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A METHOD FOR COMPUTATION OF METEOROID IMPACT DISTRIBUTION OVER SPACECRAFT

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TELEDYNE
BROWN ENGINEERING

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A METHOD FOR COMPUTATION OF METEOROID IMPACT DISTRIBUTION OVER SPACECRAFT

By

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ABSTRACT

This report describes a method for the evaluation of the meteoroid flux distribution over external surfaces of a space system. A computer program has been developed for calculating the number of particles and the angular distribution of impacts over a specific surface. The computer program is based on the application of numerical integration methods. Partial or complete blockage of one surface by another is considered in the formulation. The results of a sample problem are given in the report; these results are compatible with heat transfer view factor predictions.

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LIST OF SYMBOLS

A	area, in^2
F_{ij}	geometric shape factor from surface j to surface i
$\dot{N}$	number of meteoroid flux, No./sec
$\mathring{n}$	number of meteoroid flux per solid angle, No./sec-steradian
r	distance, in
S	surface area, in^2
T	time, sec
$\dot{W}$	number of meteoroid flux per unit area, No./sec-in^2
ψ	angle measured from the normal of surface, radians

I. INTRODUCTION

When a space vehicle is exposed to a meteoroid environment, the possibility of damage to a particular component in the vehicle depends, among other things, on the number of meteoroids and the impact angles at the location in question. For a space vehicle with complex geometric surfaces, the incoming meteoroid flux at a particular location can be partially or completely blocked by other surfaces and therefore the meteoroid flux and impingement angles at a particular location may depend on the geometry and orientation of many components of the space vehicle. Because of the geometrical complexity of typical space systems, exact mathematical solutions of the meteoroid flux distribution on the vehicle surfaces are very difficult. Therefore numerical methods must usually be utilized in the solution of this problem. The purpose of this study was to develop a computer program for solving the meteoroid impact and angular distributions over complex geometric configurations, such as Skylab. The solution is obtained by application of numerical integration techniques.

In the development of the present computer program, a theoretical model which is analogous to radiation transport between black bodies was established to calculate the meteoroid impacts and the angular distribution on each external component of the spacecraft. The blockage of meteoroid flux due to the geometry of the various components is considered. The output of the program can be used to evaluate the probability of damage to the spacecraft structure.

The purpose of this report is to describe the analytic methods and the numerical techniques used in the development of the program. In addition, a detailed description of the input and output of the program is included. The program is written in FORTRAN IV language and requires a 32-k core memory*. The principal features of the program are summarized as follows:

- The geometric surfaces considered in the program include spheres, cones, cylinders, rectangles, disks, annuli, triangles, trapezoids, or portions of these surfaces.

- Any combination of these geometric surfaces up to 200 can be analyzed simultaneously.

- A single surface can be divided into as many as 100 elements; computer results are printed for each element. (Larger surfaces may be subdivided into several smaller surfaces with each of them having 100 elements if more accurate results are required.)

- The program calculates the meteoroid flux distribution (number of impacts) and the direction of the meteoroid impacts.

- The source sphere (a large, fictitious sphere that is assumed to surround the space system) can be divided into as many elements as necessary to obtain the desired accuracy. However, increased accuracy is obtained at the expense of computer running time.

- The blocking surfaces for a specific object may be specified as computer input to reduce the computation time. All objects will be considered as possible blocking surfaces if the above option is not specified.

- The meteoroid distributions on any or all surfaces can be calculated.

- Either side of the surface can be specified as active; the results are then calculated for the active side only.

Acknowledgement is given to other staff members of Teledyne Brown Engineering who have contributed to this study, including Mr. E.

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*A version of the program for the use of 16-k core memory in the IBM 1130 computer is available, but the number of surfaces is limited to 70.

H. Ingram and Mr. C. K. T. Young for their assistance in the formulation of cartesian coordinate transformation, and Mr. W. P. Turner and Mr. J. R. Powers for numerous discussions on the Skylab structure and impact mechanics. Also, appreciation is extended to Mr. C. D. Nevins, Deputy Chief, Structural Development Branch, S&E-ASTN-E, MSFC, who as Technical Monitor for this study made many valuable suggestions.

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II. BASIC THEORY

There are two classes of meteoroids in space: sporadic flux from random orbits and cometary meteoroids that come toward the Earth from a specific direction at regular intervals during the calendar year. The meteoroid population in the space environments has been reported in the literature (Refs. 1 and 2) and this information, with methods used to calculate radiation transport will be utilized in the calculations of meteoroid flux distributions on various components of the spacecraft.

SOURCE SURFACE OF SPORADIC METEOROIDS

In calculating the number of sporadic meteoroids which are incident on the vehicle external surface, a large spherical source enclosing the vehicle on which the meteoroid flux emits diffusively is assumed. Such a model is analogical to radiation transport between black bodies. Replacing the intensity of radiation by the particle density flux, one can calculate the number of particles leaving the source surface that is incident on a specific surface area of the spacecraft per unit time.

Let $\dot{N}_1$ be the number flux leaving S_j that impinges on the S_i. According to the formulation used for calculating radiation heat transfer, it may be expressed by

$$\dot{N}_1 = \int_{S_i} \int_{S_j} \frac{\dot{n}(\phi_j) \cos\phi_i \cos\phi_j}{r^2} \, dA_i \, dA_j \tag{1}$$

where r, ϕ_i, ϕ_j, dA_i, dA_j are shown in Figure 1 and $\dot{n}(\phi_j)$ is the number of particles leaving S_j per unit area normal to the direction per unit solid angle and per unit time.

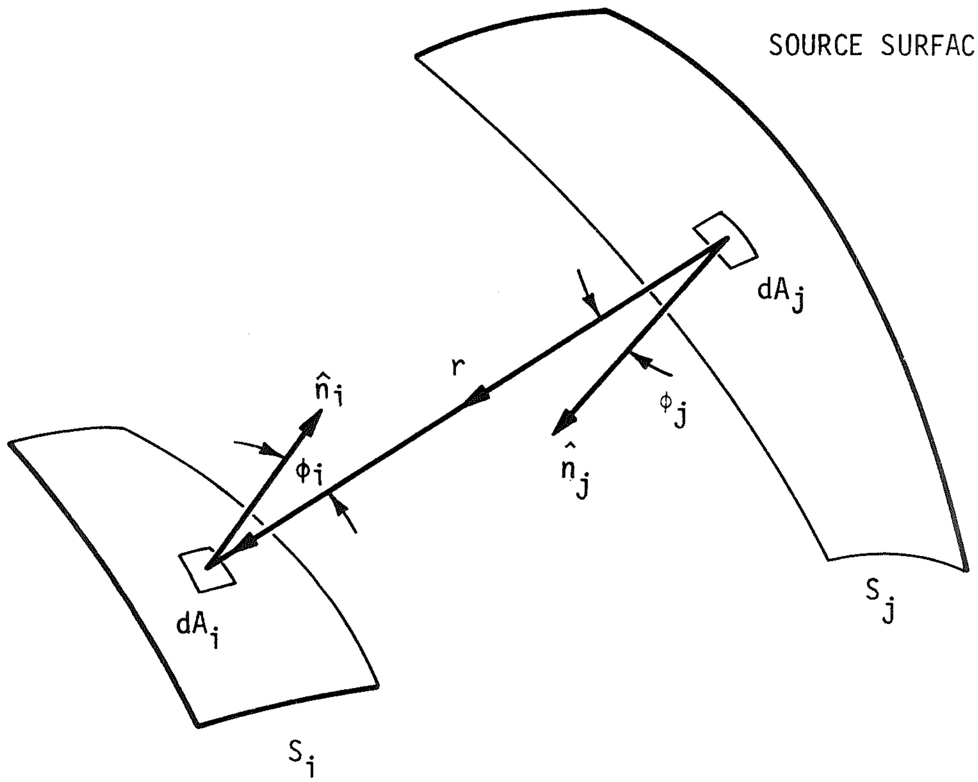


FIGURE 1. RADIATION BETWEEN INFINITESIMAL ELEMENTS

Denoting the total flux leaving S_j per unit area by $\dot{W}_1$, the relation between $\dot{W}_1$ and $\dot{n}$ is

$$\dot{n} = \dot{W}_1 / \pi \tag{2}$$

for diffusive emission, or equivalently, sporadic meteoroid distribution over a long period of time; where $\dot{n}$ is a constant.

SOURCE SURFACE OF STREAM METEOROIDS

It is assumed that all stream meteoroids move parallel to each other toward the spacecraft from a given direction. The number flux $\dot{N}_2$ impinging upon S_i can thus be obtained by

$$\dot{N}_2 = \int_S \dot{W}_2 \cos \phi_i \, dA_i = \dot{W}_2 S_{in} \tag{3}$$

where S_{in} is the projected area of S_i on a plate normal to the meteoroid direction (See Figure 2), and $\dot{W}_2$ is the number of meteoroids per unit area per unit time through S_j.

EARTH SHIELDING

When a spacecraft travels around the Earth orbit, such as Skylab, the Earth acts as a shield to reduce the impacts of sporadic meteoroids and to block the impacts of stream meteoroids. There are two ways to consider the Earth shielding factor. One is to calculate the meteoroid impacts based on different period of time; the $\dot{N} = \dot{N}_1 + \dot{N}_2$ depends on the meteoroid population at the particular time and, of course, also the orientation and the orbital position of the vehicle. The total number of meteoroids striking on the spacecraft during the mission period can be obtained by integrating

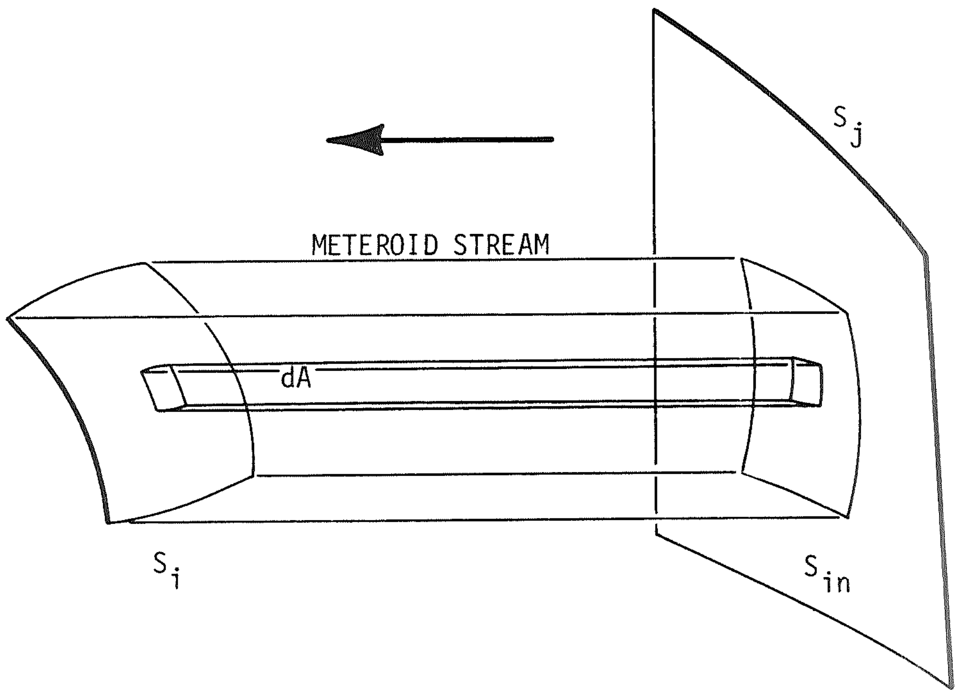


FIGURE 2. METEOROID STREAM FLUX IMPINGING ON S_i

$$N_{total} = \int_{T_1}^{T_2} \dot{N}\, dt \tag{4}$$

or

$$\dot{N}_{total} = \sum_{i=1}^{n} \dot{N}\,(T_i)\,(T_i - T_{i-1}) \tag{5}$$

where $T_0 = T_1$ and $T_n = T_2$ are the starting and ending times of the mission, respectively.

The above method would give an exact method of prediction; however, the calculation of meteorid distribution must be done repeatedly for successive times that would require excessive computer time. Another way to solve the problem is to assume that the spacecraft's orientation is essentially random and treat the problem as sporadic flux distribution. The Earth shielding effect is considered as a reducing factor, independent of the vehicle orientation. The stream meteoroids are added to sporadic meteoroids impacting the spacecraft by an averaged increasing factor, again independent of their orbital directions. Thus, sporadic meteorid distribution is assumed only in the computer program, and averaged increasing factor for stream meteoroids is used in the actual calculations of meteoroid flux distributions.

III. METHOD OF INTEGRATION

The explicit integration of Equation 1 is extremely difficult for general spacecraft geometries; therefore, a numerical scheme for calculating such integrals is used.

Rewriting Equation 1 in the form

$$\dot{N}_1 = \sum_{S_i} \sum_{S_j} \mathring{n}(\phi_j) \cos \phi_i \cos \phi_j \, \Delta A_i \, \Delta A_j \, / \, r^2 \tag{6}$$

$\dot{N}_1$ can be obtained by summing the values of the integrand for each element of one surface with each element of the other surface. The accuracies of the results are functions of the size of the finite element areas ΔA_i, ΔA_j. In accordance with the heat radiation view factor method of calculation of Reference 3, the rule of thumb for estimating the number of elements needed is that the area of each element should be less than one-tenth the square of the distance between surfaces.

Consider the diffusive emission from the source surface. Equation 1 may be rewritten as

$$\dot{N}_1 = \dot{W}_1 \int_{S_i} \int_{S_j} \frac{\cos \phi_i \cos \phi_j}{\pi \, r^2} \, dA_i \, dA_j = \dot{W}_1 S_j \, F_{ji}$$

where F_{ji} is defined as the geometric shape factor from surface j to surface i. Physically F_{ji} represents the fraction of the total radiant energy (or particles) leaving surface j which is incident upon surface i. Furthermore, according to the reciprocity theorem,

$$S_i \, F_{ij} = S_j \, F_{ji} \quad .$$

Now assuming that S_j is an enclosing surface (e.g., sphere), in which S_i is located, the energy leaving S_i, without being blocked by other surfaces, will be completely incident upon S_j, i.e., $F_{ij} = 1$ and $F_{ji} = S_i/S_j$ (see Figure 3).

The blockage of components by other components is significant in the evaluation of the meteoroid flux distribution on the vehicle. As shown in Figure 4, if the straight line connecting the surface elements i, j is intersected by a surface, the F_{ij} is set to zero. The computer program is written to examine all the surfaces as possible blocking surfaces. But even in the case of a complicated geometry, the blocking surfaces can be observed with respect to a specific surface. By specifying the possible blocking surfaces, one can reduce the computer time considerably. For example, the Service and Command Module of the Skylab is divided into five surfaces (see Figure 5). Surfaces 1, 2, and 3 will not be blocked by any other surfaces. The possible blocker for surface 4 is surface 5 and the possible blocking surface for 5 is surface 4. By giving such identifications, the program examines only the possible blocking surface and, of course, it reduces the computing time.

In the computations, there are two cartesian coordinate systems in the formulation: the source coordinate system and the surface systems. The surface systems are the systems identified with each of the components of the spacecraft. The directional cosine coefficients for each system are calculated according to the orientations of the surfaces being considered. Cartesian tensor transformations (through rotations and translations) are utilized to connect the relative positions of the elements between coordinate systems. The mathematical formulation is given in the Appendix.

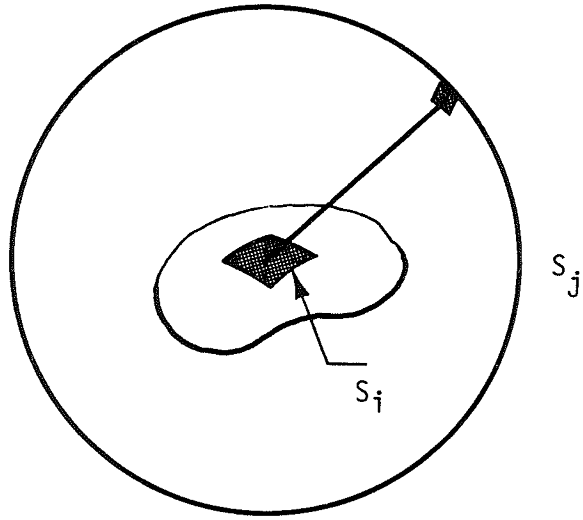


FIGURE 3. S_i IS ENCLOSED BY S_j, $F_{ij} = 1$

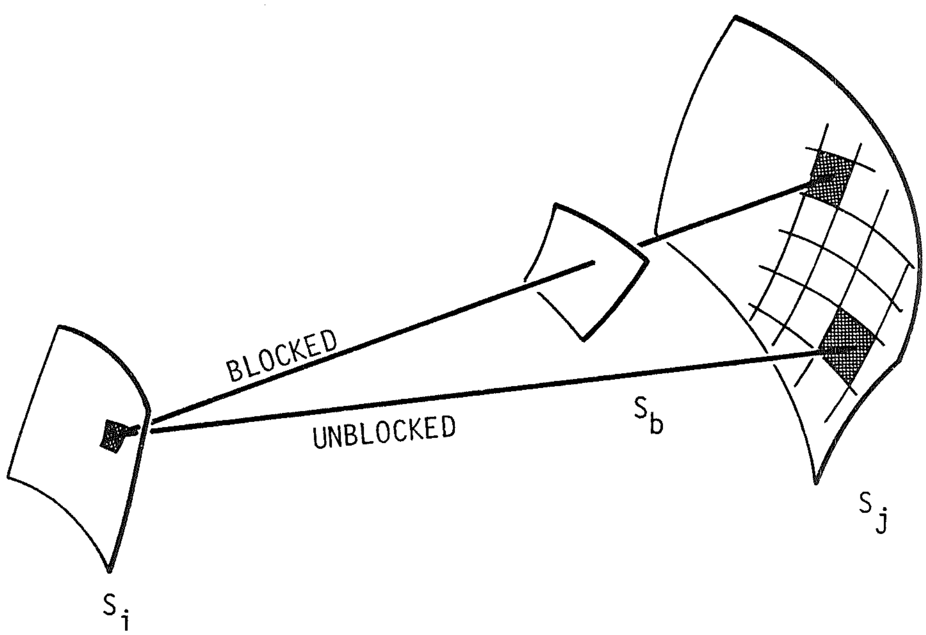
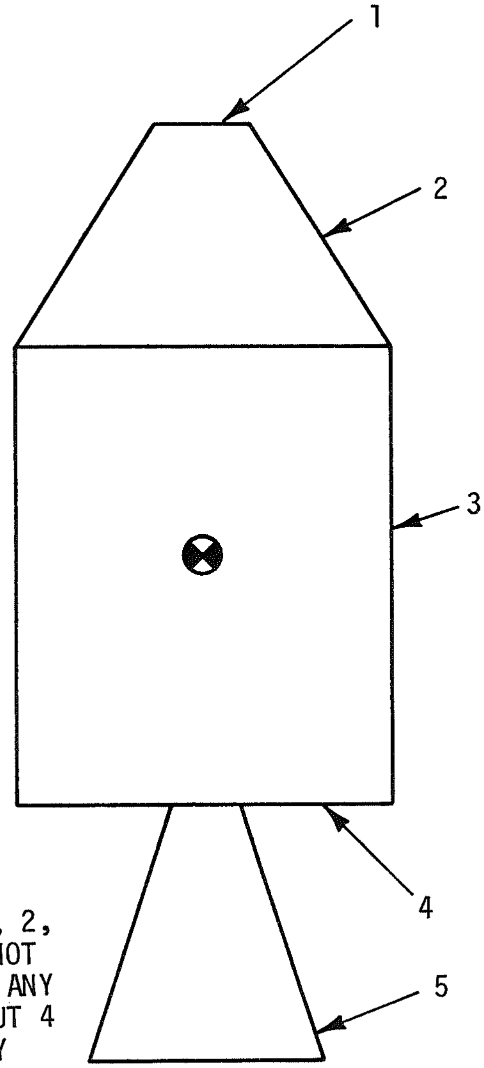


FIGURE 4. BLOCKING BY SURFACE S_b BETWEEN S_i AND S_j



NOTE: SURFACES 1, 2, AND 3 ARE NOT BLOCKED BY ANY SURFACE; BUT 4 IS POSSIBLY BLOCKED BY 5 AND VISE VERSA.

FIGURE 5. SERVICE AND COMMAND MODULE

IV. DESCRIPTION OF COMPUTER PROGRAM

This computer program was developed to calculate the meteoroid flux distribution, i.e., the number of impacts on any or all external surfaces of a spacecraft in a meteoroid environment. In order to utilize the program it is first necessary to define the actual spacecraft surfaces involved in terms of the various surfaces which the program can analyze. At present the program is formulated to consider spheres, cones, cylinders, rectangles, annuli, disks, triangles, trapezoids, or portions of these geometric configurations. These surfaces and the variables which define the surface will be described in the next section. If the surface is to be considered only as a blocking surface, it is not necessary to divide the surface into small elements. However, if the meteoroid flux distribution is desired for a surface, that surface must be divided into small elements. The program is limited to a maximum of 100 elements (10×10) for each surface. If more than 100 elements are needed for some particular surface, one may divide the original surface into two or more smaller surfaces with each subdivision containing 100 elements. At present up to 200 surfaces can be evaluated by the program; there is no limit to the number of emitting elements around the surface of the source sphere. The source surface can be divided into as many elements as necessary to obtain the required accuracy, but at the expense of the computer running time.

The computer program uses two types of cartesian coordinate systems for defining the surfaces and their relative locations. There is the source coordinate system; its location and angular orientation are chosen at the discretion of the program user. As a matter of convenience, the origin of the source coordinate system is usually located at the geometric center of the spacecraft and its z axis is in the direction of the vehicle axis. For each surface which is input, there is a surface coordinate system and the output of the surface is defined within its own object coordinate system. The surface coordinate system for each basic surface will be described in detail in the next section.

V. DESCRIPTION OF BASIC SURFACES

SPHERE -- TYPE OF SURFACE 1

The input data required to specify a sphere includes the coordinate of the sphere center, the radius, the conic angle range ($\theta_{min} \leqq \theta \leqq \theta_{max}$), the polar angel range ($\phi_{min} \leqq \phi \leqq \phi_{max}$), and the position of a point A on the z_b-axis. All of these variables are shown in Figure 6. The area of the element is

$$\Delta A = R^2 \Delta \cos \theta \Delta \phi .$$

The conic angle, θ, is measured from the z axis of the surface coordinate system (x_b, y_b, z_b) and ϕ is measured from the x axis.

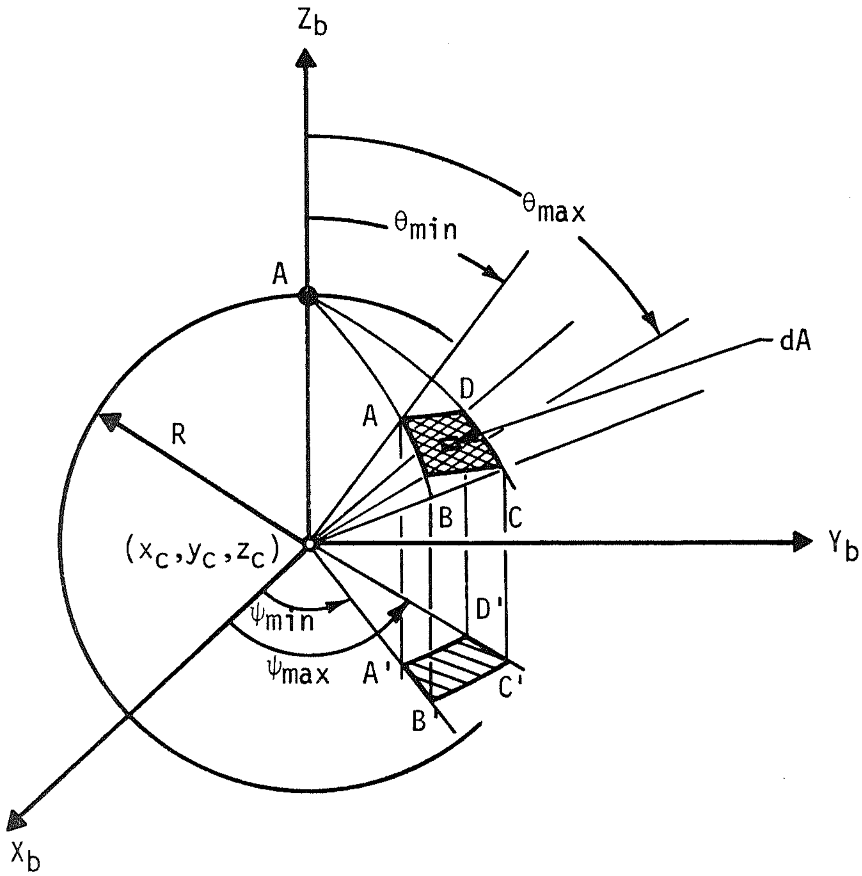
For the source coordinate system, the direction of x_b is defined on the plane containing vectors z_b and z_s. If z_b is chosen parallel to z_s, x_b is then coincident with the x_s axis.

CONE -- TYPE OF SURFACE 2

The inputs required to specify a cone include the maximum and minimum radii of the cone R_1 and R_2 (see Figure 7), the positions of A_1 and A_2 that are centers of these circular cross sections, and the range of circumferential angle ϕ ($\phi_{min} \leqq \phi \leqq \phi_{max}$). Again, once the z_b direction is chosen, the x_b direction is determined in the same manner as that of the sphere. For a cone with a vertex, A_1 is coincident with 0, and $R_1 = 0$.

CYLINDER -- TYPE OF SURFACE 3

To specify a cylinder, the input data required are the positions of cylindrical ends, A_1 and A_2, the radius R, and the circumferential



NOTES:

1. X_b, Y_b, Z_b IS THE SURFACE COORDINATE SYSTEM.

2. x_c, y_c, z_c IS THE POSITION OF CENTER IN THE SOURCE COORDINATE SYSTEM.

3. RADIUS OF SPHERE = R.

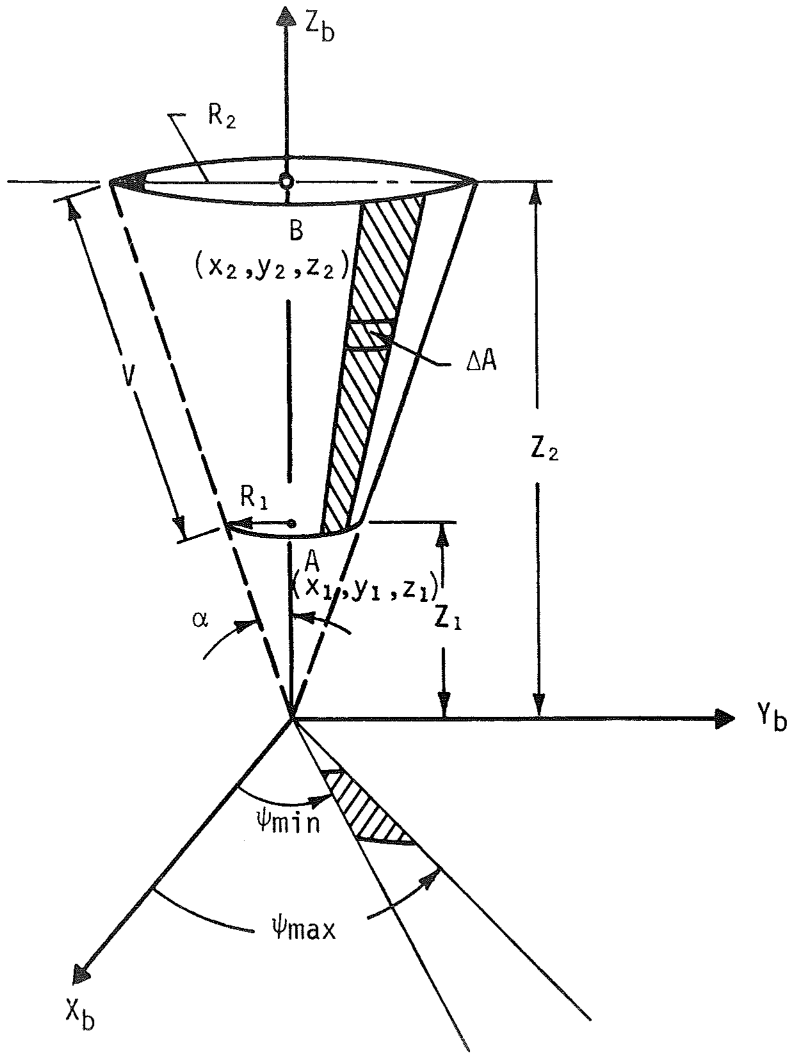
4. $0 \leq \theta \leq 90°$.

5. $-180° \leq \psi \leq 180°$.

6. $\Delta A = R^2 \; \Delta \cos \theta \; \Delta\psi$.

7. POINT A IS THE INTERSECTION POINT OF Z_b AXIS AND THE SPHERE.

FIGURE 6. SPHERE -- TYPE OF SURFACE 1



NOTES:

1. X_b, Y_b, Z_b IS THE SURFACE COORDINATE SYSTEM.
2. MAXIMUM RADIUS OF THE CONE = R_2; MINIMUM RADIUS OF THE CONE = R_1.
3. (x_1, y_1, z_1) AND (x_2, y_2, z_2) SPECIFY THE POSITIONS OF A AND B IN THE SOURCE COORDINATE SYSTEM.
4. $-180° \leq \psi \leq 180$
5. CONE ANGLE = α
6. $\Delta A = 1/2(\tan\alpha/\cos\alpha)\ \Delta(Z^2)\ \Delta\psi$

FIGURE 7. CONE -- TYPE OF SURFACE 2

angle range ($\phi_{min} \leqq \phi \leqq \phi_{max}$) (see Figure 8). A_1 (x_1, y_1, z_1) and A_2 (x_2, y_2, z_2) are expressed in the source coordinate system. The direction of x_b is determined in the same way as that of the cone surface.

RECTANGULAR PLATE -- TYPE OF SURFACE 4

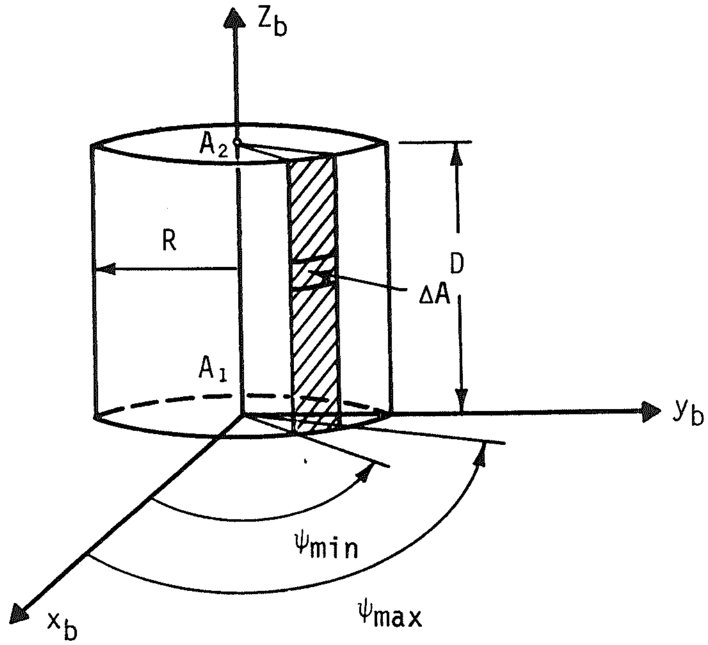
Since three points determine a plane, the coordinates of 0, A, B (see Figure 9) are required to specify the rectangular plate. The active side of the surface is in the positive z_b direction. When the other side of the plane is considered active, the input order of these three corner points must be OBA. The element $\Delta A = \Delta x \Delta y$ is also a small rectangular shape.

CIRCULAR DISK OR ANNULUS -- TYPE OF SURFACE 5

As shown in Figure 10, the data required to specify a circular disk (R_1 = 0) or annulus are the minimum and maximum radii, R_1 and R_2, of the annulus, the range of angle ϕ ($\phi_{min} < \phi < \phi_{max}$), the position of the center 0, and the unit vector OA in the z_b direction. A is a point above 0 and $|\overline{0A}| = 1$; this unit vector denotes the orientation of the plane. The direction of the x_b axis is determined in the same manner as the sphere, cone or cylinder.

TRIANGLE OR TRAPEZOID -- TYPE OF SURFACE 6

The inputs of positions A, B, C, D (Figure 11) are generally required for a triangle or trapezoid. A and B represent the same point when the triangle is specified. The active side of the surface is in the position z_b direction and the input point A, B, C, and D follow a counterclockwise rotation. The elements are defined between rays a, b and the constant x lines. y_{min}, y_{max}, x_{min}, x_{max} are calculated from the program.



NOTES:

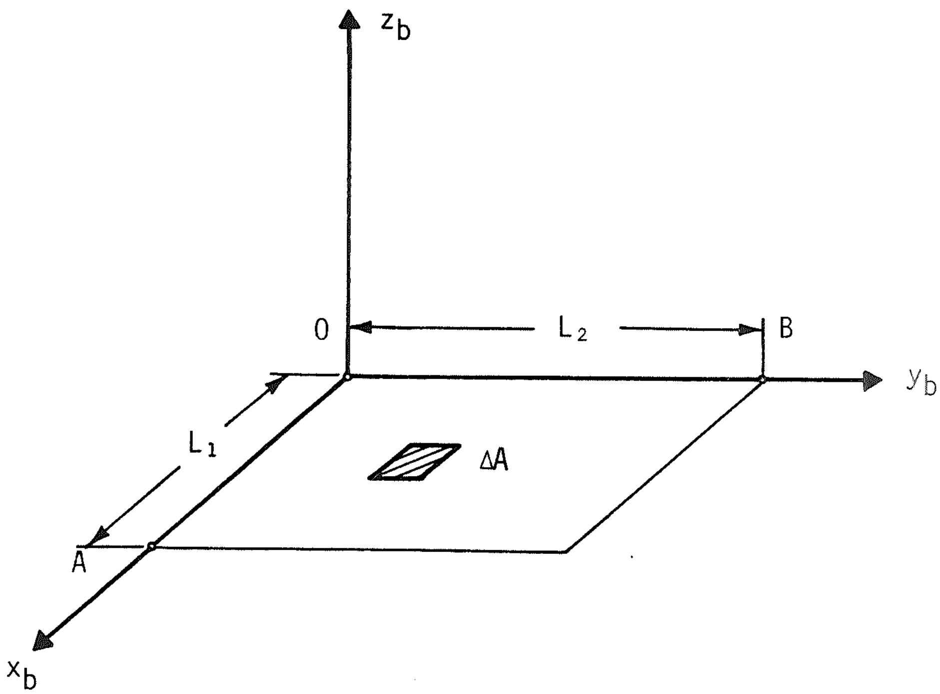
1. X_b, Y_b, Z_b IS THE SURFACE COORDINATE SYSTEM.

2. $A_1(x_1, y_1, z_1)$ AND $A_2(x_2, y_2, z_2)$ ARE THE ENDS OF THE CYLINDER IN THE SOURCE COORDINATE SYSTEM.

3. $-180° \leq \psi \leq 180°$

4. $\Delta A = R \, \Delta\psi \, \Delta Z$

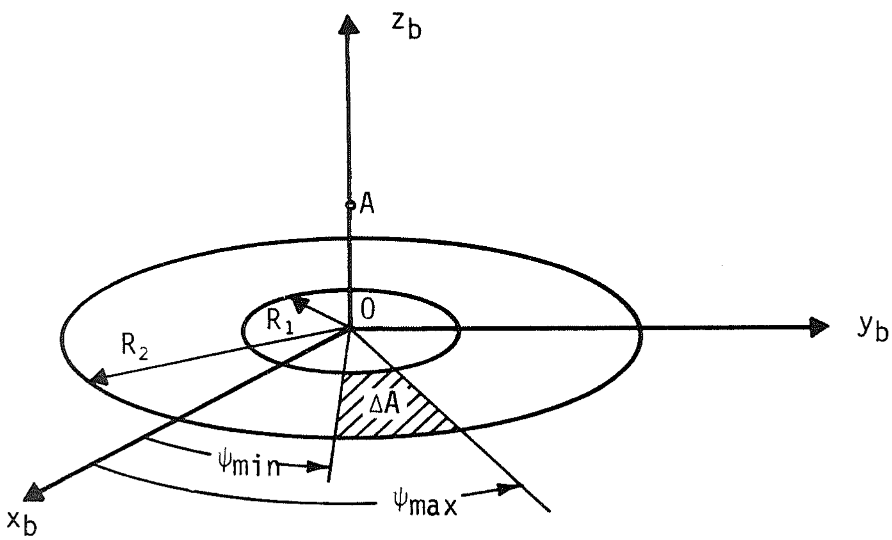
FIGURE 8. CYLINDER -- TYPE OF SURFACE 3



NOTES:

1. x_b, y_b, z_b IS THE SURFACE COORDINATE SYSTEM.
2. $O(x_0, y_0, z_0)$, $A(X_A, Y_A, Z_A)$, AND $B(X_B, Y_B, Z_B)$ REPRESENT THE CORNERS OF THE RECTANGULAR PLATE.
3. L_1 IS THE SIDE LENGTH IN THE x_b-DIRECTION.
4. L_2 IS THE SIDE LENGTH IN THE y_b-DIRECTION.
5. $\Delta A = \Delta x \ \Delta y$.

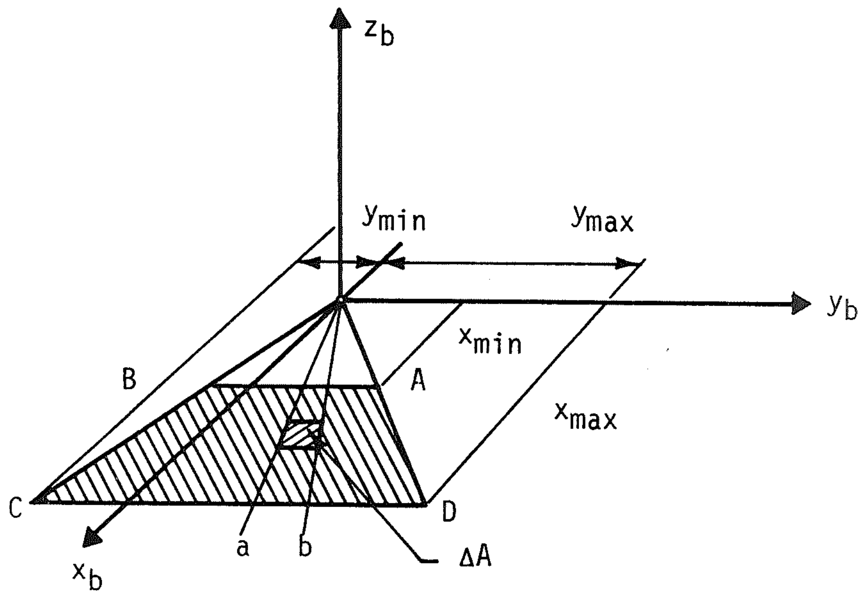
FIGURE 9. RECTANGULAR PLATE -- TYPE OF SURFACE 4



NOTES:

1. x_b, y_b, z_b IS THE SURFACE COORDINATE SYSTEM.
2. 0 IS THE CENTER OF THE DISK OR ANNULUS.
3. MINIMUM RADIUS = R_1; MAXIMUM RADIUS = R_2.
4. $|\vec{OA}| = 1$; $\vec{OA}$ IS A UNIT VECTOR IN THE POSITIVE z_b DIRECTION.
5. $\psi_{min} \leq \psi \leq \psi_{max}$ IS THE SECTION BEING CALCULATED IN THE PROGRAM.
6. $\Delta A = 0.5\ \Delta(R^2)\Delta\psi$

FIGURE 10. CIRCULAR DISK OR ANNULUS - TYPE OF SURFACE 5



NOTES:

1. x_b, y_b, z_b IS THE SURFACE COORDINATE SYSTEM.

2. A, B, C, D ARE IN A COUNTER-CLOCKWISE ROTATION.

3. ELEMENTS ARE SPECIFIED BETWEEN RAYS a, b, AND CONSTANT x LINES.

4. A, B REPRESENT THE SAME POINT WHEN THE SURFACE IS A TRIANGLE.

FIGURE 11. TRIANGLE OR TRAPEZOID -- TYPE OF SURFACE 6

VI. DETAILED DATA INPUT REQUIREMENTS

A detailed description of the input data requirements for the meteoroid flux distribution is given below, followed by the program input format.

The first card required is a problem title card. There are 80 spaces available for such information as required to identify the problem.

The second card contains the information of the source surfaces. The first number N1S defines the number of partitions in the conic angle direction ($0 < \theta < 180°$) and N2S in the circumferential angle direction ($0 \leqq \phi \leqq 360°$). RSR is the radius of the source sphere. As a rule of thumb, N1S and N2S are about 40 by 40, but they can be any larger numbers in order to obtain more accurate results. RSR may be chosen about 10^3 times larger than the dimension of the vehicle. The third card defines the number of surfaces of the vehicle, including all possible blocking surfaces and the surfaces on which the meteoroid flux distribution is calculated.

The next card set contains the information and specification of the basic surfaces. The number NTYPE(K) defines the type of surface, e.g., NTYPE(K) = 2 indicates the conic surface; K is the Kth surface in the assembly. The next card in column 1-80 describes the information of the surface. The numbers AA(K, J) specify the basic information of surface geometry. They are listed as follows:

- NTYPE(K)=1; sphere
  - ▲ AA(K, 1)=x_c*

*The notations x_c, y_c, z_c, R, etc., were defined in the last section. The dimension of all lengths is in inches and the unit of angle is degree.

- ▲ AA(K, 2)=y_C
- ▲ AA(K, 3)=z_C
- ▲ AA(K, 4)=R
- ▲ AA(K, 5)=θmin
- ▲ AA(K, 6)=θmax
- ▲ AA(K, 7)=ψmin
- ▲ AA(K, 8)=ψmax
- ▲ AA(K, 9)=x_A
- ▲ AA(K, 10)=x_B
- ▲ AA(K, 11)=x_C

● NTYPE(K)=2; cone

- ▲ AA(K, 1)=R_1
- ▲ AA(K, 2)=x_1
- ▲ AA(K, 3)=y_1
- ▲ AA(K, 4)=z_1
- ▲ AA(K, 5)=R_2
- ▲ AA(K, 6)=x_2
- ▲ AA(K, 7)=y_2
- ▲ AA(K, 8)=z_2
- ▲ AA(K, 9)=ψmin
- ▲ AA(K, 10)=ψmax

● NTYPE(K)=3; cylinder

- ▲ AA(K, 1)=R
- ▲ AA(K, 2)=x_1
- ▲ AA(K, 3)=y_1
- ▲ AA(K, 4)=z_1
- ▲ AA(K, 5)=x_2
- ▲ AA(K, 6)=y_2
- ▲ AA(K, 7)=z_2
- ▲ AA(K, 8)=ψmin
- ▲ AA(K, 9)=ψmax

● NTYPE(K)=4; rectangular plate

- ▲ AA(K, 1)=x_0
- ▲ AA(K, 2)=y_0
- ▲ AA(K, 3)=z_0
- ▲ AA(K, 4)=x_A
- ▲ AA(K, 5)=y_A
- ▲ AA(K, 6)=z_A
- ▲ AA(K, 7)=x_B
- ▲ AA(K, 8)=y_B
- ▲ AA(K, 9)=z_B

● NTYPE(K)=5; circular disk or annulus

- ▲ AA(K, 1)=Rmin
- ▲ AA(K, 2)=Rmax

- ▲ AA(K, 3)=x_0
- ▲ AA(K, 4)=y_0
- ▲ AA(K, 5)=z_0
- ▲ AA(K, 6)=x_1
- ▲ AA(K, 7)=y_1
- ▲ AA(K, 8)=z_1
- ▲ AA(K, 9)=ψ_{min}
- ▲ AA(K, 10)=ψ_{max}

- NTYPE(K)=6; triangle or trapezoid
  - ▲ AA(K, 1)=x_A
  - ▲ AA(K, 2)=y_A
  - ▲ AA(K, 3)=z_A
  - ▲ AA(K, 4)=x_B
  - ▲ AA(K, 5)=y_B
  - ▲ AA(K, 6)=z_B
  - ▲ AA(K, 7)=x_C
  - ▲ AA(K, 8)=y_C
  - ▲ AA(K, 9)=z_C
  - ▲ AA(K, 10)=x_D
  - ▲ AA(K, 11)=y_D
  - ▲ AA(K, 12)=z_D

The next card(s) identifies the information for the calculation of meteoroid flux distribution; KB is the index of the surface to be calculated and MBLOK is the number of surfaces that possibly block the KB surface. If MBLOK is specified to be any negative value, all surfaces (NB) are considered as possible blocking surfaces. The control variable, MAN, indicates the active side of the surface. When MAN=1, the active side of the surface is the one with positive curvature (cone, cylinder and sphere) or the surfaces facing the $+Z_b$ direction (for disks, rectangles, triangles, trapezoids or annuli). MAN=-1 makes the other side of the surface active. N3 and N4 are the number of partitions of surface KB. Both N3 and N4 must be equal or less than 10. If 10×10 elements are not considered large enough, one may increase the number of surfaces and still obtain 10×10 for each smaller surface.

The array IBLOK(I) specifies the surfaces that may block the KB surface. This card may be omitted if MBLOK$\leq$0, i.e., either no surfaces or all of the surfaces being considered as shielding surfaces.

The following is the input data format of the program:

CARD No. 1		Problem title or identification
FORMAT	20A4	
Col. 1-80	WRIT	
CARD No. 2		Source information
FORMAT	2I5, E10.5	
Col. 1-5	N1S	Number of partitions in θ direction of source sphere
Col. 6-10	N2S	Number of partitions in ψ direction of source sphere
Col. 11-20	RSR	Radius of source sphere (in.)
CARD No. 3		Total number of surfaces
FORMAT	10I5	
Col. 1-5	NB	Total number of surfaces input in the program
CARD No. 4		Type of surface
FORMAT	10I5	
Col. 1-5	NTYPE(K)	Type of surface
CARD No. 5		Description of the surface
FORMAT	20A4	
Col. 1-80	WRIT(I)	Name or identification of the surface
CARD(S) No. 6		Specification of surface geometric variable
FORMAT	8E10.5	
Col. 1-80	AA(K_1, J)	(The variables depend on the type surface considered; the detailed description was given on page 24)

NOTE: Cards 4 to 6 specify a single surface and will be repeated NB times.

CARD No. 7

FORMAT	10I5	
Col. 1-5	NANGL	Number of partitions for incoming meteoroid flux angle
Col. 6-10	NTOTL	Total number of surfaces on which the meteoroid flux distribution is calculated

CARD No. 8 — Specifications of surface on which the meteoroid flux distribution is calculated

FORMAT	16I5	
Col. 1-5	KB	The identification of surface
Col. 6-10	MBLOK	Number of possible blocking surfaces
Col. 11-15	MAN	+1; the active side of surface being in $+z_b$ direction or positive curvature of surface. -1; the active side of surface being in $-z_b$ direction or negative curvature of surface.
Col. 16-20	N3	Number of partitions on surface
Col. 21-25	N4	Number of partitions on surface

NOTE: N3 is the number of partitions in the θ-direction for a sphere, z-direction for cone and cylinder, x-direction for rectangular plate, r-direction for disks or annuli, and rays for triangles or trapezoids. N4 is the other direction with respect to that of N3.

CARD No. 9 — Identification of blocking surfaces

FORMAT	16I5	
Col. 1-5	IBLOK(1)	The identification number of the blocking surface
Col. 6-10	IBLOK(2)	

NOTE: This card(s) may be omitted if MBLOK $\leq$ 0. Card(s) 8-9 repeat as the number KB indicates.

VII. PROGRAM RESULTS OF A SAMPLE PROBLEM

In this section, the output of the program will be described with the aid of a sample problem. For simplicity, the Command and Service Module (CSM) of Skylab is chosen as an example. As shown in Figure 5, CSM is modeled with five basic surfaces: two cones, two annuli, and one circular cylinder. The results shown in the computer output are the number of particles that impact the specific element divided by the meteoroid flux, N_1, of the source sphere. GAMMA in the printout is the angular deviation from the direction normal to the surface.

On surface 1, i.e., the circular disk that represents the docking port, there is no blocking surface to it; therefore, the number of particles is the same as that of the source sphere. From the heat radiation point of view, the total flux on each element divided by the area of the element must be 1, which represents the shape factor of the surface. This is indeed the case shown for surfaces 1, 2, and 3.

Surfaces 4 and 5 are partially blocked by each other; therefore, the shape factor will be less than one. The distribution of meteoroid particles follows the right trend for these surfaces. The results also show that as the radius of surface 4 increases the number of particles also increases because of less blockage by surface 5. The same is true for the distribution of particles at surface 5.

Because of the symmetry of this example, the results are given for only a portion of the CSM.

```
EXAMPLE PROBLEM          COMMAND AND SERVICE MODULE


SOURCE SURFACE

RADIUS OF SURFACE SPHERE     0.10000E 04
NUMBER OF PARTITIONS IN THETA=    40
NUMBER OF PARTITIONS IN  PHI =    20


SURFACE NUMBER=  1      TYPE OF SURFACE= 5
PORT AREA
ANNULUS OR DISK     RMIN.=     0.00000E 00     RMAX.=     0.20510E 02
CENTER     0.00000E 00     0.00000E 00    -0.17900E 03     POINT1    0.00000E 00     0.00000E 00    -0.18000E 03
                 MIN. PHI=     0.00000E 00     MAX. PHI=     0.36000E 03


SURFACE NUMBER=  2      TYPE OF SURFACE= 2
 AXIAL SERVICE MODULE CONE, CREW COMPARTMENT  CSM
CONE      MIN. RADIUS=    0.20510E 02     CENTER OF R1 SECTION=     0.00000E 00     0.00000E 00    -0.17900E 03
          MAX. RADIUS=    0.77000E 02     CENTER OF R2 SECTION=     0.00000E 00     0.00000E 00    -0.92000E 02
          MIN. PHI=    0.00000E 00     MAX. PHI=     0.36000E 03


SURFACE NUMBER=  3      TYPE OF SURFACE= 3
AXIAL SERVICE MODULE CYLINDER  CSM
CYLIDER.       RADIUS=    0.77000E 02     CENTER     0.00000E 00     0.00000E 00    -0.92000E 02
                                                     0.00000E 00     0.00000E 00     0.92000E 02
               MIN. PHI=     0.00000E 00     MAX. PHI=     0.36000E 03


SURFACE NUMBER=  4      TYPE OF SURFACE= 5
AXIAL SERVICE MODULE END  CSM
ANNULUS OR DISK     RMIN.=     0.11800E 02     RMAX.=     0.77000E 02
CENTER     0.00000E 00     0.00000E 00     0.92000E 02     POINT1    0.00000E 00     0.00000E 00     0.93000E 02
                 MIN. PHI=     0.00000E 00     MAX. PHI=     0.36000E 03


SURFACE NUMBER=  5      TYPE OF SURFACE= 2
CONIC SURFACE OF ENGINE NOZZLE  CSM
CONE      MIN. RADIUS=    0.11800E 02     CENTER OF R1 SECTION=     0.00000E 00     0.00000E 00     0.92000E 02
          MAX. RADIUS=    0.53140E 02     CENTER OF R2 SECTION=     0.00000E 00     0.00000E 00     0.20600E 03
          MIN. PHI=    0.00000E 00     MAX. PHI=     0.36000E 03
```

SURFACE 1 NO. OF PARTITIONS 10 10

NO BLOCKING SURFACE IS CONSIDERED

DIFFERENTIAL AREA OF OBJECT SURFACE, 0.13215E 02

CIRCULAR DISK
CENTER OF THE DISK, X= 0.00000E 00 IN. Y= 0.00000E 00 IN. Z=-0.17900E 03 IN.
RMIN= 0.00000E 00 IN. RMAX= 0.20510E 02 IN.
MIN. PHI= 0.00000E 00 MAX. PHI= 0.36000E 03

		R(IN) FROM	0.00000E 00	0.64858E 01	0.91723E 01	0.11233E 02	0.12971E 02
		TO	0.64858E 01	0.91723E 01	0.11233E 02	0.12971E 02	0.14502E 02
			0.14502E 02	0.15886E 02	0.17159E 02	0.18344E 02	0.19457E 02
			0.15886E 02	0.17159E 02	0.18344E 02	0.19457E 02	0.20509E 02
PHI(DEGREES)	GAMMA(DEGREES)						
	FROM 0.00 TO 15.00		0.00000E 00	0.00000E 00	0.37592E 00	0.37656E 00	0.56505E 00
			0.56571E 00	0.56632E 00	0.56687E 00	0.56739E 00	0.56787E 00
	FROM 15.00 TO 30.00		0.35359E 01	0.35356E 01	0.31594E 01	0.31584E 01	0.29696E 01
			0.29687E 01	0.29677E 01	0.29669E 01	0.29661E 01	0.29653E 01
FROM 0.00	FROM 30.00 TO 45.00		0.28421E 01	0.28420E 01	0.28420E 01	0.28419E 01	0.28418E 01
			0.28418E 01	0.28417E 01	0.28416E 01	0.28416E 01	0.28415E 01
TO 36.00	FROM 45.00 TO 60.00		0.31661E 01	0.31662E 01	0.33312E 01	0.34144E 01	0.34155E 01
			0.34165E 01	0.34175E 01	0.34184E 01	0.35013E 01	0.35022E 01
	FROM 60.00 TO 75.00		0.29402E 01	0.29404E 01	0.27757E 01	0.26928E 01	0.26548E 01
			0.26171E 01	0.26167E 01	0.26164E 01	0.24968E 01	0.24965E 01
	FROM 75.00 TO 90.00		0.71937E 00	0.71943E 00	0.71950E 00	0.71956E 00	0.75682E 00
			0.79390E 00	0.79368E 00	0.79348E 00	0.83050E 00	0.83025E 00
	TOTAL NUMBER OF PARTICLES		0.13203E 02	0.13203E 02	0.13203E 02	0.13203E 02	0.13203E 02
			0.13203E 02	0.13203E 02	0.13203E 02	0.13203E 02	0.13203E 02

SURFACE 2 NO. OF PARTITIONS 10 10

NO BLOCKING SURFACE IS CONSIDERED

DIFFERENTIAL AREA OF OBJECT SURFACE, 0.31776E 03

CONE
MIN. RADIUS= 0.20510E 02 IN. MAX. RADIUS= 0.77000E 02 IN. LENGTH OF THE CONE 0.87000E 02 IN.
MIN. PHI= 0.00000E 00 MAX. PHI= 0.36000E 03

PHI(DEGREES)	GAMMA(DEGREES)					
	Z(IN) FROM	0.31083E 02	0.47672E 02	0.59826E 02	0.69898E 02	0.78690E 02
	TO	0.47672E 02	0.59826E 02	0.69898E 02	0.78690E 02	0.86595E 02
		0.86595E 02	0.93836E 02	0.10055E 03	0.10685E 03	0.11280E 03
		0.93836E 02	0.10055E 03	0.10685E 03	0.11280E 03	0.11845E 03
	FROM 0.00 TO 15.00	0.24172E 02	0.27912E 02	0.23838E 02	0.23877E 02	0.23900E 02
		0.23912E 02	0.23914E 02	0.27713E 02	0.27722E 02	0.27725E 02
	FROM 15.00 TO 30.00	0.54801E 02	0.54428E 02	0.61684E 02	0.61705E 02	0.61703E 02
		0.61683E 02	0.58067E 02	0.54258E 02	0.57487E 02	0.53941E 02
FROM 0.00	FROM 30.00 TO 45.00	0.82054E 02	0.81114E 02	0.74890E 02	0.74927E 02	0.74950E 02
		0.74543E 02	0.78222E 02	0.80751E 02	0.77565E 02	0.81140E 02
TO 36.00	FROM 45.00 TO 60.00	0.75529E 02	0.73247E 02	0.78003E 02	0.77950E 02	0.75884E 02
		0.76334E 02	0.77927E 02	0.75120E 02	0.75145E 02	0.75174E 02
	FROM 60.00 TO 75.00	0.59993E 02	0.60607E 02	0.58902E 02	0.58857E 02	0.60870E 02
		0.59814E 02	0.58162E 02	0.58453E 02	0.58373E 02	0.58306E 02
	FROM 75.00 TO 90.00	0.21058E 02	0.20314E 02	0.20313E 02	0.20322E 02	0.20337E 02
		0.21366E 02	0.21362E 02	0.21364E 02	0.21370E 02	0.21379E 02
	TOTAL NUMBER OF PARTICLES	0.31761E 03	0.31762E 03	0.31763E 03	0.31764E 03	0.31764E 03
		0.31765E 03	0.31765E 03	0.31766E 03	0.31766E 03	0.31766E 03

SURFACE 3 NO. OF PARTITIONS 10 10

NO BLOCKING SURFACE IS CONSIDERED

DIFFERENTIAL AREA OF OBJECT SURFACE, 0.89020E 03

CYLINDER
BASE CENTER COORDINATES, X= 0.00000E 00 IN. Y= 0.00000E 00 IN. Z=-0.92000E 02 IN.
LENGTH= 0.18400E 03 IN. RADIUS= 0.77000E 02 IN.
MIN. PHI= 0.00000E 00 MAX. PHI= 0.20626E 05

PHI(DEGREES)	GAMMA(DEGREES)										
	Z(IN) FROM	0.00000E 00	0.18400E 02	0.36800E 02	0.55199E 02	0.73599E 02	0.91999E 02	0.11039E 03	0.12879E 03	0.14719E 03	0.16559E 03
	TO	0.18400E 02	0.36800E 02	0.55199E 02	0.73599E 02	0.91999E 02	0.11039E 03	0.12879E 03	0.14719E 03	0.16559E 03	0.18399E 03
	FROM 0.00 TO 15.00	0.71555E 02	0.71555E 02	0.71555E 02	0.71555E 02	0.71555E 02	0.71555E 02	0.71555E 02	0.71555E 02	0.71555E 02	0.71555E 02
	FROM 15.00 TO 30.00	0.14116E 03	0.14116E 03	0.14116E 03	0.14116E 03	0.14116E 03	0.14116E 03	0.14116E 03	0.14116E 03	0.14116E 03	0.14116E 03
FROM 0.00	FROM 30.00 TO 45.00	0.21173E 03	0.21173E 03	0.21173E 03	0.21173E 03	0.21173E 03	0.21173E 03	0.21173E 03	0.21173E 03	0.21173E 03	0.21173E 03
TO 36.00	FROM 45.00 TO 60.00	0.24221E 03	0.24221E 03	0.24221E 03	0.24221E 03	0.24221E 03	0.24221E 03	0.24221E 03	0.24221E 03	0.24221E 03	0.24221E 03
	FROM 60.00 TO 75.00	0.17287E 03	0.17287E 03	0.17287E 03	0.17287E 03	0.17287E 03	0.17287E 03	0.17287E 03	0.17287E 03	0.17287E 03	0.17287E 03
	FROM 75.00 TO 90.00	0.51170E 02	0.51170E 02	0.51170E 02	0.51170E 02	0.51170E 02	0.51170E 02	0.51170E 02	0.51170E 02	0.51170E 02	0.51170E 02
	TOTAL NUMBER OF PARTICLES	0.89071E 03	0.89071E 03	0.89071E 03	0.89071E 03	0.89071E 03	0.89071E 03	0.89071E 03	0.89071E 03	0.89071E 03	0.89071E 03

SURFACE 4 NO. OF PARTITIONS 10 10

ALL SURFACES ARE CONSIDERED AS POSSIBLE BLOCKAGE

DIFFERENTIAL AREA OF OBJECT SURFACE, 0.18189E 03

CIRCULAR DISK
CENTER OF THE DISK, X= 0.00000E 00 IN. Y= 0.00000E 00 IN. Z= 0.92000E 02 IN.
RMIN= 0.11800E 02 IN. RMAX= 0.77000E 02 IN.
MIN. PHI= 0.00000E 00 MAX. PHI= 0.36000E 03

		R(IN) FROM	0.11799E 02	0.26799E 02	0.36016E 02	0.43314E 02	0.49549E 02
		TO	0.26799E 02	0.36016E 02	0.43314E 02	0.49549E 02	0.55082E 02
			0.55082E 02	0.60109E 02	0.64746E 02	0.69072E 02	0.73143E 02
			0.60109E 02	0.64746E 02	0.69072E 02	0.73143E 02	0.76999E 02
PHI(DEGREES)	GAMMA(DEGREES)						
	FROM 0.00 TO 15.00		0.00000E 00	0.43507E 01	0.86927E 01	0.10846E 02	0.10865E 02
			0.10881E 02	0.10894E 02	0.10905E 02	0.10915E 02	0.10923E 02
	FROM 15.00 TO 30.00		0.10039E 02	0.12081E 02	0.16023E 02	0.16107E 02	0.18115E 02
			0.22171E 02	0.22224E 02	0.22272E 02	0.24363E 02	0.24397E 02
FROM 0.00	FROM 30.00 TO 45.00		0.32373E 02	0.36077E 02	0.33822E 02	0.35485E 02	0.33616E 02
			0.35273E 02	0.35333E 02	0.37003E 02	0.35701E 02	0.35770E 02
TO 36.00	FROM 45.00 TO 60.00		0.34557E 02	0.38520E 02	0.37759E 02	0.37941E 02	0.38101E 02
			0.36636E 02	0.37736E 02	0.36215E 02	0.37657E 02	0.38790E 02
	FROM 60.00 TO 75.00		0.22854E 02	0.24866E 02	0.27074E 02	0.28652E 02	0.29599E 02
			0.29634E 02	0.29668E 02	0.29701E 02	0.29734E 02	0.29766E 02
	FROM 75.00 TO 90.00		0.10401E 02	0.11246E 02	0.11707E 02	0.11744E 02	0.11777E 02
			0.11808E 02	0.11837E 02	0.11866E 02	0.11893E 02	0.11919E 02
	TOTAL NUMBER OF PARTICLES		0.11022E 03	0.12714E 03	0.13508E 03	0.14077E 03	0.14207E 03
			0.14640E 03	0.14769E 03	0.14796E 03	0.15026E 03	0.15156E 03

SURFACE 5 NO. OF PARTITIONS 10 10

BLOCKING SURFACES
4

DIFFERENTIAL AREA OF OBJECT SURFACE, 0.24739E 03

CONE
MIN. RADIUS= 0.11800E 02 IN. MAX. RADIUS= 0.53140E 02 IN. LENGTH OF THE CONE 0.11400E 03 IN.
MIN. PHI= 0.00000E 00 MAX. PHI= 0.36000E 03

		Z(IN) FROM	0.32035E 02	0.55387E 02	0.71479E 02	0.84562E 02	0.95876E 02
		TO	0.55387E 02	0.71479E 02	0.84562E 02	0.95876E 02	0.10598E 03
			0.10598E 03	0.11521E 03	0.12376E 03	0.13175E 03	0.13928E 03
			0.11521E 03	0.12376E 03	0.13175E 03	0.13928E 03	0.14642E 03
PHI(DEGREES)	GAMMA(DEGREES)						
	FROM 0.00 TO 15.00		0.24103E 01	0.18905E 02	0.18880E 02	0.18846E 02	0.21297E 02
			0.21265E 02	0.21228E 02	0.19039E 02	0.19010E 02	0.18978E 02
	FROM 15.00 TO 30.00		0.18615E 02	0.29189E 02	0.43973E 02	0.48041E 02	0.45490E 02
			0.43539E 02	0.43472E 02	0.45548E 02	0.48027E 02	0.47961E 02
FROM 0.00	FROM 30.00 TO 45.00		0.27108E 02	0.38364E 02	0.46632E 02	0.49827E 02	0.58344E 02
			0.61657E 02	0.61624E 02	0.60130E 02	0.59714E 02	0.59692E 02
TO 36.00	FROM 45.00 TO 60.00		0.31477E 02	0.35488E 02	0.38496E 02	0.45286E 02	0.47221E 02
			0.51003E 02	0.53783E 02	0.55268E 02	0.55241E 02	0.56113E 02
	FROM 60.00 TO 75.00		0.24347E 02	0.25949E 02	0.29672E 02	0.31387E 02	0.33050E 02
			0.34027E 02	0.36861E 02	0.39711E 02	0.43064E 02	0.43304E 02
	FROM 75.00 TO 90.00		0.90663E 01	0.11956E 02	0.11988E 02	0.12327E 02	0.12794E 02
			0.13139E 02	0.13505E 02	0.13891E 02	0.12272E 02	0.12639E 02
	TOTAL NUMBER OF PARTICLES		0.11302E 03	0.15985E 03	0.18964E 03	0.20571E 03	0.21819E 03
			0.22463E 03	0.23047E 03	0.23359E 03	0.23733E 03	0.23868E 03

VIII. PROGRAM LISTING

```
C       MAIN PROGRAM
        COMMON NREAD,NWRIT,PI,NB,NANGL,NTOTL,N1S,N2S,RSR,
       1 SAREA,MBLOK,NTYPE(200),AA(200,18),GAMMA(18),
       2 FLUX(100,10),W(200,3),XSB(40,40),YSB(40,40),
       3 ZSB(40,40),XS(40,40),YS(40,40),ZS(40,40),
       4 IBLOK(200),LIM1,LIM2,MAN
        LIM2=40
        LIM1=40
        CALL STONE
        STOP
        END
```

```
      SUBROUTINE STONE
      DIMENSION WRIT(20)
      COMMON NREAD,NWRIT,PI,NB,NANGL,NTOTL,N1S,N2S,RSR,
     1 SAREA,MBLOK,NTYPE(200),AA(200,18),GAMMA(18),
     2 FLUX(100,10),W(200,3),XSB(40,40),YSB(40,40),
     3 ZSB(40,40),XS(40,40),YS(40,40),ZS(40,40),
     4 IBLOK(200),LIM1,LIM2,MAN
      PI=3.1415926
      NREAD=5
      NWRIT=6
C     NTYPE=1  SPHERE
C     NTYPE=2  CONE
C     NTYPE=3  CYLINDER
C     NTYPE=4  FLAT PLATE
C     NTYPE=5  CIRCULAR DISK
C     NTYPE=6  TRIANGLE OR TRAPEZOID
      READ (NREAD,140) (WRIT(I),I=1,20)
      WRITE(NWRIT,141)
  141 FORMAT (1H1,//)
      WRITE(NWRIT,140) (WRIT(I),I=1,20)
      READ(NREAD,590) N1S,N2S,RSR
  590 FORMAT(2I5,F10.5)
      WRITE(NWRIT,550) RSR,N1S,N2S
  550 FORMAT(  ////5X,14HSOURCE SURFACE//5X,9HRADIUS OF,
     1 15H SURFACE SPHERE,E15.5/5X,20HNUMBER OF PARTITIONS,
     210H IN THETA=,I5/5X30HNUMBER OF PARTITIONS IN  PHI =,
     3 I5)
      READ(NREAD,510) NB
      DO 30 K=1,NB
      READ(NREAD,510) NTYPE(K)
      READ(NREAD,140) (WRIT(I),I=1,20)
  140 FORMAT(20A4)
      N=NTYPE(K)
      WRITE(NWRIT,150)K,N
  150 FORMAT(//5X,15HSURFACE NUMBER=,I3,5X,
     1 16HTYPE OF SURFACE=,I2)
      WRITE(NWRIT,140) (WRIT(I),I=1,20)
      GO TO (210,220,230,240,250,260),N
  210 NN=11
      READ(NREAD,520) (AA(K,J),J=1,NN)
      WRITE(NWRIT,521)(AA(K,J),J=1,NN)
  521 FORMAT(5X,6HSPHERE,5X,6HCENTER,3E15.5,7HRADIUS=,
     1 E15.5,/16X,11HMIN. THETA=,E15.5,20X,11HMAX. THETA=,
     2E15.5/16X,11HMIN.  PHI =,E15.5,20X,11HMAX.  PHI =,
     3 E15.5)
      GO TO 30
  220 NN=10
      READ(NREAD,520) (AA(K,J),J=1,NN)
      WRITE(NWRIT,522)(AA(K,J),J=1,NN)
```

```
522 FORMAT(5X4HCONE,5X12HMIN. RADIUS=,E15.5,5X,
   1 21HCENTER OF R1 SECTION=,3E15.5/14X12HMAX. RADIUS=,
   2E15.5,5X,21HCENTER OF R2 SECTION=,3E15.5/14X,
   3 9HMIN. PHI=,E15.5,5X,9HMAX. PHI=,E15.5)
    GO TO 30
230 NN=9
    READ(NREAD,520) (AA(K,J),J=1,NN)
    WRITE(NWRIT,523)(AA(K,J),J=1,NN)
523 FORMAT(5X,8HCYLIDER,5X,7HRADIUS=,E15.5,5X,6HCENTER,
   1 3E15.5/51X,3E15.5/18X,9HMIN. PHI=,E15.5,5X
   2 9HMAX. PHI=,E15.5)
    GO TO 30
240 NN=9
    READ(NREAD,520) (AA(K,J),J=1,NN)
    WRITE(NWRIT,524)(AA(K,J),J=1,NN)
524 FORMAT(5X,9HRECTANGLE,49X,6HPOINT1,3E15.5/6X,
   1 6HPOINT2,3E15.5,6X,6HPOINT3,3E15.5)
    GO TO 30
250 NN=10
    READ(NREAD,520) (AA(K,J),J=1,NN)
    WRITE(NWRIT,525)(AA(K,J),J=1,NN)
525 FORMAT(5X,15HANNULUS OR DISK,5X,6HRMIN.=,E15.5,
   1 5X,6HRMAX.=,E15.5,/5X6HCENTER,3E15.5,4X,6HPOINT1,
   23E15.5,/20X,9HMIN. PHI=,E15.5,5X,9HMAX. PHI=,E15.5)
    GO TO 30
260 NN=12
    READ(NREAD,520) (AA(K,J),J=1,NN)
    WRITE(NWRIT,526)(AA(K,J),J=1,NN)
526 FORMAT(5X,21HTRIANGLE OR TRAPEZOID/6X,1HA,3E15.5,
   1 8X,1HB,3E15.5,/6X,1HC,3E15.5,8X,1HD,3E15.5)
    GO TO 30
 30 CONTINUE
    READ(NREAD,510) NANGL,NTOTL
    CALL DEF
    AM=NANGL
    DEL=PI/(AM*2.)
    DO 50 I=1,NANGL
    AI=I
    GAMMA(I)=AI*DEL
 50 CONTINUE
510 FORMAT(10I5)
520 FORMAT(8E10.5)
    CALL BALL
    RETURN
    END
```

```
      SUBROUTINE DEE
      DIMENSION EE(9)
      COMMON NREAD,NWRIT,PI,NB,NANGL,NTOTL,N1S,N2S,RSR,
     1 SAREA,MBLOK,NTYPE(200),AA(200,18),GAMMA(18),
     2 FLUX(100,10),W(200,3),XSB(40,40),YSB(40,40),
     3 ZSB(40,40),XS(40,40),YS(40,40),ZS(40,40),
     4 IBLOK(200),LIM1,LIM2,MAN
      CF=PI/180.
      DO 100 K=1,NB
      NN=NTYPE(K)
      GO TO (10,20,30,40,50,60),NN
   10 AA(K,14)=AA(K,1)
      AA(K,15)=AA(K,2)
      AA(K,16)=AA(K,3)
      X=AA(K,9)-AA(K,1)
      Y=AA(K,10)-AA(K,2)
      Z=AA(K,11)-AA(K,3)
      AA(K,10)=AA(K,4)
      AA(K,11)=CF*AA(K,5)
      AA(K,12)=CF*AA(K,6)
      AA(K,17)=CF*AA(K,7)
      AA(K,18)=CF*AA(K,8)
      GO TO 5
   20 R2=AA(K,5)
      AA(K,17)=CF*AA(K,9)
      AA(K,18)=CF*AA(K,10)
      X=AA(K,6)-AA(K,2)
      Y=AA(K,7)-AA(K,3)
      Z=AA(K,8)-AA(K,4)
      D=SQRT(X*X+Y*Y+Z*Z)
      R1=AA(K,1)
      Z1=R1*D/(R2-R1)
      Z2=Z1+D
      RATIO=Z1/D
      AA(K,14)=AA(K,2)-RATIO*X
      AA(K,15)=AA(K,3)-RATIO*Y
      AA(K,16)=AA(K,4)-RATIO*Z
      AA(K,10)=R1
      AA(K,11)=R2
      AA(K,12)=Z1
      AA(K,13)=Z2
      GO TO 5
   30 X=AA(K,5)-AA(K,2)
      Y=AA(K,6)-AA(K,3)
      Z=AA(K,7)-AA(K,4)
      D=SQRT(X*X+Y*Y+Z*Z)
      AA(K,14)=AA(K,2)
      AA(K,15)=AA(K,3)
      AA(K,16)=AA(K,4)
```

```
      AA(K,10)=AA(K,1)
      AA(K,11)=D
      AA(K,17)=CF*AA(K,8)
      AA(K,18)=AA(K,9)*CF
      GO TO 5
   40 DO 41 I=1,2
      L1=4+(I-1)*3
      L2=L1+1
      L3=L2+1
      XD=AA(K,L1)-AA(K,1)
      YD=AA(K,L2)-AA(K,2)
      ZD=AA(K,L3)-AA(K,3)
      AA(K,I+9)=SQRT(XD*XD+YD*YD+ZD*ZD)
   41 CONTINUE
      AA(K,14)=AA(K,1)
      AA(K,15)=AA(K,2)
      AA(K,16)=AA(K,3)
      AX=(AA(K,4)-AA(K,1))/AA(K,10)
      AY=(AA(K,5)-AA(K,2))/AA(K,10)
      AZ=(AA(K,6)-AA(K,3))/AA(K,10)
      BX=(AA(K,7)-AA(K,1))/AA(K,11)
      BY=(AA(K,8)-AA(K,2))/AA(K,11)
      BZ=(AA(K,9)-AA(K,3))/AA(K,11)
      CX=AY*BZ-AZ*BY
      CY=AZ*BX-AX*BZ
      CZ=AX*BY-AY*BX
      AA(K,1)=AX
      AA(K,2)=AY
      AA(K,3)=AZ
      AA(K,4)=BX
      AA(K,5)=BY
      AA(K,6)=BZ
      AA(K,7)=CX
      AA(K,8)=CY
      AA(K,9)=CZ
      GO TO 100
   50 D=1.
      AA(K,17)=CF*AA(K,9)
      AA(K,18)=CF*AA(K,10)
      X=AA(K,6)-AA(K,3)
      Y=AA(K,7)-AA(K,4)
      Z=AA(K,8)-AA(K,5)
      AA(K,14)=AA(K,3)
      AA(K,15)=AA(K,4)
      AA(K,16)=AA(K,5)
      AA(K,10)=AA(K,1)
      AA(K,11)=AA(K,2)
    5 H=SQRT(X*X+Y*Y+Z*Z)
      R=SQRT(X*X+Y*Y)
      SINTH=R/H
      COSTH=Z/H
      ABSR=ABS(R)-1.E-5
      IF (ABSR)  7,8,8
    7 SINPH=0.
      COSPH=1.
      GO TO 9
    8 SINPH=Y/R
      COSPH=X/R
    9 AA(K,1)=COSTH*COSPH
```

```
      AA(K,2)=SINPH*COSTH
      AA(K,3)=-SINTH
      AA(K,4)=-SINPH
      AA(K,5)=COSPH
      AA(K,6)=0.
      AA(K,7)=SINTH*COSPH
      AA(K,8)=SINTH*SINPH
      AA(K,9)=COSTH
      GO TO 100
   60 XA=AA(K,10)-AA(K,7)
      YA=AA(K,11)-AA(K,8)
      ZA=AA(K,12)-AA(K,9)
      A=SQRT(XA*XA+YA*YA+ZA*ZA)
      XB=AA(K,4)-AA(K,1)
      YB=AA(K,5)-AA(K,2)
      ZB=AA(K,6)-AA(K,3)
      B=SQRT(XB*XB+YB*YB+ZB*ZB)
      XD=AA(K,1)-AA(K,10)
      YD=AA(K,2)-AA(K,11)
      ZD=AA(K,3)-AA(K,12)
      D=SQRT(XD*XD+YD*YD+ZD*ZD)
      RATIO=B/(A-B)
      AA(K,14)=AA(K,1)+XD*RATIO
      AA(K,15)=AA(K,2)+YD*RATIO
      AA(K,16)=AA(K,3)+ZD*RATIO
      YI=XA/A
      YJ=YA/A
      YK=ZA/A
      ZI=YD*ZB-ZD*YB
      ZJ=ZD*XB-XD*ZB
      ZK=XD*YB-YD*XB
      TZ=SQRT(ZI*ZI+ZJ*ZJ+ZK*ZK)
      ZI=ZI/TZ
      ZJ=ZJ/TZ
      ZK=ZK/TZ
      XI=YJ*ZK-YK*ZJ
      XJ=YK*ZI-YI*ZK
      XK=YI*ZJ-YJ*ZI
      EE(1)=XI
      EE(2)=XJ
      EE(3)=XK
      EE(4)=YI
      EE(5)=YJ
      EE(6)=YK
      EE(7)=ZI
      EE(8)=ZJ
      EE(9)=ZK
      DO 61 L=1,9,3
      XCO=AA(K,L)-AA(K,14)
      YCO=AA(K,L+1)-AA(K,15)
      ZCO=AA(K,L+2)-AA(K,16)
      AA(K,L)=XCO*EE(1)+YCO*EE(2)+ZCO*EE(3)
      AA(K,L+1)=XCO*EE(4)+YCO*EE(5)+ZCO*EE(6)
      AA(K,L+2)=XCO*EE(7)+YCO*EE(8)+ZCO*EE(9)
   61 CONTINUE
      AA(K,12)=AA(K,8)
      AA(K,13)=AA(K,11)
      AA(K,11)=AA(K,10)
      AA(K,10)=AA(K,1)
```

```
      DO 62 L=1,9
   62 AA(K,L)=EE(L)
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE NORML(SXB,SYB,SZB,KB,D,COSB)
      COMMON NREAD,NWRIT,PI,NB,NANGL,NTOTL,N1S,N2S,RSR,
     1 SAREA,MBLOK,NTYPE(200),AA(200,18),GAMMA(18),
     2 FLUX(100,10),W(200,3),XSB(40,40),YSB(40,40),
     3 ZSB(40,40),XS(40,40),YS(40,40),ZS(40,40),
     4 IBLOK(200),LIM1,LIM2,MAN
      K=KB
      X=W(KB,1)
      Y=W(KB,2)
      Z=W(KB,3)
      A2=(X-SXB)/D
      B2=(Y-SYB)/D
      C2=(Z-SZB)/D
      NN=NTYPE(K)
      GO TO (102,202,302,402,402,402),NN
  102 COSB=-(A2*X+B2*Y+C2*Z)/AA(K,10)
      RETURN
  202 R=SQRT(X*X+Y*Y)
      AM=AA(K,10)/AA(K,12)
      AM=AM*AM
      XX=X/R
      YY=Y/R
      ZZ=-SQRT(AM)
      RRR=SQRT(XX*XX+YY*YY+ZZ*ZZ)
      XX=XX/RRR
      YY=YY/RRR
      ZZ=ZZ/RRR
      COSB=-(A2*XX+B2*YY+C2*ZZ)
      RETURN
  302 COSB=-(A2*X+B2*Y)/AA(K,10)
      RETURN
  402 COSB=-C2
      RETURN
      END
```

```
      SUBROUTINE BALL
      DIMENSION CC(3),YY(11)
      COMMON NREAD,NWRIT,PI,NB,NANGL,NTOTL,N1S,N2S,RSR,
     1 SAREA,MBLOK,NTYPE(200),AA(200,18),GAMMA(18),
     2 FLUX(100,10),W(200,3),XSB(40,40),YSB(40,40),
     3 ZSB(40,40),XS(40,40),YS(40,40),ZS(40,40),
     4 IBLOK(200),LIM1,LIM2,MAN
      N1=N1S
      N2=N2S
      R=RSR
      DEL1=-2./FLOAT(N1)
      DEL2=2.*PI/FLOAT(N2)
      SAREA=RSR*RSR*DEL1*DEL2
      SAREA=ABS(SAREA)
      IF (N1-LIM1) 1,1,2
    1 LM1=N1
      GO TO 3
    2 LM1=LIM1
    3 IF (N2-LIM2)  4,4,5
    4 LM2=N2
      GO TO 6
    5 LM2=LIM2
    6 DO 100 J=1,LM2
      AJ=J
      PHI=(AJ-0.5)*DEL2
      SINPH=SIN(PHI)
      COSPH=COS(PHI)
      DO 100 I=1,LM1
      AI=I
      COSTH=1.+(AI-0.5)*DEL1
      SINTH=SQRT(1.-COSTH*COSTH)
      XS(I,J)=R*SINTH*COSPH
      YS(I,J)=R*SINTH*SINPH
      ZS(I,J)=R*COSTH
  100 CONTINUE
      DO 10 LB=1,NTOTL
      READ(NREAD,150) KB,MBLOK,MAN,N3,N4
      K=KB
C     TRANSFER XS,YS,ZS, TO BODY COORDINATE SYSTEM
      DO 90 II=1,LM1
      DO 90 JJ=1,LM2
      XCO=XS(II,JJ)-AA(KB,14)
      YCO=YS(II,JJ)-AA(KB,15)
      ZCO=ZS(II,JJ)-AA(KB,16)
      XSB(II,JJ)=XCO*AA(K,1)+YCO*AA(K,2)+ZCO*AA(K,3)
      YSB(II,JJ)=XCO*AA(K,4)+YCO*AA(K,5)+ZCO*AA(K,6)
      ZSB(II,JJ)=XCO*AA(K,7)+YCO*AA(K,8)+ZCO*AA(K,9)
   90 CONTINUE
      N=N3*N4
```

```
      NNN=NTYPE(KB)
      GO TO (11,12,13,14,15,16),NNN
   11 DEL3=(COS(AA(K,12))-COS(AA(K,11)))/FLOAT(N3)
      DEL4=(AA(K,18)-AA(K,17))/FLOAT(N4)
      ELEM=-DEL3*DEL4*AA(KB,10)*AA(KB,10)
      GO TO 19
   12 DEL3=(AA(KB,13)*AA(KB,13)-AA(KB,12)*AA(KB,12))/FLOAT(N3)
      DEL4=(AA(K,18)-AA(K,17))/FLOAT(N4)
      AL=SQRT(AA(K,12)*AA(K,12)+AA(K,10)*AA(K,10))
      COSA=AA(K,12)/AL
      TANA=AA(K,10)/AA(K,12)
      ELEM=DEL3*DEL4*0.5*TANA/COSA
      GO TO 19
   13 DEL3=AA(K,11)/FLOAT(N3)
      DEL4=(AA(K,18)-AA(K,17))/FLOAT(N4)
      ELEM=AA(K,10)*DEL3*DEL4
      GO TO 19
   14 DEL3=AA(K,10)/FLOAT(N3)
      DEL4=AA(K,11)/FLOAT(N4)
      ELEM=DEL3*DEL4
      GO TO 19
   15 DEL3=(AA(K,11)*AA(K,11)-AA(K,10)*AA(K,10))/FLOAT(N3)
      DEL4=(AA(K,18)-AA(K,17))/FLOAT(N4)
      ELEM=DEL3*DEL4/2.
      GO TO 19
   16 XMAX=AA(K,11)
      XMIN=AA(K,10)
      AL=AA(K,13)-AA(K,12)
      DEL3=(XMAX*XMAX-XMIN*XMIN)/FLOAT(N3)
      DEL4=AL/FLOAT(N4)
      ELEM=0.5*DEL4*DEL3/XMAX
   19 IF (MBLOK) 60,30,33
   33 READ(NREAD,150) (IBLOK(I),I=1,MBLOK)
  150 FORMAT(16I5)
      GO TO 30
   60 MBLOK=NB
      DO 61 J=1,NB
   61 IBLOK(J)=J
   30 DO 20 J=1,NANGL
      DO 20 I=1,N
   20 FLUX(I,J)=0.
      DO 40 J=1,N4
      DO 40 I=1,N3
      CALL PLACE(I,J,KB,CC,DEL3,DEL4)
      DO 40 II=1,N1
      DO 40 JJ=1,N2
      CALL BLOCK(AREA,BETA,KB,NBLOK,II,JJ,CC,DEL1,DEL2,ELEM)
      IF (NBLOK)  40,41,40
   41 L=(J-1)*N3+I
      DO 50 M=1,NANGL
      IF (BETA-GAMMA(M)) 52,52,50
   50 CONTINUE
   52 FLUX(L,M)=FLUX(L,M)+AREA
   40 CONTINUE
      CALL CAPT(KB,YY,N3,N4,DEL3,DEL4,ELEM)
      CALL TYPE(KB,YY,N3,N4)
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PLACE(IB,JB,K,CC,DEL1,DEL2)
      DIMENSION CT(3),CC(3)
      COMMON NREAD,NWRIT,PI,NB,NANGL,NTOTL,N1S,N2S,RSR,
     1 SAREA,MBLOK,NTYPE(200),AA(200,18),GAMMA(18),
     2 FLUX(100,10),W(200,3),XSB(40,40),YSB(40,40),
     3 ZSB(40,40),XS(40,40),YS(40,40),ZS(40,40),
     4 IBLOK(200),LIM1,LIM2,MAN
      NN=NTYPE(K)
      GO TO (10,20,30,40,50,60),NN
   10 R=AA(K,10)
      X=(FLOAT(IB)-0.5)*DEL1+COS(AA(K,11))
      Y=(FLOAT(JB)-0.5)*DEL2 +AA(K,17)
      COSTH=X
      SINTH=SQRT(1.-X*X)
      COSPH=COS(Y)
      SINPH=SIN(Y)
      RS=R*SINTH
      RC=R*COSTH
      W(K,1)=RS*COSPH
      W(K,2)=RS*SINPH
      W(K,3)=RC
      GO TO 100
   20 Z1=AA(K,12)
      R1=AA(K,10)
      X=Z1*Z1+(FLOAT(IB)-0.5)*DEL1
      Y=(FLOAT(JB)-0.5)*DEL2 +AA(K,17)
      Z=SQRT(X)
      R=Z*R1/Z1
      PHI=Y
      W(K,1)=R*COS(PHI)
      W(K,2)=R*SIN(PHI)
      W(K,3)=Z
      GO TO 100
   30 R=AA(K,10)
      X=(FLOAT(IB)-0.5)*DEL1
      Y=(FLOAT(JB)-0.5)*DEL2 +AA(K,17)
      Z=X
      PHI=Y
      W(K,1)=R*COS(PHI)
      W(K,2)=R*SIN(PHI)
      W(K,3)=Z
      GO TO 100
   40 X=(FLOAT(IB)-0.5)*DEL1
      Y=(FLOAT(JB)-0.5)*DEL2
      W(K,1)=X
      W(K,2)=Y
      W(K,3)=0.
      GO TO 100
   50 X=AA(K,10)*AA(K,10)+(FLOAT(IB)-0.5)*DEL1
```

```
      Y=(FLOAT(JB)-0.5)*DEL2 +AA(K,17)
      R=SQRT(X)
      PHI=Y
      W(K,1)=R*COS(PHI)
      W(K,2)=R*SIN(PHI)
      W(K,3)=0.
      GO TO 100
   60 XMIN=AA(K,10)*AA(K,10)
      YMIN=AA(K,12)
      X=XMIN+(FLOAT(IB)-0.5)*DEL1
      X=SQRT(X)
      Y=YMIN+(FLOAT(JB)-0.5)*DEL2
      Y=X*Y/AA(K,13)
      W(K,1)=X
      W(K,2)=Y
      W(K,3)=0.
  100 CC(1)=W(K,1)*AA(K,1)+W(K,2)*AA(K,4)+W(K,3)*AA(K,7)
     1 +AA(K,14)
      CC(2)=W(K,1)*AA(K,2)+W(K,2)*AA(K,5)+W(K,3)*AA(K,8)
     1 +AA(K,15)
      CC(3)=W(K,1)*AA(K,3)+W(K,2)*AA(K,6)+W(K,3)*AA(K,9)
     1 +AA(K,16)
      IF (MBLOK)  620,620,610
  610 DO 70 KK=1,MBLOK
      NNN=IBLOK(KK)
      DO 70 KB=1,NB
      IF (NNN-KB)  70,90,70
   90 CT(1)=CC(1)-AA(KB,14)
      CT(2)=CC(2)-AA(KB,15)
      CT(3)=CC(3)-AA(KB,16)
      W(KB,1)=CT(1)*AA(KB,1)+CT(2)*AA(KB,2)+CT(3)*AA(KB,3)
      W(KB,2)=CT(1)*AA(KB,4)+CT(2)*AA(KB,5)+CT(3)*AA(KB,6)
      W(KB,3)=CT(1)*AA(KB,7)+CT(2)*AA(KB,8)+CT(3)*AA(KB,9)
   70 CONTINUE
  620 RETURN
      END
```

```
      SUBROUTINE BLOCK(AREA,BETA,KB,NBLOK,II,JJ,CC,DEL1,DEL2,ELEM)
      DIMENSION CC(3),S(3),ROOT(2)
      COMMON NREAD,NWRIT,PI,NB,NANGL,NTOTL,N1S,N2S,RSR,
     1 SAREA,MBLOK,NTYPE(200),AA(200,18),GAMMA(18),
     2 FLUX(100,10),W(200,3),XSB(40,40),YSB(40,40),
     3 ZSB(40,40),XS(40,40),YS(40,40),ZS(40,40),
     4 IBLOK(200),LIM1,LIM2,MAN
      NOVER=0
      IF (II-LIM1) 91,91,92
   91 IF (JJ-LIM2)  90,90,92
   92 NOVER=1
      CALL SST(SX,SY,SZ,SBX,SBY,SBZ,II,JJ,DEL1,DEL2,KB)
      XD=W(KB,1)-SBX
      YD=W(KB,2)-SBY
      ZD=W(KB,3)-SBZ
      GO TO 93
   90 XD=W(KB,1)-XSB(II,JJ)
      YD=W(KB,2)-YSB(II,JJ)
      ZD=W(KB,3)-ZSB(II,JJ)
      SBX=XSB(II,JJ)
      SBY=YSB(II,JJ)
      SBZ=ZSB(II,JJ)
   93 D=ZD*ZD+YD*YD+XD*XD
      D=SQRT(D)
      RAY=D*0.9999
      CALL NORML(SBX,SBY,SBZ,KB,D,COSB)
      THRO=FLOAT(MAN)*COSB
      IF (THRO)  700,700,600
  700 NBLOK=100
      RETURN
  600 IF (MBLOK)  620,620,610
  610 DO 100 KK=1,MBLOK
      NNN=IBLOK(KK)
      DO 100 K=1,NB
      IF (NNN-K)  100,810,100
  810 IF (NOVER)  820,800,820
  820 XCO=SX-AA(K,14)
      YCO=SY-AA(K,15)
      ZCO=SZ-AA(K,16)
      GO TO 830
  800 XCO=XS(II,JJ)-AA(K,14)
      YCO=YS(II,JJ)-AA(K,15)
      ZCO=ZS(II,JJ)-AA(K,16)
  830 A1=XCO*AA(K,1)+YCO*AA(K,2)+ZCO*AA(K,3)
      B1=XCO*AA(K,4)+YCO*AA(K,5)+ZCO*AA(K,6)
      C1=XCO*AA(K,7)+YCO*AA(K,8)+ZCO*AA(K,9)
      A2=(W(K,1)-A1)/D
      B2=(W(K,2)-B1)/D
      C2=(W(K,3)-C1)/D
      NN=NTYPE(K)
      GO TO (10,20,30,40,50,60) ,NN
   10 A=A2*A2+B2*B2+C2*C2
      B=2.*(A1*A2+B1*B2+C1*C2)
      C=A1*A1+B1*B1+C1*C1-AA(K,10)*AA(K,10)
      CALL QUART(A,B,C,ROOT,MISS)
      IF (MISS)  100,19,100
   19 DO 112 LOPE=1,2
      TT=ROOT(LOPE)
      PARA=ABS(TT)
```

```
      X=A1+A2*TT
      Y=B1+B2*TT
      Z=C1+C2*TT
      IF (PARA-RAY)  12,12,112
   12 THETA=ATAN(SQRT(X*X+Y*Y)/Z)
      IF (Z) 14,14,15
   14 THETA=PI+THETA
   15 IF (THETA-AA(K,11)) 112,16,16
   16 IF (THETA-AA(K,12)) 17,17,112
   17 PHI=ASTAN(X,Y)
      IF (PHI-AA(K,17)) 112,18,18
   18 IF (PHI-AA(K,18))  11,11,112
  112 CONTINUE
      GO TO 100
   11 NBLOK=K
      RETURN
   20 AM=AA(K,10)/AA(K,12)
      AM=AM*AM
  201 A=A2*A2+B2*B2-AM*C2*C2
      B=2.*(A1*A2+B1*B2-AM*C1*C2)
      C=A1*A1+B1*B1-AM*C1*C1
      CALL QUART(A,B,C,ROOT,MISS)
      IF (MISS)  100,29,100
   29 DO 212 LOPE=1,2
      TT=ROOT(LOPE)
      PARA=ABS(TT)
      X=A1+A2*TT
      Y=B1+B2*TT
      Z=C1+C2*TT
      IF (PARA-RAY)  22,22,212
   22 ZMIN=AA(K,12)
      ZMAX=AA(K,13)
      IF (Z-ZMIN)  212,26,26
   26 IF (Z-ZMAX)  27,27,212
   27 PHI=ASTAN(X,Y)
      IF (PHI-AA(K,17)) 212,28,28
   28 IF (PHI-AA(K,18))  21,21,212
  212 CONTINUE
      GO TO 100
   21 NBLOK=K
      RETURN
   30 A=A2*A2+B2*B2
      B=2.*(A1*A2+B1*B2)
      C=A1*A1+B1*B1-AA(K,10)*AA(K,10)
      CALL QUART(A,B,C,ROOT,MISS)
      IF (MISS)  100,39,100
   39 DO 312 LOPE=1,2
      TT=ROOT(LOPE)
      X=A1+A2*TT
      Y=B1+B2*TT
      Z=C1+C2*TT
      PARA=ABS(TT)
      IF (PARA-RAY)  32,32,312
   32 ZMIN=0.
      ZMAX=AA(K,11)
      IF (Z-ZMIN)  312,36,36
   36 IF(Z-ZMAX)  37,37,312
   37 PHI=ASTAN(X,Y)
      IF (PHI-AA(K,17))  312,38,38
   38 IF (PHI-AA(K,18))  31,31,312
```

```
312 CONTINUE
    GO TO 100
 31 NBLOK=K
    RETURN
 40 TT=-C1/C2
    X=A1+A2*TT
    Y=B1+B2*TT
    Z=0.
    XMIN=0.
    YMIN=0.
    YMAX=AA(K,10)
    XMAX=AA(K,9)
    IF (X-XMIN)  100,46,46
 46 IF (X-XMAX)   47,47,100
 47 IF (Y-YMIN)  100,48,48
 48 IF (Y-YMAX)  49,49,100
 49 PARA=ABS(TT)
    IF(PARA-RAY)  41,41,100
 41 NBLOK=K
    RETURN
 50 TT=-C1/C2
    PARA=ABS(TT)
    IF (PARA-RAY)  51,51,100
 51 X=A1+A2*TT
    Y=B1+B2*TT
    Z=0.
    R=SQRT(X*X+Y*Y)
    PHI=ASTAN(X,Y)
    IF (R-AA(K,10)) 100,56,56
 56 IF (R-AA(K,11)) 57,57,100
 57 IF (PHI-AA(K,17))  100,58,58
 58 IF (PHI-AA(K,18))  59,59,100
 59 NBLOK=K
    RETURN
 60 TT=-C1/C2
    PARA=ABS(TT)
    IF (PARA-RAY)  61,61,60
 61 X=A1+A2*TT
    Y=B1+B2*TT
    Z=0.
    XMAX=AA(K,11)
    XMIN=AA(K,10)
    THMAX=AA(K,13)/AA(K,11)
    THMIN=AA(K,12)/AA(K,11)
    TH=Y/X
    IF (X-XMIN) 100,66,66
 66 IF (X-XMAX) 67,67,100
 67 IF (TH-THMIN) 100,68,68
 68 IF (TH-THMAX) 69,69,100
 69 NBLOK=K
    RETURN
100 CONTINUE
620 NBLOK=0
    IF (NOVER)  710,720,710
710 S(1)=SX
    S(2)=SY
    S(3)=SZ
    GO TO 730
720 S(1)=XS(II,JJ)
```

```
      S(2)=YS(II,JJ)
      S(3)=ZS(II,JJ)
  730 A=(CC(1)-S(1))/D
      B=(CC(2)-S(2))/D
      C=(CC(3)-S(3))/D
      COSA=S(1)*A+S(2)*B+S(3)*C
      COSA=ABS(COSA)/RSR
      FACT=1./PI
C     FACT=INTENSITY FUNCTION, N/PI FOR DIFFUSIVE RADIATION
      COSB=ABS(COSB)
      AREA=SAREA*ELEM*FACT*COSA*COSB/D/D
      BETA=ATAN(SQRT(1.-COSB*COSB)/COSB)
      RETURN
      END
```

```
      SUBROUTINE QUART(A,B,C,T,MISS)
      DIMENSION T(2)
      DELTA=B*B-4.*A*C
      IF (DELTA) 11,12,12
   11 MISS=1
      RETURN
   12 MISS=0
      DEL=SQRT(DELTA)
      T(1)=(-B+DEL)/(2.*A)
      T(2)=(-B-DEL)/(2.*A)
      RETURN
      END
```

```
      FUNCTION ASTAN(X,Y)
      PI=3.1415926
      IF (Y)  34,12,12
   12 IF(X)   23,1,1
   34 IF (X)    23,23,4
    1 ASTAN=ATAN(Y/X)
      RETURN
   23 ASTAN=PI+ATAN(Y/X)
      RETURN
    4 ASTAN=2.*PI+ATAN(Y/X)
      RETURN
      END
```

```
      SUBROUTINE  CAPT(K,Y,N1,N2,DEL1,DEL2,ELEM)
      DIMENSION X(11),Y(11)
      COMMON NREAD,NWRIT,PI,NB,NANGL,NTOTL,N1S,N2S,RSR,
     1 SAREA,MBLOK,NTYPE(200),AA(200,18),GAMMA(18),
     2 FLUX(100,10),W(200,3),XSB(40,40),YSB(40,40),
     3 ZSB(40,40),XS(40,40),YS(40,40),ZS(40,40),
     4 IBLOK(200),LIM1,LIM2,MAN
      AA(K,17)=AA(K,17)*180./PI
      AA(K,18)=AA(K,18)*180./PI
      WRITE(NWRIT,130) K,N1,N2
  130 FORMAT(1H1//5X7HSURFACE,I5,5X17HNO. OF PARTITIONS,2I5)
      IF (NB-MBLOK)  778,777,778
  777 WRITE(NWRIT,877)
  877 FORMAT(/41H  ALL SURFACES ARE CONSIDERED AS POSSIBLE,
     1 9H BLOCKAGE)
      GO TO 779
  778 IF (MBLOK) 775,776,775
  776 WRITE(NWRIT,876)
  876 FORMAT(/34H NO BLOCKING SURFACE IS CONSIDERED)
      GO TO 779
  775 WRITE(NWRIT,875)
  875 FORMAT(/18H BLOCKING SURFACES)
      WRITE(NWRIT,874) (IBLOK(I),I=1,MBLOK)
  874 FORMAT(5X,10I5)
  779 CONTINUE
      NN=NTYPE(K)
      GO TO (10,20,30,40,50,60),NN
   10 PQ=1.
      DEL=DEL2*180./PI
      WRITE(NWRIT,616) ELEM
  616 FORMAT(/5X,36HDIFFERENTIAL AREA OF OBJECT SURFACE,E15.5)
      WRITE(NWRIT,11) (AA(K,I),I=14,16),AA(K,10)
   11 FORMAT(////,7H SPHERE,/4H XC=,E12.5,4H IN.,5X,
     1 3HYC=,E12.5,4H IN.,5X,3HZC=,E12.5,4H IN.,5X,
     2 7HRADIUS=,E12.5,4H IN.)
      AA(K,11)=AA(K,11)*180./PI
      AA(K,12)=AA(K,12)*180./PI
      WRITE(NWRIT,111) AA(K,11),AA(K,12),AA(K,17),AA(K,18)
  111 FORMAT (7X,11HMIN. THETA=,E15.5,5X,11HMAX. THETA=,
     1 E15.5,/7X,9HMIN. PHI=,E15.5,7X9HMAX. PHI=,E15.5)
      X(1)=AA(K,11)
      DO 13 I=1,N1
   13 X(I+1)=X(I)+DEL1*180./PI
      I1=N1+1
      DO 14 I=1,I1
      A=X(I)
      A=SQRT(1.-A*A)/A
      THETA=ATAN(A)
      IF (A) 15,15,16
```

```
   15 THETA=THETA+PI
   16 X(I)=THETA*180./PI
   14 CONTINUE
      NO=0
      NF=0
 1003 ND=N1-NF
      IF(ND) 1004,1004,1005
 1005 IS=NF+1
      IF (ND-5)  1001,1002,1002
 1001 NF=ND+IS-1
      GO TO 1111
 1002 NF=IS+4
 1111 IS1=IS+1
      NF1=NF+1
      IF (NO)   1006,1007,1006
 1007 WRITE(NWRIT,17) (X(I),I=IS,NF)
      WRITE(NWRIT,18) (X(I),I=IS1,NF1)
      GO TO 1100
 1006 WRITE(NWRIT,1008) (X(I),I=IS,NF)
      WRITE(NWRIT,1009) (X(I),I=IS1,NF1)
   17 FORMAT(///40X,10HTHETA FROM,5E12.5)
   18 FORMAT(48X,2HTO,5E12.5)
 1008 FORMAT(/50X,5E12.5)
 1009 FORMAT(50X,5E12.5)
 1100 NO=1
      GO TO 1003
 1004 Y(1)=AA(K,17)
      DO 19 I=1,N2
   19 Y(I+1)=Y(I)+DEL
      WRITE(NWRIT,12)
   12 FORMAT(5X,12HPHI(DEGREES),6X,14HGAMMA(DEGREES))
      RETURN
   20 R2=AA(K,11)
      D=AA(K,13)-AA(K,12)
      DEL=DEL2*180./PI
      R1=AA(K,10)
      WRITE(NWRIT,616) ELEM
      WRITE(NWRIT,21) R1,R2,D
   21 FORMAT(////5H CONE/13H MIN. RADIUS=,E12.5,4H IN.,
     1 5X,12HMAX. RADIUS=,E12.5,4H IN.,5X,
     2 18HLENGTH OF THE CONE,E12.5,4H IN.)
      WRITE(NWRIT,222) AA(K,17),AA(K,18)
  222 FORMAT(10H MIN. PHI=,E15.5,5X,9HMAX. PHI=,E15.5)
      X(1)=AA(K,12)*AA(K,12)
      DO 23 I=1,N1
   23 X(I+1)=X(I)+DEL1
      I1=N1+1
      DO 24 I=1,I1
   24 X(I)=SQRT(X(I)-AA(K,12))
      NO=0
      NF=0
 2003 ND=N1-NF
      IF(ND) 2004,2004,2005
 2005 IS=NF+1
      IF (ND-5)  2001,2002,2002
 2001 NF=ND+IS-1
      GO TO 2222
 2002 NF=IS+4
 2222 IS1=IS+1
```

```
      NF1=NF+1
      IF (NO)   2006,2007,2006
 2007 WRITE(NWRIT,27) (X(I),I=IS,NF)
      WRITE(NWRIT,28) (X(I),I=IS1,NF1)
      GO TO 2100
 2006 WRITE(NWRIT,1008) (X(I),I=IS,NF)
      WRITE(NWRIT,1009) (X(I),I=IS1,NF1)
 2100 NO=1
   27 FORMAT(///40X,10HZ(IN) FROM,5E12.5)
   28 FORMAT(48X,2HTO,5E12.5)
      GO TO 2003
 2004 Y(1)=AA(K,17)
      DO 29 I=1,N2
   29 Y(I+1)=Y(I)+DEL
      WRITE(NWRIT,12)
      RETURN
   30 DEL=DEL2*180./PI
      D=AA(K,11)
      WRITE(NWRIT,616) ELEM
      WRITE(NWRIT,32) (AA(K,I),I=14,16),D,AA(K,10)
   32 FORMAT(////9H CYLINDER,/25H BASE CENTER COORDINATES,,
     1 5X,2HX=,E12.5,4H IN.,5X,2HY=,E12.5,4H IN.,5X,2HZ=,
     2 E12.5,4H IN.,/8H LENGTH=,E12.5,4H IN.,
     3 5X,7HRADIUS=,E12.5,4H IN.)
      WRITE(NWRIT,222) AA(K,17),AA(K,18)
      X(1)=0.
      DO 33 I=1,N1
   33 X(I+1)=X(I)+DEL1
      I1=N1+1
      NO=0
      NF=0
 3003 ND=N1-NF
      IF(ND) 3004,3004,3005
 3005 IS=NF+1
      IF (ND-5)  3001,3002,3002
 3001 NF=ND+IS-1
      GO TO 3333
 3002 NF=IS+4
 3333 IS1=IS+1
      NF1=NF+1
      IF (NO)   3006,3007,3006
 3007 WRITE(NWRIT,27) (X(I),I=IS,NF)
      WRITE(NWRIT,28) (X(I),I=IS1,NF1)
      GO TO 3100
 3006 WRITE(NWRIT,1008) (X(I),I=IS,NF)
      WRITE(NWRIT,1009) (X(I),I=IS1,NF1)
 3100 NO=1
      GO TO 3003
 3004 Y(1)=AA(K,17)
      DO 39 I=1,N2
   39 Y(I+1)=Y(I)+DEL
      WRITE(NWRIT,12)
      RETURN
   40 WRITE(NWRIT,616) ELEM
      WRITE(NWRIT,41) (AA(K,I),I=14,16),AA(K,9),AA(K,10)
   41 FORMAT(////11H FLAT PLATE,/24H ONE CORNER OF THE PLATE,
     1 5X,2HX=,E12.5,4H IN.,5X,3H Y=,E12.5,4H IN.,5X,3H Z=,
     2 E12.5,4H IN.,/17H SIDE LENGTHS L1=, E12.5,4H IN.,
     3 5X,3HL2=,E12.5,4H IN.)
```

```
      X(1)=0.
      Y(1)=0.
      DO 43 I=1,N1
   43 X(I+1)=X(I)+DEL1
      I1=N1+1
      NO=0
      NF=0
 4003 ND=N1-NF
      IF(ND) 4004,4004,4005
 4005 IS=NF+1
      IF (ND-5)  4001,4002,4002
 4001 NF=ND+IS-1
      GO TO 4444
 4002 NF=IS+4
 4444 IS1=IS+1
      NF1=NF+1
      IF (NO)   4006,4007,4006
 4007 WRITE(NWRIT,47) (X(I),I=IS,NF)
      WRITE(NWRIT,48) (X(I),I=IS1,NF1)
      GO TO 4100
 4006 WRITE(NWRIT,1008) (X(I),I=IS,NF)
      WRITE(NWRIT,1009) (X(I),I=IS1,NF1)
 4100 NO=1
   47 FORMAT(40X,10HX(IN) FROM,5E12.5)
   48 FORMAT(48X,2HTO,5E12.5)
      GO TO 4003
 4004 DO 49 I=1,N2
   49 Y(I+1)=Y(I)+DEL2
      WRITE(NWRIT,44)
   44 FORMAT(5X,5HY(IN),11X,14HGAMMA(DEGREES))
      RETURN
   50 DEL=DEL2*180./PI
      WRITE(NWRIT,616) ELEM
      WRITE(NWRIT,52) (AA(K,I),I=14,16),(AA(K,I),I=10,11)
   52 FORMAT(////14H CIRCULAR DISK/20H CENTER OF THE DISK,
     1 5X,2HX=,E12.5,4H IN.,5X,3H Y=,E12.5,4H IN.,
     2 5X,3H Z=,E12.5,4H IN./6H RMIN=,E12.5
     3,4H IN.,5X,5HRMAX=,E12.5,4H IN.)
      WRITE(NWRIT,222) AA(K,17),AA(K,18)
      X(1)=AA(K,10)*AA(K,10)
      Y(1)=AA(K,17)
      DO 53 I=1,N1
   53 X(I+1)=X(I)+DEL1
      I1=N1+1
      DO 54 I=1,I1
   54 X(I)=SQRT(X(I))
      NO=0
      NF=0
 5003 ND=N1-NF
      IF(ND) 5004,5004,5005
 5005 IS=NF+1
      IF (ND-5)  5001,5002,5002
 5001 NF=ND+IS-1
      GO TO 5555
 5002 NF=IS+4
 5555 IS1=IS+1
      NF1=NF+1
      IF (NO)   5006,5007,5006
 5007 WRITE(NWRIT,57) (X(I),I=IS,NF)
```

```
      WRITE(NWRIT,58) (X(I),I=IS1,NF1)
   57 FORMAT(///40X10HR(IN) FROM,5E12.5)
   58 FORMAT(48X,2HTO,5E12.5)
      GO TO 5100
 5006 WRITE(NWRIT,1008) (X(I),I=IS,NF)
      WRITE(NWRIT,1009) (X(I),I=IS1,NF1)
 5100 NO=1
      GO TO 5003
 5004 DO 59 I=1,N2
   59 Y(I+1)=Y(I)+DEL
      WRITE(NWRIT,12)
      RETURN
   60 XMAX=AA(K,11)
      XMIN=AA(K,10)
      YMIN=AA(K,12)
      THMIN=ATAN(AA(K,12)/AA(K,10))*180./PI
      THMAX=ATAN(AA(K,13)/AA(K,10))*180./PI
      WRITE(NWRIT,616) ELEM
      WRITE(NWRIT,62) (AA(K,I),I=3,12),XMIN,XMAX,THMIN,THMAX
   62 FORMAT(////22H TRIANGLE OR TRAPAZOID,/
     1 28H FOUR CORNERS OF THE SURFACE/18X,5HX(IN),15X,
     2 5HY(IN),15X,5HZ(IN)/5X,3E20.5,/5X,1HB,3E20.5,/5X,
     3 1HC,3E20.5,/6H XMIN=,E12.5,4HIN.,5X,5HRMAX=,E12.5,
     44H IN.,/12H MIN. THETA=,E12.5,8H DEGREES,5X,
     5 11HMAX. THETA=,E12.5,8H DEGREES)
      DO 63 I=1,N1
   63 X(I+1)=X(I)+DEL1
      I1=N1+1
      DO 64 I=1,I1
   64 X(I)=SQRT(X(I))
      NO=0
      NF=0
 6003 ND=N1-NF
      IF (ND) 6004,6004,6005
 6005 IS=NF+1
      IF (ND-5) 6001,6002,6002
 6001 NF=ND+IS-1
      GO TO 6666
 6002 NF=IS+4
 6666 IS1=IS+1
      NF1=NF+1
      IF (NO) 6006,6007,6006
 6007 WRITE(NWRIT,67) (X(I),I=IS,NF)
      WRITE(NWRIT,68) (X(I),I=IS1,NF1)
   67 FORMAT(///40X10HX(IN) FROM,5E12.5)
   68 FORMAT(48X,2HTO,5E12.5)
      GO TO 6100
 6006 WRITE(NWRIT,1008) (X(I),I=IS,NF)
      WRITE(NWRIT,1009) (X(I),I=IS1,NF1)
 6100 NO=1
      GO TO 6003
 6004 DO 69 I=1,2
      AI=I
      Z=YMIN+AI*DEL2
   69 Y(I+1)=ATAN(Z/XMAX)*108./PI
      WRITE(NWRIT,65)
   65 FORMAT(4X,14HTHETA(DEGREES),5X,14HGAMMA(DEGREES))
      RETURN
      END
```

```
      SUBROUTINE TYPE(KOBJ,YY,N1,N2)
      DIMENSION YY(11),ATOT(100)
      COMMON NREAD,NWRIT,PI,NB,NANGL,NTOTL,N1S,N2S,RSR,
     1 SAREA,MBLOK,NTYPE(200),AA(200,18),GAMMA(18),
     2   AN(100,10),W(200,3),XSB(40,40),YSB(40,40),
     3 ZSB(40,40),XS(40,40),YS(40,40),ZS(40,40),
     4 IBLOK(200),LIM1,LIM2,MAN
      N=N1*N2
      MID=NANGL/2
      DELTA=90./FLOAT(NANGL)
      DO 420 I=1,N
      ATOT(I)=0.
      DO 420 J=1,NANGL
  420 ATOT(I)=ATOT(I)+AN(I,J)
      DO 230 I=1,N2
      WRITE(NWRIT,370)
  370 FORMAT(///)
      A2=0.
      L1=(I-1)*N1+1
      L2=L1+N1-1
      DO 220 MN=1,NANGL
      A1=A2
      A2=A1+DELTA
      NO=0
      NF=L1-1
 1003 ND=L2-NF
      IF(ND) 220,220,1004
 1004 IS=NF+1
      IF (ND-5)  1001,1002,1002
 1001 NF=ND+IS-1
      GO TO 1111
 1002 NF=IS+4
 1111 IF (MN-MID) 310,320,330
  330 IF(MN-MID-1) 310,340,310
  310 IF (NO) 1006,1005,1006
 1005 WRITE(NWRIT,300) A1,A2,(AN(J,MN),J=IS,NF)
      GO TO 1007
 1006 WRITE(NWRIT,450)(AN(J,MN),J=IS,NF)
  450 FORMAT(50X,5E12.5)
  300 FORMAT(/20X,4HFROM,F6.2,3H TO,F6.2,11X,5E12.5)
 1007 NO=1
      GO TO 1003
  320 IF (NO)  3006,3005,3006
 3005 WRITE(NWRIT,360) YY(I),A1,A2,(AN(J,MN),J=IS,NF)
      GO TO 3007
 3006 WRITE(NWRIT,450) (AN(J,MN),J=IS,NF)
 3007 NO=1
      GO TO 1003
  360 FORMAT(/5H FROM,F7.2,8X,4HFROM,F6.2,3H TO,F6.2,11X,5E12.5)
```

```
 340 IF (NO) 4006,4005,4006
4005 WRITE(NWRIT,350) YY(I+1),A1,A2,(AN(J,MN),J=IS,NF)
 350 FORMAT(/5H   TO,F7.2,8X,4HFROM,F6.2,3H TO,F6.2,11X,5E12.5)
     GO TO 4007
4006 WRITE(NWRIT,450) (AN(J,MN),J=IS,NF)
4007 NO=1
     GO TO 1003
 220 CONTINUE
     NO=0
     NF=L1-1
2003 ND=L2-NF
     IF (ND) 230,230,2004
2004 IS=NF+1
     IF (ND-5) 2001,2002,2002
2001 NF=ND+IS-1
     GO TO 2222
2002 NF=IS+4
2222 IF (NO) 5006,5005,5006
5005 WRITE(NWRIT,440) (ATOT(J),J=IS,NF)
 440 FORMAT(/14X25HTOTAL NUMBER OF PARTICLES,11X,5E12.5)
     GO TO 5007
5006 WRITE(NWRIT,450) (ATOT(J),J=IS,NF)
5007 NO=1
     GO TO 2003
 230 CONTINUE
     RETURN
     END
```

```
      SUBROUTINE SST(SX,SY,SZ,SBX,SBY,SBZ,I,J,DEL1,DEL2,K)
      COMMON NREAD,NWRIT,PI,NB,NANCL,NTOTL,N1S,N2S,RSR,
     1 SAREA,MBLOK,NTYPE(200),AA(200,18),GAMMA(18),
     2 FLUX(100,10),W(200,3),XSB(40,40),YSB(40,40),
     3 ZSB(40,40),XS(40,40),YS(40,40),ZS(40,40),
     4 IBLOK(200),LIM1,LIM2,MAN
      AI=I
      AJ=J
      COSTH=1.+(AI-0.5)*DEL1
      SINTH=SQRT(1.-COSTH*COSTH)
      RS=RSR*SINTH
      PHI=(AJ-0.5)*DEL2
      SINPH=SIN(PHI)
      COSPH=COS(PHI)
      SX=RS*COSPH
      SY=RS*SINPH
      SZ=RSR*COSTH
      XCO=SX-AA(K,14)
      YCO=SY-AA(K,15)
      ZCO=SZ-AA(K,16)
      SBX=XCO*AA(K,1)+YCO*AA(K,2)+ZCO*AA(K,3)
      SBY=XCO*AA(K,4)+YCO*AA(K,5)+ZCO*AA(K,6)
      SBZ=XCO*AA(K,7)+YCO*AA(K,8)+ZCO*AA(K,9)
      RETURN
      END
```

APPENDIX. CARTESIAN COORDINATE TRANSFORMATIONS

Let P be a point whose coordinates are x_c, y_c, z_c with respect to a source coordinate system, and x_b, y_b, z_b are the coordinates of P with respect to the surface coordinate system (see Figure A-1). The origin of the surface coordinate system are x_0, y_θ, z_0, with respect to the source coordinate system; $(\hat{i}_c, \hat{j}_c, \hat{k}_c)$ and $(\hat{i}_b, \hat{j}_b, \hat{k}_b)$ are sets of unit vectors for source and surface coordinate systems, respectively (as shown in Figure A-1).

The relationship between the base unit vectors is assumed in the form

$$
\begin{aligned}
\hat{i}_b &= a_1 \hat{i}_c + a_2 \hat{j}_c + a_3 \hat{k}_c \\
\hat{j}_b &= b_1 \hat{i}_c + b_2 \hat{j}_c + b_3 \hat{k}_c \qquad\qquad (A\text{-}1) \\
\hat{k}_b &= c_1 \hat{i}_c + c_2 \hat{j}_c + c_3 \hat{k}_c \,.
\end{aligned}
$$

The directional cosines e_{ij} are thus defined as follows:

$$
\begin{aligned}
&e_{11} = \hat{i}_c \cdot \hat{i}_b, \quad e_{12} = \hat{i}_c \cdot \hat{j}_b, \quad e_{13} = \hat{i}_c \cdot \hat{k}_b, \\
&e_{21} = \hat{j}_c \cdot \hat{i}_b, \quad e_{22} = \hat{j}_c \cdot \hat{j}_b, \quad e_{22} = \hat{j}_c \cdot \hat{k}_b, \qquad (A\text{-}2) \\
&e_{31} = \hat{k}_c \cdot \hat{i}_b, \quad e_{32} = \hat{k}_c \cdot \hat{j}_b, \quad e_{33} = \hat{k}_c \cdot \hat{k}_b.
\end{aligned}
$$

From Equation A-1, e_{ij} are

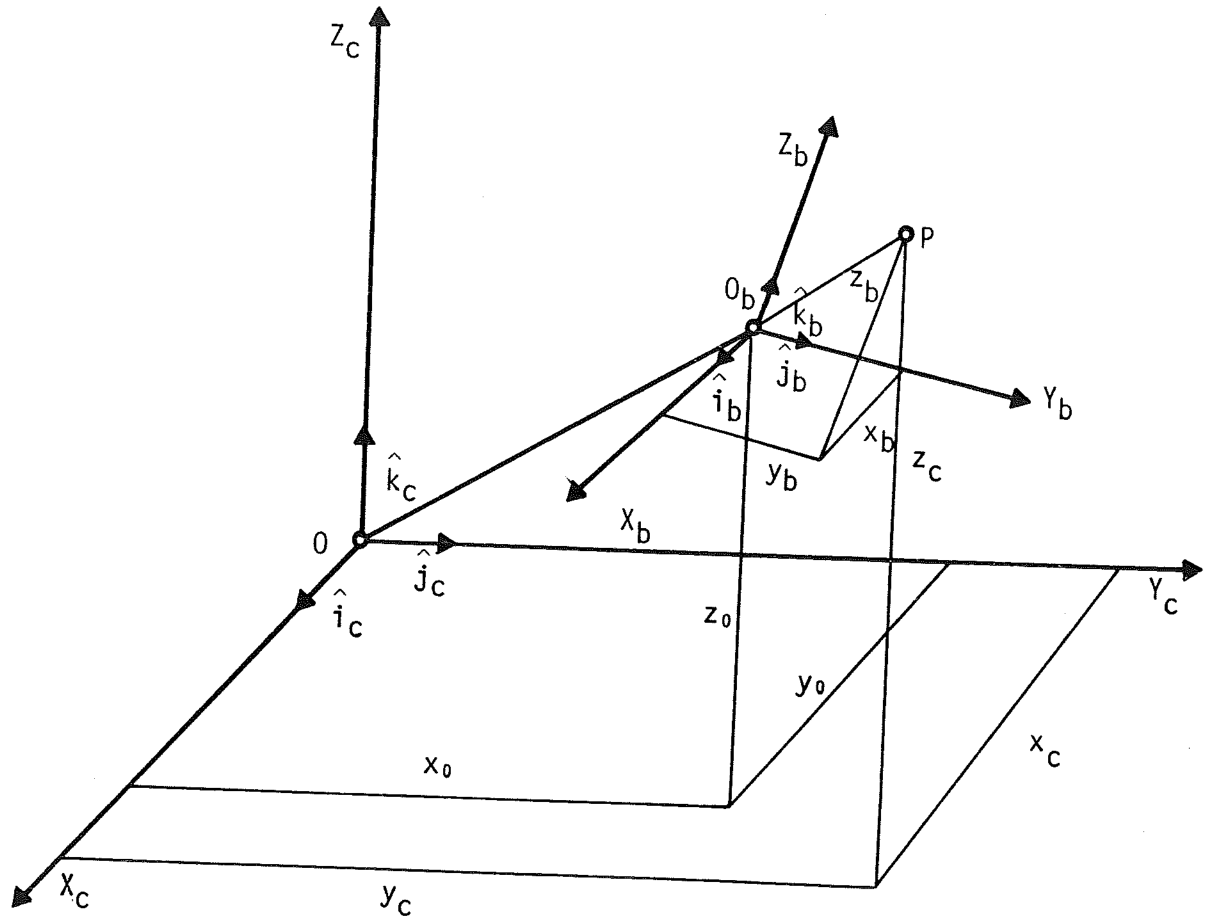


FIGURE A-1. CARTESIAN COORDINATE SYSTEMS

$$e_{11} = a_1, \quad e_{12} = b_1, \quad e_{13} = c_1$$

$$e_{21} = a_2, \quad e_{22} = b_2, \quad e_{23} = c_2 \tag{A-3}$$

$$e_{31} = a_3, \quad e_{32} = b_3, \quad e_{33} = c_3 \quad .$$

Now, Point P is written in vectoral forms

$$\vec{OP} = x_c \hat{i}_c + y_c \hat{j} + z_c \hat{k}_c \tag{A-4}$$

or

$$\vec{OP} = \vec{OO_b} + \vec{O_b P}$$

and

$$\vec{O_b P} = \vec{OP} - \vec{OO_b}$$

$$= (x_c - x_0)\hat{i}_c + (y_c - y_0)\hat{j}_c + (z_c - z_0)\hat{k}_c , \tag{A-5}$$

In the surface coordinate system, $\vec{O_b P}$ is

$$\vec{O_b P} = x_b \hat{i}_b + y_b \hat{j}_b + z_b \hat{k}_b . \tag{A-6}$$

Substituting Equation A-1 in Equation A-6 yields

$$\vec{O_b P} = (e_{11} \; x_b + e_{12} \; y_b + e_{13} \; z_b) \hat{i}_c$$

$$+ (e_{21} \; x_b + e_{22} \; y_b + e_{23} \; z_b) \hat{j}_c \tag{A-7}$$

$$+ (e_{31} \; x_b + e_{32} \; y_b + e_{33} \; z_b) \hat{k}_c \quad .$$

A comparison of Equation A-5 and Equation A-7 results in

$$x_c = e_{11}\ x_b + e_{12}\ y_b + e_{13}\ z_b + x_0$$

$$y_c = e_{21}\ x_b + e_{22}\ y_b + e_{23}\ z_b + y_0 \qquad \text{(A-8)}$$

$$z_c = e_{31}\ x_b + e_{32}\ y_b + e_{33}\ z_b + z_0 .$$

The reverse transformation of Equation A-8 may be written as

$$x_b = (x_c - x_0)\ e_{11} + (y_c - y_0)\ e_{21} + (z_c - z_0)\ e_{31}$$

$$y_c = (x_c - x_0)\ e_{12} + (y_c - y_0)\ e_{22} + (z_c - z_0)\ e_{32}$$

$$z_c = (x_c - x_0)\ e_{13} + (y_c - y_0)\ e_{23} + (z_c - z_0)\ e_{33} . \qquad \text{(A-9)}$$

Now, the transformation formulas between the source and surface coordinate systems are obtained. The matrix coefficients e_{ij} (in Equation A-1 and A-2) depend on the surface orientations and (x_0, y_0, z_0) represent the location of the surface with respect to the source coordinate system.

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