REFLECTIVITY
  1.00000
INPUT BRDF TYPE
    1
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
    1     5     6     0     5     5
INPUT CENTER POSITION
  0.0         0.0         1.00000
INPUT APERTURE DIMENSIONS
  4.50000   0.0
INPUT APERTURE REFLECTIVITY
  1.00000
INPUT BRDF TYPE
    1
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
```

```
INPUT CENTER POSITION
  0.0         0.0        12.30000
INPUT APERTURE DIMENSIONS
  1.00000   0.0
INPUT APERTURE REFLECTIVITY
  1.00000
INPUT BRDF TYPE
    1
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
    1     7    -1     0     6     6
INPUT CENTER POSITION
  0.0         0.0        31.80000
INPUT APERTURE DIMENSIONS
  1.00000   0.0
INPUT APERTURE REFLECTIVITY
  1.00000
INPUT BRDF TYPE
    1
```

```
INPUT NUMBER OF TUBES
     4
INPUT AXIS NUMBER FOR TUBE, AND REFERENCE AXIS NUMBER
     1     1
'NPUT REFTUB
  1.00000
INPUT BRDF TYPE
     1
INPUT XAB,YAB,ZAB
  0.0        0.0        0.0
INPUT ITYPE
     1
INPUT RADIUS
  4.45000
INPUT SLOPE
  0.01820
INPUT IBAFF,IWCBAF
     2     0
INPUT XAB,YAB,ZAB
  0.0        0.0        0.0
INPUT ITYPE
     1
INPUT RADIUS
  8.90000
INPUT SLOPE
  0.0
INPUT MBAF
     6
INPUT ZB(I),I=1,MBAF
  0.0        25.00000  50.00000  75.00000 100.00000 125.00000
  PUT S(I),I=1,MBAF
  0.0        0.0        0.0        0.0        0.0        0.0
INPUT AXIS NUMBER FOR TUBE, AND REFERENCE AXIS NUMBER
     4     3
INPUT REFTUB
  1.00000
INPUT BRDF TYPE
     1
INPUT XAB,YAB,ZAB
  0.0        0.0        0.0
INPUT ITYPE
     1
INPUT RADIUS
  6.35000
INPUT SLOPE
  0.0
INPUT IBAFF,IWCBAF
     1     0
INPUT AXIS NUMBER FOR TUBE, AND REFERENCE AXIS NUMBER
     6     6
INPUT REFTUB
  1.00000
INPUT BRDF TYPE
     1
INPUT XAB,YAB,ZAB
  0.0        0.0       12.30000
.NPUT ITYPE
     1
INPUT RADIUS
  1.00000
INPUT SLOPE
  0.0
INPUT IBAFF,IWCBAF
```

```
INPUT AXIS NUMBER FOR TUBE, AND REFERENCE AXIS NUMBER
    4     3
INPUT REFTUB
  1.00000
INPUT BRDF TYPE
    1
INPUT XAB,YAB,ZAB
  0.0        0.0        0.0
INPUT ITYPE
    1
INPUT RADIUS
 10.00000
INPUT SLOPE
  0.0
INPUT IBAFF,IWCBAF
    1      0
```

```
INPUT NUMBER OF SECTIONS
      7
INPUT JTYPE,JSECT1,JBACK,JNEXT,JSECT2,JSECT3 OF SECTION
      0      1      1      2      1      0
INPUT TUBE, APERTURE, DIRECTION, SECTION, AND FLAG FOR FIRST HOLE
      2      4      2      4      0
INPUT JTYPE,JSECT1,JBACK,JNEXT,JSECT2,JSECT3 OF SECTION
    103      1      2      0      0      0
INPUT JTYPE,JSECT1,JBACK,JNEXT,JSECT2,JSECT3 OF SECTION
    200      1      3      0      0      0
INPUT JTYPE,JSECT1,JBACK,JNEXT,JSECT2,JSECT3 OF SECTION
      0      2      5      4      1      0
INPUT TUBE, APERTURE, DIRECTION, SECTION, AND FLAG FOR FIRST HOLE
      1      2      2      1      0
INPUT JTYPE,JSECT1,JBACK,JNEXT,JSECT2,JSECT3 OF SECTION
    106      4      5      7      3      0
INPUT JTYPE,JSECT1,JBACK,JNEXT,JSECT2,JSECT3 OF SECTION
    200      2      0      6      0      0
INPUT JTYPE,JSECT1,JBACK,JNEXT,JSECT2,JSECT3 OF SECTION
      0      3      7      8      0      0
```

INPUT NUMBER OF BRDF TYPES
2
INPUT GENERAL SPECULAR AND DIFFUSE MULTIPLIERS
-1.00000 -1.00000
SET NO. 1 INPUT TABLES TO HAVE MULTPLIERS
0 0 0 0 0 0 0 0

SET NO.= 1 TABLE NO.= 1

SPECULAR REFLECTIVITY= 0.02500 MAXIMUM INCIDENT ANGLE FOR TABLE= 20.00000

2.00000	0.14000
2.50000	0.11000
3.00000	0.05300
4.50000	0.02700
6.00000	0.01400
13.00000	0.00720
37.00000	0.00370
40.00000	0.00180
56.00000	0.00090
61.00000	0.00050
180.00000	0.00030

SET NO.= 1 TABLE NO.= 2

SPECULAR REFLECTIVITY= 0.04000 MAXIMUM INCIDENT ANGLE FOR TABLE= 45.00000

2.00000	0.28000
3.00000	0.14000
4.00000	0.06700
7.00000	0.03400
8.50000	0.01700
25.00000	0.00750
70.00000	0.00380
180.00000	0.00170

SET NO.= 1 TABLE NO.= 3

SPECULAR REFLECTIVITY= 0.03500 MAXIMUM INCIDENT ANGLE FOR TABLE= 75.00000

1.00000	1.10000
1.20000	0.82000
1.30000	0.40000
1.50000	0.20000
2.00000	0.09800
3.00000	0.05000
4.00000	0.02500
8.50000	0.01200
19.00000	0.00600
75.00000	0.00400
97.00000	0.00320
180.00000	0.00230

SET NO.= 1 TABLE NO.= 4

SPECULAR REFLECTIVITY= 0.40000 MAXIMUM INCIDENT ANGLE FOR TABLE= 90.00000

1.00000	1.10000
1.20000	0.82000
1.30000	0.40000

2.00000	0.09800
3.00000	0.05000
4.00000	0.02500
8.50000	0.01200
19.00000	0.00600
75.00000	0.00400
7.00000	0.00320
180.00000	0.00230

INPUT GENERAL SPECULAR AND DIFFUSE MULTIPLIERS

-1.00000 -1.00000

SET NO. 2 INPUT TABLES TO HAVE MULTPLIERS

0 0 0 0 0 0 0 0

SET NO.= 2 TABLE NO.= 1

SPECULAR REFLECTIVITY= 0.95000 MAXIMUM INCIDENT ANGLE FOR TABLE= 90.00000

0.75000	0.00700
1.50000	0.00280
2.50000	0.00200
3.50000	0.00160
4.50000	0.00130
5.50000	0.00100
6.50000	0.00080
7.50000	0.00060
8.50000	0.00051
9.50000	0.00045
12.50000	0.00040
17.50000	0.00025
25.00000	0.00016
5.00000	0.00010
180.00000	0.00004

```
INPUT NCAP
    4
INPUT CRITICAL APERTURE AND ASSOCIATED MIRROR NUMBERS
    3     1
INPUT CRITICAL APERTURE AND ASSOCIATED MIRROR NUMBERS
    5     0
INPUT CRITICAL APERTURE AND ASSOCIATED MIRROR NUMBERS
    6     2
INPUT CRITICAL APERTURE AND ASSOCIATED MIRROR NUMBERS
    7     0
APERTURE  1 SEES APERTURES--
    2     0     0     0     0     0     0     0
APERTURE  2 SEES APERTURES--
    1     3     0     0     0     0     0     0
APERTURE  3 SEES APERTURES--
    2     4     0     0     0     0     0     0
APERTURE  4 SEES APERTURES--
    3     0     0     0     0     0     0     0
APERTURE  1 SEES SECTIONS--
    1     2     3   104     0     0     0     0
APERTURE  2 SEES SECTIONS--
  101     2     4     5     0     0     0     0
APERTURE  3 SEES SECTIONS--
    5     6     0     0     0     0     0     0
APERTURE  4 SEES SECTIONS--
    5     7     0     0     0     0     0     0
SECTION  1 SEES SECTIONS--
    1     2   104     0     0     0     0     0
SECTION  2 SEES SECTIONS--
    1     2   104     0     0     0     0     0
SECTION  3 SEES SECTIONS--
    3     0     0     0     0     0     0     0
SECTION  4 SEES SECTIONS--
  101   102     4     0     0     0     0     0
SECTION  5 SEES SECTIONS--
    5     0     0     0     0     0     0     0
SECTION  6 SEES SECTIONS--
    6     0     0     0     0     0     0     0
SECTION  7 SEES SECTIONS--
    7     0     0     0     0     0     0     0
```

I.3 INPUT DATA EXPLANATION

Input Data Explanation

The input data for the BAFFLE I and its evaluation is shown in Section A-1 of Appendix A; Section A-2 gives a card-by-card listing of the terms along with labels. These labeled data are printed out by the program after the data is read in, and should be used to do a quick scan of the input data to look for obvious errors. The order is the same as that in the input format, Section VI.

The following paragraphs give a description of why certain input values are used. This will not include dimensional values which are characteristic of the system, but only those values that describe the system program definition and the run to be performed. The input format section explains, for all the cards, the number used. Reference is made to the card number order in Section A-2 with the term self-explanatory (se) referring to those cards that are straightforward.

Card Number	Comments
1	(se)
2	(se)
3	(se)
4	The Hexagonal Grid was selected to fill the entrance aperture. The X-Y grid values should be sufficient to cover the entrance aperture. The angle values select the desired off-axis value (in this case 6.0°) and the next value in the selected sequence (in this case 7.0°).
5	The entrance aperture is filled with 6 elements in the X and Y direction.
6	Based upon the baffle surface reflectivity, the attenuation cut-off value should permit 5-6 reflections

Card Number	Comments
7	The initial maximum recursion should be not so high as to use additional computer time without much benefit. The value 2 permits a single differential breakdown (i.e., 4 times as many central rays) while permitting a look at the system complexity. A higher value should be used only if required, as judged by the entrance aperture coverage.
8	The entrance aperture fractional coverage is similar to Card 7 in that extreme values (0 or 1) either restrict the evaluation or require more time, reducing the advantages of the differential technique.
9	(se)
10	The coordinate system used to define the focal plane describes the detector plane.
11	(se)
12	The additional detector coordinates.
13	(se)
14	(se)
15	(se)
16	The number is sufficient to describe the various sections comprising the system.
17	The 1st coordinate system refers to the one at the center on the mirror. The (XYZ) values are measured from the 1st coordinate system origins using a coordinate system tilted parallel to the mirror normal (7°).
18	The 2nd system origin is measured from the 1-system origin.

Card Number	Comments
19	As stated above. the tilt angle is (0, 7°, 0) from the 1st coordinate system.
20	The 3rd system is referenced to the 2nd system.
21	The 3rd system has the same origin as the 2-system.
22	The 3rd system is tilted (0,7°,0) relative to the 2nd system.
23	The 4th system is referenced to the 3rd system.
24	The 4th system origin measured in 4th system with origin at position of 3rd system.
25	The tilt angle of the 4th system relative to the 3rd system is (0, -3.5, 0).
26	The 5th system is referenced to the 3rd.
27	(se)
28	(se)
29	The 6th system is referenced to the 3rd.
30	(se)
31	(se)
32	The 7th system is referenced to the 1st.
33	(se)
34	(se)
35	(se)
36	The mirror is concave (1); the used section is on negative side of z-axis of 2nd system and is referenced to the 2nd coordinate system.

Card Number	Comments
37	The center of the mirror is coincident with the origin of the 2nd system.
38	(se)
39	(se)
40	It has a BRDF of Type 2; a table contains the mirror BRDF versus angle values
41	The second mirror is concave (1); the used section is on the positive Z-axis of the 5th system.
42	The center of the 2nd mirror is coincident with the origin of the 5th system.
43	(se)
44	(se)
45	(se)
46	There are 8 apertures.
47	The 1st aperture is circular (1), has no section; is below it (0), has the 1st section forward of it (1), has no aperture inside it (0), has an axis coincident with the 1st coordinate with the 1st coordinate system, and is referenced to the first coordinate system.
48	(se)
49	(se)
50	(se)
51	The BRDF values used are from the 1st table.
52-86	(se) Describes the other 7 apertures in similar manner.
87	There are 4 tubes.
88-126	Describes the 4 tubes in the system.

Card Number	Comments
127	There are 7 sections.
127-136	(se) Describes the 7 sections.
137	There are 2 BRDF types.
138-141	(se)
142	There are 4 critical apertures in the system.
143-146	Aperture-mirror relationship if aperture defines mirror.
147-150	Aperture to Aperture viewability.
151-154	Aperture to Section viewability.
155-161	Section to Section viewability.

I.4 OUTPUT EXAMPLES

```
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SYSTEM TITLE : BAFFLE I TEST

BAFFLE DESIGN ITERATION  0

* * * * * * * * OPTICAL FORM DATA * * * * * * * *

*** COORDINATE SYSTEMS ***

AXIS NO.           ORIGIN                    AXIS TILTS
     1         0.0   0.0   0.0           0.0   0.0   0.0
     2       -15.5   0.0 126.1           0.0   7.0   0.0
     3       -30.7   0.0 123.2           0.0  14.0   0.0
     4       -24.4   0.0  33.8           0.0  10.5   0.0
     5       -30.7  -3.7  14.7          45.9  19.7 -13.6
     6       -30.7  -7.1  13.4          65.5  31.0 -27.1
     7         0.0   0.0   0.0           0.0  90.0   0.0

*** SECTIONS ***
                                   SECTION      SECTION CONTENTS
SECTION TYPE     Z1       Z2        AXIS     MIRRORS APERTURES      TUBES
   1       0    0.0    125.00        1          0      1  2  0      1  0
   2     103  125.05     0.0         2          0      2  0  3      0  1
   3     200  125.95     0.0         2          1      3  0  0      0  0
   4       0   33.78   120.78        4          0      5  4  0      2  0
   5     106   33.78    25.66        5          0      5  7  6      3  4
   6     200    0.0     15.68        5          2      0  6  0      0  0
   7       0   25.66    45.16        6          0      7  8  0      3  0

*** MIRRORS ***
                  APERTURE   MIRROR    CENTER    VERTEX   MIRROR    MIRROR
MIRROR  SECTION     NUMS      TYPE    POSITION  POSITION   AXIS   DIMENSIONS
   1       3       3   0       1       -25.9      126.1      2     152.0   0.0
   2       6       0   6       1        37.1       14.7      5      22.4   0.0

*** APERTURES ***
                  APERTURE  Z-AXIS   APERTURE  APERTURE
APERTURE SECTION    TYPE   POSITION    AXIS    DIMENSIONS
    1      0  1      1        0.0        1      4.5   0.0
    2      1  2      1      125.0        1      4.6   0.0
    3      2  3      1      126.0        2      6.4   0.0
    4      1  4      1      120.8        4      6.4   0.0
    5      4  5      1       33.8        4      0.5   0.0
    6      5  6      1       15.7        5      4.5   0.0
    7      5  7      1       25.7        6      0.5   0.0
    8      7 -1      1       45.2        6      1.0   0.0

*** TUBES ***

       TUBE                   TUBE     REAL TUBE        IMAG TUBE      BAFFLE
TUBE   TYPE    Z1     Z2      AXIS     DIMENSIONS       DIMENSIONS     GROUP
  1      1     0.0    0.0      1        8.9    8.9      4.5    4.5       1
  2      1     0.0    0.0      4        6.4    6.4
  3      1     0.0    0.0      6        1.0    1.0
  4      1     0.0    0.0      4       10.0   10.0
```

SYSTEM TITLE : BAFFLE I TEST

BAFFLE DESIGN ITERATION 5

*** BAFFLE GROUPS ***

BAFFLE GROUP	SECTION	BAFFLE TYPE	Z1	Z2	NO. OF BAFFLES	MATERIALS
1	6	1	0.0	125.0	6	

SYSTEM TITLE : BAFFLE I TEST

BAFFLE DESIGN ITERATION 5

* * * * * * BAFFLE GROUP SUMMARY * * * * * *

*** BAFFLE GROUP NUMBER 1 ***

BAFFLE	TYPE	Z	INNER DIMENSIONS	
1	1	0.0	4.45	4.45
2	1	25.0	4.91	4.91
3	1	50.0	5.36	5.36
4	1	75.0	5.82	5.82
5	1	100.0	6.27	6.27
6	0	125.0	6.73	6.73

SYSTEM TITLE : BAFFLE I TEST

BAFFLE DESIGN ITERATION 0

* * * HAND CALCULATED VIEW FACTOR SUMMARY * * *

CRITICAL APERTURES	ASSOC. MIRROR NUMBER
3	1
5 -	2
6	2
7	0

APERTURE TO APERTURE

0	1	0	0
1	0	1	0
0	1	0	1
0	0	1	0

APERTURE TO SECTION

1	1	1	-1	0	0	0
-1	1	0	1	1	0	0
0	0	0	0	1	1	0
0	0	0	0	1	0	1

SECTION TO SECTION

1	1	0	-1	0	0	0
1	1	0	1	0	0	0
0	0	1	0	0	0	0
-1	1	0	1	0	0	0
0	0	0	0	1	0	0
0	0	0	0	0	1	0
0	0	0	0	0	0	1

SYSTEM TITLE : BAFFLE I TEST

BAFFLE DESIGN ITERATION 0

* * * * * INCOMING RAYS DESCRIPTION * * * * *

SOURCE TYPE.....4 POINT
GRID PATTERN.....HEXAGONAL
WITH DIFFERENTIALS

	INITIAL VALUE	FINAL VALUE	INCREMENT
X VALUE	-5.00000	5.00000	2.00000
Y VALUE	-5.00000	5.00000	2.00000

SOURCE DISTANCE IS 270.00000

INTENSITY CUTOFF VALUE IS 0.1000D-04

MAXIMUM RECURSION LEVEL IS 2

FRACTIONAL COVERING IS 0.80000

* * * * * DETECTOR DESCRIPTION * * * * *

DETECTOR PLANE CENTERED AT -30.72408 -7.10196 45.15684
ON AXIS NO. 4
AFTER APERTURE NO. 8

DETECTOR NO.	POSITION	
1	0.0	0.0

THE DETECTOR PLANE IS 8 BY 6 UNITS
EACH DETECTOR UNIT MEASURES 0.20000 BY 0.20000

THE DETECTOR SUBTENSE IS 0.35D-06

```
SYSTEM TITLE : BAFFLE I TEST

BAFFLE DESIGN ITERATION  0

STRAY LIGHT INTERACTION LEVEL  1


* * * * * * * CRITICAL SURFACES * * * * * * *

*** TUBES ***
TUBE  SOLID
 NO.  ANGLE          POINTS
  3  0.10-01   -8.10, 25.66; -6.10, 25.66; -8.10, 45.16; -6.10, 45.16;
  3  0.10-01  -29.72, 45.16;-31.72, 45.16;-31.72, 64.66;-29.72, 64.66;
  3  0.10-01   -8.10, 64.66; -6.10, 64.66; -8.10, 84.16; -6.10, 84.16;
  3  0.10-01  -29.72, 84.16;-31.72, 84.16;-31.72,103.66;-29.72,103.66;

*** APERTURES ***
APERTURE       SOLID
   NO.   SIDE  ANGLE            POINTS
    7      1  0.30-02  -29.72, -6.10;-29.72, -8.10;-31.72, -8.10;

*** BAFFLES ***
BAFFLE BAFFLE          SOLID
GROUP    UNIT  SIDE   ANGLE            POINTS
   1       5   TOP  0.80-04   -4.15, -0.00; -6.74,  2.83: -9.26, -0.00;
```

SYSTEM TITLE : BAFFLE 1 TEST

SOURCE POSITION: PHI = 2.00 DEGREES
ALPHA = 0.0 DEGREES

DETECTOR POSITION: X = 0.0 Y = 0.0

BAFFLE DESIGN ITERATION 0

STRAY LIGHT INTERACTION LEVEL 1

* * * * * * UNWANTED ENERGY SUMMARY * * * * * *

DETECTOR NUMBER 1

UNWANTED COMPONENT	SYSTEM BRDF	POINT SOURCE REJECTION RATIO
BAFFLE DIFFRACTION	0.0	0.0
BAFFLE DIFFUSE	0.0	0.0
BAFFLE SPECULAR	0.0	0.0
MIRROR DIFFUSE	0.440-03	0.330-09
MIRROR SPECULAR	0.170-06	0.610-13
SPECULAR T-PUT	0.0	0.0
TOTAL SYSTEM	0.440-03	0.330-09

ASSUMED DETECTOR SUBTENSE = 0.350-05 STERADIANS

WAVELENGTH = 0.0 MICRONS

TOTAL INCOMING ENERGY = 0.250 02

COMPUTATION THRESHOLD = 0.100-04

ITERATIVE DIFFERENTIAL DATA:
NUMBER OF ITERATIONS = 2
AREA THRESHOLD = 0.80
INITIAL NUMBER OF DIFF'S = 16
FINAL NUMBER OF DIFF'S = 40

COMPUTE TIME = 0.320 01 SECONDS THIS PASS
0.430 01 SECONDS TOTAL

SYSTEM TITLE : BAFFLE I TEST

SOURCE POSITION: PHI = 3.00 DEGREES
ALPHA = 0.0 DEGREES

DETECTOR POSITION: X = 0.0 Y = 0.0

BAFFLE DESIGN ITERATION 6

STRAY LIGHT INTERACTION LEVEL 1

* * * * * * UNWANTED ENERGY SUMMARY * * * * * *

DETECTOR NUMBER 1

UNWANTED COMPONENT	SYSTEM BRDF	POINT SOURCE REJECTION RATIO
BAFFLE DIFFRACTION	0.0	0.0
BAFFLE DIFFUSE	0.0	0.0
BAFFLE SPECULAR	0.0	0.0
MIRROR DIFFUSE	0.62D-03	0.22D-09
MIRROR SPECULAR	0.19D-08	0.65D-15
SPECULAR T-PUT	0.0	0.0
TOTAL SYSTEM	0.62D-03	0.22D-09

ASSUMED DETECTOR SUBTENSE = 0.35D-06 STERADIANS

WAVELENGTH = 0.0 MICRONS

TOTAL INCOMING ENERGY = 0.32D 02

COMPUTATION THRESHOLD = 0.10D-04

ITERATIVE DIFFERENTIAL DATA:
NUMBER OF ITERATIONS = 2
AREA THRESHOLD = 0.80
INITIAL NUMBER OF DIFF'S = 16
FINAL NUMBER OF DIFF'S = 40

COMPUTE TIME = 0.25D 01 SECONDS THIS PASS
0.68D 01 SECONDS TOTAL

APPENDIX II

MARK VII TEST EXAMPLE

II.1 INPUT DATA CARDS

```
MK7        GUERAP             06/12/73     11:28:57              PAGE      1

 1: MARK VII TEST
 2: 1,0,0,0,0,1,
 3: 6,
 4: -18.,18.,-18.,18.,0.,10.,0.,0.,
 5: 13,13,11,1,
 6: 1.E-5,
 7: 1,
 8: .8,
 9: 0.,0.,0.,
10: 2,1,
11: 0.,0.,
12: .5,.5,
13: 8,
14: .2,
15: .01,34.08,
16: 1,
17: 4,
18: 1,-1,-1,
19: 0.,0.,-51.85,
20: 91.4,
21: 1.,
22: 2,
23: 1,1,-1,
24: 0.,0.,181.96,
25: 170.97,
26: 1.,
27: 2,
28: 1,-1,-1,
29: 0.,0.,19.03,
30: 22.26,
31: 1.,
32: 2,
33: 0,-1,-1,
34: 0.,0.,25.26,
35: 999.99999
36: 1.,
37: 2,
38: 14,
39: 1,0,1,0,1,
40: 0.,0.,0.,
41: 13.6,
42: 1.,
43: 1,
44: 1,5,6,0,1,
45: 0.,0.,37.7
46: 13.15,
47: 1.,
48: 1,
49: -1,6,6,0,1,
50: 0.,0.,39.2,
51: 8.65,
52: 1.,
53: 1,
54: -1,4,5,0,1,
55: 0.,0.,25.26,
```

```
 56: 5.5,
 57: 1.,
 58: 1,
 59: -1,3,4,0,1,
 60: 0.,0.,19.,
 61: 4.5,
 62: 1.,
 63: 1,
 64: -1,2,3,8,1,
 65: 0.,0.,11.3,
 66: 8.6,
 67: 1.,
 68: 1,
 69: -1,1,2,0,1,
 70: 0.,0.,4.4,
 71: 8.6,
 72: 1.,
 73: 1,
 74: 1,7,3,6,1,
 75: 0.,0.,11.3,
 76: 7.395,
 77: 1.,
 78: 1,
 79: 1,3,8,5,1,
 80: 0.,0.,19.,
 81: 3.65,
 82: 1.,
 83: 1,
 84: 1,8,9,0,1,
 85: 0.,0.,25.26,
 86: 1.,
 87: 1.,
 88: 1,
 89: 1,9,10,0,1,
 90: 0.,0.,39.9,
 91: 7.5,
 92: 1.,
 93: 1,
 94: 1,10,12,0,1,
 95: 0.,0.,41.1,
 96: 2.2,
 97:   ,
 98: 1,
 99: 1,11,9,0,1,
100: 0.,0.,25.26,
101: 4.6,
102: 1.,
103: 1,
104: 1,12,-1,0,1,
105: 0.,0.,45.68,
106: 2.2,
107: 1.,
108: 1,
109: 7,
110: 1,
```

```
111: 1.,
112: 1,
113: 0.,0.,0.,
114: 1,
115: 18.8,
116: -.0092,
117: 2,
118: 0.,0.,0.,
119: 1,
120: 19.1,
121: 0.,
122: 7,
123: 0.,4.4,11.3,19.,25.26,30.,37.7,
124: 0.,0.,0.,0.,0.,0.,0.,
125: 1,
126: 1.,
127: 1,
128: 0.,0.,25.26,
129: 1,
130: 5.50001,
131: .2234,
132: 2,
133: 0.,0.,25.26,
134: 1,
135: 5.5,
136: .1481,
137: 8,
138: 25.26,25.8,27.8,30.8,32.8,35.8,37.7,39.2,
139: 0.,0.,0.,0.,0.,0.,0.,0.,
140: 1,
141: 1.,
142: 1,
143: 0.,0.,19.,
144: 1,
145: 4.5,
146: .1562,
147: 2,
148: 0.,0.,19.,
149: 1,
150: 4.05,
151: .0546,
152: 4,
153: 19.,20.5,22.,25.26,
154: 0.,0.,0.,0.,
155: 1,
156: 1.,
157: 1,
158: 0.,0.,4.4,
159: 1,
160: 8.6,
161: 0.,
162: 2,
163: 0.,0.,4.4,
164: 1,
165: 6.5,
```

```
166: 0.,
167: 4,
168: 4.4,6.4,9.3,11.3,
169: 0.,0.,0.,0.,
170: 1,
171: 1.,
172: 1,
173: 0.,0.,25.26,
174: 1,
175: 4.6,
176: .1815,
177: 2,
178: 0.,0.,25.26,
179: 1,
180: 5.5,
181: .1481,
182: 8,
183: 25.26,25.8,27.8,30.8,32.8,35.8,37.7,39.9,
184: 0.,0.,0.,0.,0.,0.,0.,0.,
185: 1,
186: 1.,
187: 1,
188: 0.,0.,19.,
189: 1,
190: 3.65,
191: .0546,
192: 1,
193: 1,
194: 1.,
195: 1,
196: 0.,0.,41.1,
197: 1,
198: 2.2,
199: 0.,
200: 1,
201: 12,
202: 0,1,1,7,
203: 4,1,7,6,
204: 0,1,6,5,
205: 3,1,5,4,
206: 2,1,4,2,
207: 202,1,2,3,
208: 200,2,0,8,
209: 0,6,9,10,
210: 0,5,13,11,
211: 200,3,11,12,
212: 200,4,10,13,
213: 0,7,12,14,
214: 2,
215: -1.,-1.,
216: 0,
217: -1.,-1.,
218: 0,
219: 5,
220: 2,1,
```

```
221: 8,2,
222: 10,0,
223: 11,3,
224: 13,4,
225: 2,
226: 1,3,
227: 2,4,
228: 3,5,
229: 4,
230: 1,2,3,4,5,6,
231: 3,4,5,6,7,8,
232: 1,2,3,8,9,12,
233: 9,10,
234: 9,11,12,
235: 1,2,3,4,5,8,
236: 1,2,3,4,5,8,
237: 1,2,3,4,5,8,
238: 1,2,3,4,5,
239: 1,2,3,4,5,
240: 6,
241: 7,
242: 1,2,3,8,
243: 9,12,
244: 10,
245: 11,
246: 9,12,
247: 0,
```

11.2 INPUT DATA, WITH LABELS, AS PRINTED OUT BY GUERAP II

```
CP67USERID  SCHREYER    06/12/73    11.45.53

INPUT TITLE
MARK VII TEST
INPUT IDIFFR,IBSPEC,IBDIFF,IMSPEC,IMDIFF,IOPTN
     1      0      0      0      0      1
INPUT INMOD
     6
INPUT XST,XFIN,YST,YFIN,ALPHA1,ALPHA2,BETA1,BETA2,
-18.00000  18.00000 -18.00000  18.00000   0.0      10.00000   0.0      0.0
INPUT N,NN,NNN,NNNN
    13     13     11      1
INPUT INTENSITY CUTOFF VALUE
 0.10000-04
INPUT MAXIMUM RECURSION LEVEL
     1
INPUT FRACTIONAL COVERING DESIRED
  0.80000
INPUT XDET,YDET,ZDET
  0.0         0.0         0.0
INPUT NUMBER OF DETECTORS AND AXES OF DETECTOR PLANE
     2      1
INPUT X,Y POSITION OF DETECTOR
  0.0         0.0
INPUT X,Y POSITION OF DETECTOR
  0.50000     0.50000
INPUT NBINS
     8
INPUT BINSIZ
  0.20000
INPUT DTAREA,EFL
  0.01000   34.08000


INPUT NUMBER OF LOCAL COORDINATE SYSTEMS
     1
```

```
INPUT NUMBER OF MIRRORS
    4
INPUT MIRROR TYPE, MIRROR AND REFERENCE AXES NUMBERS
    1     -1     -1
INPUT XCENTR,YCENTR,ZCENTR
  0.0          0.0       -51.85000
INPUT MIRROR RADIUS
 91.40000
INPUT MIRROR REFLECTIVITY
  1.00000
INPUT BRDF TYPE
    2
INPUT MIRROR TYPE, MIRROR AND REFERENCE AXES NUMBERS
    1      1     -1
INPUT XCENTR,YCENTR,ZCENTR
  0.0          0.0       181.96000
INPUT MIRROR RADIUS
170.97000
INPUT MIRROR REFLECTIVITY
  1.00000
INPUT BRDF TYPE
    2
INPUT MIRROR TYPE, MIRROR AND REFERENCE AXES NUMBERS
    1     -1     -1
INPUT XCENTR,YCENTR,ZCENTR
  0.0          0.0        19.03000
INPUT MIRROR RADIUS
 22.26000
INPUT MIRROR REFLECTIVITY
  1.00000
INPUT BRDF TYPE
    2
INPUT MIRROR TYPE, MIRROR AND REFERENCE AXES NUMBERS
    0     -1     -1
INPUT XCENTR,YCENTR,ZCENTR
  0.0          0.0        25.26000
INPUT MIRROR RADIUS
999.99999
INPUT MIRROR REFLECTIVITY
  1.00000
INPUT BRDF TYPE
    2
```

```
INPUT NUMBER OF APERTURES
   14
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
   1     0     1     0     1     0
INPUT CENTER POSITION
  0.0         0.0         0.0
INPUT APERTURE DIMENSIONS
 18.80000   0.0
INPUT APERTURE REFLECTIVITY
  1.00000
INPUT BRDF TYPE
   1
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
   1     5     6     0     1     0
INPUT CENTER POSITION
  0.0         0.0         37.70000
INPUT APERTURE DIMENSIONS
 18.15000   0.0
INPUT APERTURE REFLECTIVITY
  1.00000
INPUT BRDF TYPE
   1
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
  -1     6     6     0     1     0
INPUT CENTER POSITION
  0.0         0.0         39.20000
INPUT APERTURE DIMENSIONS
  8.65000   0.0
INPUT APERTURE REFLECTIVITY
  1.00000
INPUT BRDF TYPE
   1
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
  -1     4     5     0     1     0
INPUT CENTER POSITION
  0.0         0.0         25.26000
INPUT APERTURE DIMENSIONS
  5.50000   0.0
INPUT APERTURE REFLECTIVITY
  1.00000
INPUT BRDF TYPE
   1
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
  -1     3     4     9     1     0
INPUT CENTER POSITION
  0.0         0.0         19.00000
INPUT APERTURE DIMENSIONS
  4.50000   0.0
INPUT APERTURE REFLECTIVITY
  1.00000
INPUT BRDF TYPE
   1
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
  -1     2     3     8     1     0
INPUT CENTER POSITION
  0.0         0.0         11.30000
INPUT APERTURE DIMENSIONS
  8.60000   0.0
INPUT APERTURE REFLECTIVITY
  1.00000
INPUT BRDF TYPE
   1
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
  -1     1     2     0     1     0
```

```
INPUT CENTER POSITION
  0.0        0.0        4.40000
INPUT APERTURE DIMENSIONS
  8.60000   0.0
INPUT APERTURE REFLECTIVITY
  1.00000
INPUT BRDF TYPE
     1
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
     1      7      3      6      1      0
INPUT CENTER POSITION
  0.0        0.0        11.30000
INPUT APERTURE DIMENSIONS
  7.39500   0.0
INPUT APERTURE REFLECTIVITY
  1.00000
INPUT BRDF TYPE
     1
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
     1      3      8      5      1      0
INPUT CENTER POSITION
  0.0        0.0        19.00000
INPUT APERTURE DIMENSIONS
  3.65000   0.0
INPUT APERTURE REFLECTIVITY
  1.00000
INPUT BRDF TYPE
     1
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
     1      8      9      0      1      0
INPUT CENTER POSITION
  0.0        0.0        25.26000
INPUT APERTURE DIMENSIONS
  1.00000   0.0
INPUT APERTURE REFLECTIVITY
  1.00000
INPUT BRDF TYPE
     1
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
     1      9      10     0      1      0
INPUT CENTER POSITION
  0.0        0.0        39.90000
INPUT APERTURE DIMENSIONS
  7.50000   0.0
INPUT APERTURE REFLECTIVITY
  1.00000
INPUT BRDF TYPE
     1
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
     1      10     12     0      1      0
INPUT CENTER POSITION
  0.0        0.0        41.10000
INPUT APERTURE DIMENSIONS
  2.20000   0.0
INPUT APERTURE REFLECTIVITY
  1.00000
INPUT BRDF TYPE
     1
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
     1      11     9      0      1      0
INPUT CENTER POSITION
  0.0        0.0        25.26000
INPUT APERTURE DIMENSIONS
  4.60000   0.0
INPUT APERTURE REFLECTIVITY
  1.00000
```

```
INPUT BRDF TYPE
    1
INPUT KATYP,KABACK,KANEXT,KOTHER,KAXES,KREF
    1    12    -1     0     1     0
INPUT CENTER POSITION
  0.0         0.0        45.68000
INPUT APERTURE DIMENSIONS
  2.20000    0.0
INPUT APERTURE REFLECTIVITY
  1.00000
INPUT BRDF TYPE
    1
```

```
INPUT NUMBER OF TUBES
    7
INPUT AXIS NUMBER FOR TUBE, AND REFERENCE AXIS NUMBER
    1     0
INPUT REFTUB
  1.00000
INPUT BRDF TYPE
    1
INPUT XAB,YAB,ZAB
  0.0         0.0         0.0
INPUT ITYPE
    1
INPUT RADIUS
 18.80000
INPUT SLOPE
 -0.00920
INPUT IBAFF,IWCBAF
    2     0
INPUT XAB,YAB,ZAB
  0.0         0.0         0.0
INPUT ITYPE
    1
INPUT RADIUS
 19.10000
INPUT SLOPE
  0.0
INPUT MBAF
    7
INPUT ZB(I),I=1,MBAF
  0.0         4.40000   11.30000   19.00000   25.26000   30.00000   37.70000
INPUT S(I),I=1,MBAF
  0.0         0.0         0.0         0.0         0.0         0.0         0.0
INPUT AXIS NUMBER FOR TUBE, AND REFERENCE AXIS NUMBER
    1     0
INPUT REFTUB
  1.00000
INPUT BRDF TYPE
    1
INPUT XAB,YAB,ZAB
  0.0         0.0        25.26000
INPUT ITYPE
    1
INPUT RADIUS
  5.50001
INPUT SLOPE
  0.22340
INPUT IBAFF,IWCBAF
    2     0
INPUT XAB,YAB,ZAB
  0.0         0.0        25.26000
INPUT ITYPE
    1
INPUT RADIUS
  5.50000
INPUT SLOPE
  0.14810
INPUT MBAF
    8
INPUT ZB(I),I=1,MBAF
 25.26000  25.80000   27.80000   30.80000   32.80000   35.80000   37.70000   39.20000
INPUT S(I),I=1,MBAF
  0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
INPUT AXIS NUMBER FOR TUBE, AND REFERENCE AXIS NUMBER
    1     0
```

```
INPUT REFTUB
  1.00000
INPUT BRDF TYPE
    1
INPUT XAB,YAB,ZAB
  0.0        0.0       19.00000
INPUT ITYPE
    1
INPUT RADIUS
  4.50000
INPUT SLOPE
  0.15620
INPUT IBAFF,IWCBAF
    2     0
INPUT XAB,YAB,ZAB
  0.0        0.0       19.00000
INPUT ITYPE
    1
INPUT RADIUS
  4.05000
INPUT SLOPE
  0.05460
INPUT MBAF
    4
INPUT ZB(I),I=1,MBAF
 19.00000  20.50000  22.00000  25.26000
INPUT S(I),I=1,MBAF
  0.0        0.0        0.0        0.0
INPUT AXIS NUMBER FOR TUBE, AND REFERENCE AXIS NUMBER
    1     0
INPUT REFTUB
  1.00000
INPUT BRDF TYPE
    1
INPUT XAB,YAB,ZAB
  0.0        0.0        4.40000
INPUT ITYPE
    1
INPUT RADIUS
  8.60000
INPUT SLOPE
  0.0
INPUT IBAFF,IWCBAF
    2     0
INPUT XAB,YAB,ZAB
  0.0        0.0        4.40000
INPUT ITYPE
    1
INPUT RADIUS
  6.50000
INPUT SLOPE
  0.0
INPUT MBAF
    4
INPUT ZB(I),I=1,MBAF
  4.40000   6.40000   9.30000  11.30000
INPUT S(I),I=1,MBAF
  0.0        0.0        0.0        0.0
INPUT AXIS NUMBER FOR TUBE, AND REFERENCE AXIS NUMBER
    1     0
INPUT REFTUB
  1.00000
INPUT BRDF TYPE
    1
INPUT XAB,YAB,ZAB
  0.0        0.0       25.26000
```

```
INPUT ITYPE
    1
INPUT RADIUS
  4.60000
INPUT SLOPE
  0.18150
INPUT IBAFF,IWCBAF
    2      0
INPUT XAB,YAB,ZAB
  0.0          0.0        25.26000
INPUT ITYPE
    1
INPUT RADIUS
  5.50000
INPUT SLOPE
  0.14810
INPUT MBAF
    8
INPUT ZB(I),I=1,MBAF
 25.26000  25.80000  27.80000  30.80000  32.80000  35.80000  37.70000  39.90000
INPUT S(I),I=1,MBAF
  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
INPUT AXIS NUMBER FOR TUBE, AND REFERENCE AXIS NUMBER
    1      0
INPUT REFTUB
  1.00000
INPUT BRDF TYPE
    1
INPUT XAB,YAB,ZAB
  0.0          0.0        19.00000
INPUT ITYPE
    1
INPUT RADIUS
  3.65000
INPUT SLOPE
  0.05460
INPUT IBAFF,IWCBAF
    1      0
INPUT AXIS NUMBER FOR TUBE, AND REFERENCE AXIS NUMBER
    1      0
INPUT REFTUB
  1.00000
INPUT BRDF TYPE
    1
INPUT XAB,YAB,ZAB
  0.0          0.0        41.10000
INPUT ITYPE
    1
INPUT RADIUS
  2.20000
INPUT SLOPE
  0.0
INPUT IBAFF,IWCBAF
    1      0
```

```
INPUT NUMBER OF SECTIONS
  12
INPUT JTYPE,JSECT1,JBACK,JNEXT,JSECT2,JSECT3 OF SECTION
   0     1     1     7     0     0
INPUT JTYPE,JSECT1,JBACK,JNEXT,JSECT2,JSECT3 OF SECTION
   4     1     7     6     0     0
INPUT JTYPE,JSECT1,JBACK,JNEXT,JSECT2,JSECT3 OF SECTION
   0     1     6     5     0     0
INPUT JTYPE,JSECT1,JBACK,JNEXT,JSECT2,JSECT3 OF SECTION
   3     1     5     4     0     0
INPUT JTYPE,JSECT1,JBACK,JNEXT,JSECT2,JSECT3 OF SECTION
   2     1     4     2     0     0
INPUT JTYPE,JSECT1,JBACK,JNEXT,JSECT2,JSECT3 OF SECTION
 202     1     2     3     0     0
INPUT JTYPE,JSECT1,JBACK,JNEXT,JSECT2,JSECT3 OF SECTION
 200     2     0     8     0     0
INPUT JTYPE,JSECT1,JBACK,JNEXT,JSECT2,JSECT3 OF SECTION
   0     6     9    10     0     0
INPUT JTYPE,JSECT1,JBACK,JNEXT,JSECT2,JSECT3 OF SECTION
   0     5    13    11     0     0
INPUT JTYPE,JSECT1,JBACK,JNEXT,JSECT2,JSECT3 OF SECTION
 200     3    11    12     0     0
INPUT JTYPE,JSECT1,JBACK,JNEXT,JSECT2,JSECT3 OF SECTION
 200     4    10    13     0     0
INPUT JTYPE,JSECT1,JBACK,JNEXT,JSECT2,JSECT3 OF SECTION
   0     7    12    14     0     0
```

```
INPUT NUMBER OF BRDF TYPES
    2
INPUT GENERAL SPECULAR AND DIFFUSE MULTIPLIERS
 -1.00000  -1.00000
SET NO.    1 INPUT TABLES TO HAVE MULTPLIERS
    0      0      0      0      0      0      0      0


SET NO.=   1   TABLE NO.=   1

SPECULAR REFLECTIVITY=    0.02500   MAXIMUM INCIDENT ANGLE FOR TABLE=   20.00000

   2.00000    0.14000
   2.50000    0.11000
   3.00000    0.05300
   4.50000    0.02700
   6.00000    0.01400
  13.00000    0.00720
  37.00000    0.00370
  40.00000    0.00180
  56.00000    0.00090
  61.00000    0.00050
 180.00000    0.00030


SET NO.=   1   TABLE NO.=   2

SPECULAR REFLECTIVITY=    0.04000   MAXIMUM INCIDENT ANGLE FOR TABLE=   45.00000

   2.00000    0.28000
   3.00000    0.14000
   4.00000    0.06700
   7.00000    0.03400
   8.50000    0.01700
  25.00000    0.00750
  70.00000    0.00380
 180.00000    0.00170


SET NO.=   1   TABLE NO.=   3

SPECULAR REFLECTIVITY=    0.03500   MAXIMUM INCIDENT ANGLE FOR TABLE=   75.00000

   1.00000    1.10000
   1.20000    0.82000
   1.30000    0.40000
   1.50000    0.20000
   2.00000    0.09800
   3.00000    0.05000
   4.00000    0.02500
   8.50000    0.01200
  19.00000    0.00600
  75.00000    0.00400
  97.00000    0.00320
 180.00000    0.00230


SET NO.=   1   TABLE NO.=   4

SPECULAR REFLECTIVITY=    0.40000   MAXIMUM INCIDENT ANGLE FOR TABLE=   90.00000

   1.00000    1.10000
   1.20000    0.82000
   1.30000    0.40000
```

1.50000	0.20000
2.00000	0.09800
3.00000	0.05000
4.00000	0.02500
8.50000	0.01200
19.00000	0.00600
75.00000	0.00400
97.00000	0.00320
180.00000	0.00230

INPUT GENERAL SPECULAR AND DIFFUSE MULTIPLIERS

-1.00000 -1.00000

SET NO. 2 INPUT TABLES TO HAVE MULTPLIERS

0 0 0 0 0 0 0 0

SET NO.= 2 TABLE NO.= 1

SPECULAR REFLECTIVITY= 0.95000 MAXIMUM INCIDENT ANGLE FOR TABLE= 90.00000

0.75000	0.00700
1.50000	0.00280
2.50000	0.00200
3.50000	0.00160
4.50000	0.00130
5.50000	0.00100
6.50000	0.00080
7.50000	0.00060
8.50000	0.00051
9.50000	0.00045
12.50000	0.00040
17.50000	0.00025
25.00000	0.00016
45.00000	0.00010
180.00000	0.00004

```
INPUT NCAP
    5
INPUT CRITICAL APERTURE AND ASSOCIATED MIRROR NUMBERS
    2     1
INPUT CRITICAL APERTURE AND ASSOCIATED MIRROR NUMBERS
    8     2
INPUT CRITICAL APERTURE AND ASSOCIATED MIRROR NUMBERS
   10     0
INPUT CRITICAL APERTURE AND ASSOCIATED MIRROR NUMBERS
   11     3
INPUT CRITICAL APERTURE AND ASSOCIATED MIRROR NUMBERS
   13     4
APERTURE  1 SEES APERTURES--
    2     0     0     0     0     0     0     0
APERTURE  2 SEES APERTURES--
    1     3     0     0     0     0     0     0
APERTURE  3 SEES APERTURES--
    2     4     0     0     0     0     0     0
APERTURE  4 SEES APERTURES--
    3     5     0     0     0     0     0     0
APERTURE  5 SEES APERTURES--
    4     0     0     0     0     0     0     0
APERTURE  1 SEES SECTIONS--
    1     2     3     4     5     6     0     0
APERTURE  2 SEES SECTIONS--
    3     4     5     6     7     8     0     0
APERTURE  3 SEES SECTIONS--
    1     2     3     8     9    12     0     0
APERTURE  4 SEES SECTIONS--
    9    10     0     0     0     0     0     0
APERTURE  5 SEES SECTIONS--
    9    11    12     0     0     0     0     0
SECTION  1 SEES SECTIONS--
    1     2     3     4     5     8     0     0
SECTION  2 SEES SECTIONS--
    1     2     3     4     5     8     0     0
SECTION  3 SEES SECTIONS--
    1     2     3     4     5     8     0     0
SECTION  4 SEES SECTIONS--
    1     2     3     4     5     0     0     0
SECTION  5 SEES SECTIONS--
    1     2     3     4     5     0     0     0
SECTION  6 SEES SECTIONS--
    6     0     0     0     0     0     0     0
SECTION  7 SEES SECTIONS--
    7     0     0     0     0     0     0     0
SECTION  8 SEES SECTIONS--
    1     2     3     8     0     0     0     0
SECTION  9 SEES SECTIONS--
    9    12     0     0     0     0     0     0
SECTION 10 SEES SECTIONS--
   10     0     0     0     0     0     0     0
SECTION 11 SEES SECTIONS--
   11     0     0     0     0     0     0     0
SECTION 12 SEES SECTIONS--
    9    12     0     0     0     0     0     0
```

II.3 INPUT DATA EXPLANATION

The input data to the Mark VII has many of the features common to the Baffle I. There are some differences because of the on-axis design which make it worthy of a data input discussion analogous to that used for the Baffle I. However, only those model features that would assist one with the program operation will be discussed. For reference the number corresponding to those in the input data list will be used. The input data list can be divided into the following groups:

1 - 15	Run Data
16	Coordinate System
17 - 37	Mirrors
38 - 108	Apertures
109 - 200	Tubes
201 - 213	Sections
214 - 218	BRDF Table
219 - 247	Critical aperture and viewability of apertures and sections

If another baffle, aperture, or any element should be added to alter the number of times any card is used, these number groupings will change accordingly with a higher number of input values resulting. (Se means self-explanatory.)

1 - 15 The run data is analogous to that used in the Baffle I

16 The on-axis feature premits a single coordinate system. The coordinate systems are mainly positioned in accordance with

normal optical design ray tracing procedures. Additional systems are used for systems of design complexity in the program modeling.

17 - 37 The radius of curvature of the primary is located outside the entrance aperture, i.e., in the negative z-direction. The aspheric secondary and tertiary are represented by their nearest fitting spheres. The plane quaternary is given the radius of curvature 999.999, which reflects to infinite.

38 - 108 The 3rd aperture is negative type, i.e., the mirror or clear portion is outside its radius. This applies also to the 4th - 7th apertures. The 9th aperture is inside the 5th, so for the 5th aperture, KOTHER = 9. They must have the same z-value for KOTHER $\neq$ 0. The KOTHER = 5 for the 9th aperture; however, the smaller radius refers it to the inner aperture. The 2nd and 3rd apertures form the primary clear aperture but they have different z values. Therefore for the 2nd, KOTHER = 0.

109 - 200 The 1st tube has an imaginary input radius of 18.9 with a slope of -0.00920. This corresponds to the first baffle edge in a cylindrical tube of radius 19.1, and also serves as the 1st aperture. The final baffle in this tube at Z = 37.7 serves as the 2nd aperture.

The 2nd tube begins at the plane of the quaternary, z = 25.26. The imaginary tube or baffle edges have an input radius of 5.50001 and a slope of 0.2234, while the real tube has the values 5.5 and 0.14810, respectively. The first baffle serves as the 4th aperture, while the last at z = 39.2 is the 3rd aperture. The 3rd and 4th tubes have similar characteristics.

The 5th tube has an imaginary tube inside the real tube. The imaginary input radius is 4.6 with slope 0.1815, while the real tube has 5.5 and 0.148, respectively. The baffle positions are made coincident in z-value with those in the 2nd tube. The 6th tube has no baffles with the real tube input radius of 3.65 and slope 0.05460. The input serves as the 9th aperture.

201 - 213 The sections are as shown in the system figure. The 2nd section is within the 4th tube (JTYPE = 4), is within the 1st tube (JSECT1 = 1), has 7th aperture as its backward aperture (JBACK = 7), has 6th aperture as its forward aperture (JNEXT = 6), and no holes (JSECT 2 = 0).

The 6th section, which is the primary mirror section, is described as follows: the 2nd tube obscures a portion of the primary mirror (JTYPE = 202), the 6th section is within the 1st tube (JSECT1 = 1), the 2nd aperture is its backward aperture (JBACK = 2), the 3rd aperture is its forward aperture (JNEXT = 3), and has JSECT2 = 0 since its central hole or obscuration is already referred to in JTYPE = 202.

214 - 218 (Se)

219 - 247 The critical apertures define the mirrors and stops (field stop, Lyot stop). The Lyot stop is approximately coincident with the quaternary, therefore the 5th critical aperture serves both requirements. The critical aperture and aperture numbers are as follows: 1-2, 2-8, 3-10, 4-11, and 5-13.

II.4 SAMPLE PROGRAM OUTPUTS

GUERAP II PROGRAM 06/12/73 11.45.40 PAGE 1

SYSTEM TITLE : MARK VII TEST

BAFFLE DESIGN ITERATION 0

* * * * * * * OPTICAL FORM DATA * * * * * * *

*** COORDINATE SYSTEMS ***

AXIS NO.	ORIGIN			AXIS TILTS		
1	0.0	0.0	0.0	0.0	0.0	0.0

*** SECTIONS ***

SECTION	TYPE	Z1	Z2	SECTION AXIS	SECTION CONTENTS MIRRORS	APERTURES			TUBES	
1	0	0.0	4.40	1	0	1	7	0	1	0
2	4	4.40	11.30	1	0	7	6	0	1	4
3	0	11.30	19.00	1	0	6	5	0	1	0
4	3	19.00	25.26	1	0	5	4	0	1	3
5	2	25.26	37.70	1	0	4	2	0	1	2
6	202	37.70	39.20	1	1	2	3	0	0	2
7	200	0.00	11.30	1	2	0	8	0	0	0
8	0	19.00	25.26	1	0	9	10	0	6	0
9	0	25.26	39.90	1	0	13	11	0	5	0
10	200	39.90	41.10	1	3	11	12	0	0	0
11	200	25.26	25.26	1	4	10	13	0	0	0
12	0	41.10	45.68	1	0	12	14	0	7	0

*** MIRRORS ***

MIRROR	SECTION	APERTURE NUMS		MIRROR TYPE	CENTER POSITION	VERTEX POSITION	MIRROR AXIS	MIRROR DIMENSIONS	
1	6	2	3	1	-51.9	39.6	1	91.4	0.0
2	7	0	8	1	182.0	11.0	1	171.0	0.0
3	10	11	12	1	19.0	41.3	1	22.3	0.0
4	11	10	13	0	25.3	1025.3	1	1000.0	0.0

*** APERTURES ***

APERTURE	SECTION		APERTURE TYPE	Z-AXIS POSITION	APERTURE AXIS	APERTURE DIMENSIONS	
1	0	1	1	0.0	1	18.8	0.0
2	5	6	1	37.7	1	18.2	0.0
3	6	6	-1	39.2	1	8.7	0.0
4	4	5	-1	25.3	1	5.5	0.0
5	3	4	-1	19.0	1	4.5	0.0
6	2	3	-1	11.3	1	8.6	0.0
7	1	2	-1	4.4	1	8.6	0.0
8	7	3	1	11.3	1	7.4	0.0
9	3	8	1	19.0	1	3.7	0.0
10	8	9	1	25.3	1	1.0	0.0
11	9	10	1	39.9	1	7.5	0.0
12	10	12	1	41.1	1	2.2	0.0
13	11	9	1	25.3	1	4.6	0.0
14	12	-1	1	45.7	1	2.2	0.0

SYSTEM TITLE : MARK VII TEST

BAFFLE DESIGN ITERATION 0

*** TUBES ***

TUBE	TUBE TYPE	Z1	Z2	TUBE AXIS	REAL TUBE DIMENSIONS		IMAG TUBE DIMENSIONS		BAFFLE GROUP
1	1	0.0	0.0	1	19.1	19.1	18.8	18.8	1
2	1	0.0	0.0	1	5.5	5.5	5.5	5.5	2
3	1	0.0	0.0	1	4.1	4.1	4.5	4.5	3
4	1	0.0	0.0	1	6.5	6.5	8.6	8.6	4
5	1	0.0	0.0	1	5.5	5.5	4.6	4.6	5
6	1	0.0	0.0	1	3.7	3.7			
7	1	0.0	0.0	1	2.2	2.2			

*** BAFFLE GROUPS ***

BAFFLE GROUP	SECTION	BAFFLE TYPE	Z1	Z2	NO. OF BAFFLES	MATERIALS
1	9	1	0.0	37.7	7	
2	10	1	25.3	39.2	8	
3	11	1	19.0	25.3	4	
4	12	1	4.4	11.3	4	
5	13	1	25.3	39.9	8	

SYSTEM TITLE : MARK VII TEST

BAFFLE DESIGN ITERATION 0

* * * * * * BAFFLE GROUP SUMMARY * * * * * *

*** BAFFLE GROUP NUMBER 1 ***

BAFFLE	TYPE	Z	INNER DIMENSIONS	
1	1	0.0	18.80	18.80
2	1	4.4	18.76	18.76
3	1	11.3	18.70	18.70
4	1	19.0	18.63	18.63
5	1	25.3	18.57	18.57
6	1	30.0	18.52	18.52
7	1	37.7	18.45	18.45

*** BAFFLE GROUP NUMBER 2 ***

BAFFLE	TYPE	Z	INNER DIMENSIONS	
1	1	25.3	5.50	5.50
2	1	25.8	5.58	5.58
3	1	27.8	5.88	5.88
4	1	30.8	6.32	6.32
5	1	32.8	6.62	6.62
6	1	35.8	7.06	7.06
7	1	37.7	7.34	7.34
8	1	39.2	7.56	7.56

*** BAFFLE GROUP NUMBER 3 ***

BAFFLE	TYPE	Z	INNER DIMENSIONS	
1	1	19.0	4.05	4.05
2	1	20.5	4.13	4.13
3	1	22.0	4.21	4.21
4	1	25.3	4.39	4.39

*** BAFFLE GROUP NUMBER 4 ***

BAFFLE	TYPE	Z	INNER DIMENSIONS	
1	1	4.4	6.50	6.50
2	1	6.4	6.50	6.50
3	1	9.3	6.50	6.50
4	1	11.3	6.50	6.50

SYSTEM TITLE : MARK VII TEST

BAFFLE DESIGN ITERATION 0

*** BAFFLE GROUP NUMBER 5 ***

BAFFLE	TYPE	Z	INNER DIMENSIONS	
1	1	25.3	4.60	4.60
2	1	25.8	4.70	4.70
3	1	27.8	5.06	5.06
4	1	30.8	5.61	5.61
5	1	32.8	5.97	5.97
6	1	35.8	6.51	6.51
7	1	37.7	6.86	6.86
8	1	39.9	7.26	7.26

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