UCID- 17275

Lawrence Livermore Laboratory

USER'S MANUAL FOR CNVUFAC, THE GENERAL DYNAMICS HEAT-TRANSFER RADIATION VIEW FACTOR PROGRAM

Robert L. Wong

MASTER

June 25, 1976

This is an informal report intended primarily for internal or limited external distribution. The opinions and conclusions stated are those of the author and may or may not be those of the laboratory
Prepared for U. S. Department of Energy under contract No. W-7405-Eng-48.

DISCLAIMER

Available from : National Technical Information Service - U.S. Department of Commerce
5285 Port Royal Road - Springfield, VA 22161 - $7.00 per copy - (Microfiche $3.50)

PAGES ___i___ to ___ii___

WERE INTENTIONALLY

LEFT BLANK

CONTENTS

USER'S MANUAL FOR CNVUFAC, THE GENERAL DYNAMICS HEAT-TRANSFER RADIATION VIEW FACTOR PROGRAM

ABSTRACT

CNVUFAC, the General Dynamics heat-transfer radiation view factor program, has been adapted for use on the LLL CDC 7600 computer system. The input and output have been modified, and a node incrementing logic was included to make the code compatible with the TRUMP thermal analyzer and related codes.

The program performs the multiple integration necessary to evaluate the geometric black-body radiation node to node view factors. Card image output that contains node number and view factor information is generated for input into the related program GRAY. Program GRAY is then used to include the effects of gray-body emissivities and multiple reflections, generating the effective gray-body view factors usable in TRUMP.

CNVUFAC uses an elemental area summation scheme to evaluate the multiple integrals. The program permits shadowing and self-shadowing. The basic configuration shapes that can be considered are cylinders, cones, spheres, ellipsoids, flat plates, disks, toroids, and polynomials of revolution. Portions of these shapes can also be considered.

INTRODUCTION

LLL needed a general program to calculate heat-transfer radiation view factors and shape factors (also called configuration factors) for use in the TRUMP[1] thermal analyzer and with related codes.[*,2,3] The need was actually for two programs: One to generate the black-body configuration factors that involve the evaluation of the geometric multiple integrals[4,5] and a second to include the multiple-reflection gray-body effects.[3-5]

---

[*] A. E. Edwards has written a more limited radiation view factor code at LLL.

Several of the former type of programs were written by programmers in the aerospace industry. J. C. Oglebay, from NASA-Lewis,[6] recommended the program CNVUFAC, written by General Dynamics,[7] as being the simplest to use and adequate for most applications. A copy of the code was subsequently obtained from him.

Oglebay made several changes to the original code. The most important was to change from a formatted input to a name list input and to allow for a calculation simplification when symmetry permits. The latter change is useful in axisymmetric calculations and saves considerable computer time.

In adapting this code to LLL, it was decided to change back to the formatted input more commonly used here. To make the program more useful for calculating the node-to-node shape factors required by TRUMP, the logic for an automatic node incrementing option was also instituted.

Section 1 describes the use of the program. Section 2 contains sample problems. Because the original report[7] is out of print, the program description has been extracted and included in Appendix A. The list of program symbols has been extracted and updated, and it is included in Appendix B. Appendix C contains the program listing.

1. PROGRAM USE

1.1 OBTAINING THE PROGRAM

CNVUFAC is obtaining from the ELF system at LLL using the following directory:

.980012:OBJECT:CNVUFAC

If the Fortran version is desired, it is stored as

.980012:FORTRAN:FNVUFAC

1.2 PROGRAM EXECUTION

The program is executed from the teletype using one of the three options shown in Fig. 1. If the name of the input file is not included on the execute line, the program will request it. If no names is entered, the program will assume the input file is named VUFIN.

```
CNVUFAC / 1 1.1

TYPE INPUT FILE NAME.
FIRST 3 CHARACTERS ARE APPENDED TO OUTPUT FILE NAMES.
VUFIN

OUTPUT FILE NAMES ARE:
OUTPUT= VUFOUT
VIEW FACTOR CARDS= VUFCARD

 ALL DONE


CNVUFAC VUFIN / 1 1.1

OUTPUT FILE NAMES ARE:
OUTPUT= VUFOUT
VIEW FACTOR CARDS= VUFCARD

 ALL DONE


CNVUFAC / 1 1.1

TYPE INPUT FILE NAME.
FIRST 3 CHARACTERS ARE APPENDED TO OUTPUT FILE NAMES.


OUTPUT FILE NAMES ARE:
OUTPUT= VUFOUT
VIEW FACTOR CARDS= VUFCARD

 ALL DONE
```

FIG. 1. Teletype execution line options.

Two output files are generated. One contains the problem output and the other contains the card images with the node and view factor information for use in program GRAY for the gray body calculations. The card images are not automatically punched, and the file is only generated when the node incrementing option (described in Section 1.6) is used.

The output files are named by appending the first three letters of the input file name in front of OUT for the output file and in front of CARD for the card image file. Thus, if the input file VUFIN, the output file is named VUFOUT, and the card image file is named VUFCARD.

1.3 PROGRAM INPUT FORMAT

The input format is shown in Fig. 2. Card 1 is the title card, and Card 2 is the program control card. L is the number of sections, and Cards 3 through

Card no.	1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
1	TITLE CARD							
2	IFLAG L	NYSM NMI	NODE1 NODE2	IIRD(1) IICD(1)	IIRD(2) IICD(2)			
	Repeat cards 3 through 6 for each section, for L sections.							
3	ICD MA	IIRB IIRE	NA IICB	IICE KEM	KSH KRE			
	Either card 4a or 4b is used. Card 4a is used for all configurations other than the polynomial of revolution. Card 4b is used for the polynaomia of revolution ICD = 8.							
4a	R	SR	AL	SMOLLA	B	W		
4b	AL	AD	A1	A2	A3	A4	A5	
5	SWITCH	PIT	YAW	ROL	XO	YO	ZO	
	Card 6 is used only for matrix incrementing option, NMI70.							
6	DPI	DYA	DRL	DXO	DYO	DZO		

GPO 967–291 LL-3807 REV. 11/66

FIG. 2. CNVUFAC input format.

6 are repeated as a group for each of the L sections. Cards 3, 4a, and 4b contain the section geometric information. Card 4a is used if the section is not a polynomial of revolution (ICD = 8), and card 4b is used if it is. Card 5 contains information relating the orientation and the position of the section configuration coordinate system to the base coordinate system. Card 6 is used only if the matrix incrementing option is used.

The input variables are described as follows:

1. <u>Title Card, 8A10</u>

Problem name, cols. 1-80.

2. <u>Program Control Card, 10I5</u>

IFLAG	Problem control. IFLAG = 0 if this the last problem set, = 1 if another problem set follows.
L	The number of sections considered (maximum of 10).
NSYM	The number of symmetric view factors from one segment of the emitter to the entire receiver (where a segment may be one row or one column). (See Section 1.4 for a description of this option.) NSYM = 1 for no symmetry.
NMI	The number of matrix incrementations, i.e., the number of times the matrix incrementations listed in card 6 is to be made. (See Section 1.5 for a description of this option.) NMI = 0 for no matrix incrementing.
NODE1	The number of the first node in Section 1 in the node incrementing option. (See Section 1.6 for a description of this option.) NODE1 = 0 for no node incrementing. The following five parameters are used only with the node incrementing option.
NODE2	The number of the first node in Section 2.
IIRD(1)	The number of rows to be incremented in Section 1 from IIRB(1) to IIRE(1). The last increment is adjusted to agree with IIRE(1).
IICD(1)	The number of columns incremented in section 1 from IICB(1) to IICE(1). The last increment is adjusted to agree with IICE(1).
IIRD(2)	Similar to IIRD(1) applying to Section 2.
IICD(2)	Similar to IICD(1) applying to Section 2.

3. Section Identification Card, 10I5

ICD Configuration Indicator

1 - cylinder

2 - cone

3 - sphere

4 - ellipsoid

5 - flat plate

6 - disk

7 - toroid

8 - polynomial of revolution

MA(rows) The number of flat plate elements around a cylinder, cone, sphere, disk, or polynomial of revolution configuration. The number of divisions around the toroid configuration. The number of divisions lengthwise on the flat plate configuration, and the number of x-axis divisions along the ellipsoid configuration. (See Figs. A-3 through A-10.)

IIRB The number of the first row to be considered on each configuration.

IIRE The number of the last row to be considered on each configuration.

NA(Cols.) The number of divisions lengthwise on a cylinder, cone, or polynomial of a revolution configuration. The number of divisions widthwise on the flat plate configuration. The number of divisions radially on the disk configuration. The number of divisions down the sphere configuration, and the number of divisions around the ellipsoid or toroid configuration. (See Figs. A-3 through A-10.)

IICB The number of the first column to be considered on each configuration.

IICE The number of the last column to be considered on each configuration.

KEM Emitter indicator. KEM = 1 if the section is an emitter, = 0 if it is not.

KSH Shadower indicator. KSH = 1 if the section is a shadower, = 0 if it is not. Note that shadowing calculations require considerable computer time. Sometimes computer time can be saved by using view factor algebra[4,5] to evaluate shadowing effects. See Section 1.3 for an example.

KRE — Receiver indicator. KRE = 1 if the section is a receiver, = 0 if it is not.

4. Section Geometry Card, 7E10.3

The following section geometry parameters are shown in Figs. A-3 through A-10.

R — The radius of the cylinder, cone, sphere, and disk configurations. The major radius of the toroid (measured from the z-axis to the center of a cross section whose plane contains the z-axis).

SR — The minor radius of the toroid.

AL — The length along the configuration coordinate system x-axis of the cylinder, cone, flat plate, or polynomial of revolution configuration.

SMOLLA — The semi-axis of the ellipsoid configuration along the x-axis.

B — The semi-axis (radius) of the ellipsoid configuration perpendicular to the x-axis.

W — The width of the flat plate configuration along the y-axis.

A0, A1, A2, A3, A4, A5, — Constants used to describe the polynomial of revolution configuration.

5. Section Configuration Coordinate Orientation and Position Card, 7E10.3

SWITCH — An indicator telling which side of a configuration is being considered. The normal side (input 1.0) is the outside except in the case of the flat plate and disk configurations where the normal side is the side of the z-axis. Input -1.0 if the reverse side is being considered.

PIT — Pitch angle in degrees of a configuration x-axis in the base coordinate system. PIT is the angle between the configuration system x-axis and the x-y plane of the base coordinate system. ($-90^{\circ} \leq PIT \leq 90^{\circ}$)

YAW — Yaw angle in degrees of a configuration x-axis in the base coordinate system. YAW is the angle between the projection of the configuration coordinate system x-axis on the base coordinate x-y plane and the base coordinate system x-axis. Measuring from the base positive x-axis toward the negative y-axis. $(0^\circ \le YAW \le 360^\circ)$

ROL Roll angle in degrees measured in a plane normal to the configuration x-axis, from the base coordinate system x-y plane to the configuration coordinate system positive y-axis. ROL is measured positively around the configuration x-axis in a clockwise direction as viewed from the configuration coordinate system origin and looking toward the positive x configuration axis. $(0^\circ \le ROL \le 360^\circ)$

XO The x coordinate of a configuration coordinate system origin in the base coordinate system.

YO The y coordinate of a configuration coordinate system origin in the base coordinate system.

ZO The z coordinate of a configuration coordinate system origin in the base coordinate system.

6. Section Matrix Incrementation Card, 6E10.3

DPI The increment to pitch in degrees in the base coordinate system.

DYA The increment to yaw in degrees in the base coordinate system.

DRL The increment in roll in degrees in the base coordinate system.

DXO The increment to the base x coordinate.

DYO The increment to the base y coordinate.

DZO The increment to the base z coordinate.

1.4 SYMMETRIC VIEW FACTOR OPTION, NSYM

This option was added by Oglebay[6] and saves considerable computer time when symmetry allows it to be used. It is especially useful in axisymmetric problems, and permits the easy calculation of view factors for a section of itself.

The option can be used if, due to symmetry, the view factor is identical to any emitter segment (where a segment may be a row or a column) to the entire receiver. For this case, this emitter segment to receiver view factor is the same as that for the entire emitter to the entire receiver. Only this one emitter segment need be input.

Note that when using NSYM, the values output are for the entire emitter. The emitter segment area is multiplied by NSYM to obtain the total emitter area. The receiver to total emitter view factor is then determined by the reciprocity relationship[4,5]

$$A_1F_{1-2} = A_2F_{2-1}$$

(where A and F are, respectively, the area and view factor).

The cylinder example in Section 2.1 demonstrates the use of this option.

1.5 MATRIX INCREMENTING OPTION, NMI

In calculating view factors, the variable NMI can be very helpful. If the positions and/or orientations are not regularly spaced or if each case is uniquely different, NMI is set equal to zero and each case is calculated separately. However, if the positions and/or orientations are regularly spaced or oriented, NMI is greater than zero. The program will then increment the transformations regularly as directed by the transformation incrementation data. NMI times and print the configuration factor for each increment on card 6. After the last increment, all positions are reset to their original position before going to the next case. The opposed disk example in Section 2.2 illustrates the use of this option.

1.6 NODE INCREMENTING OPTION, NODE1.

This option was added to allow for the easy calculation of the node to node view factors required for use in the TRUMP[1] thermal analysis code. The option can only be used for radiation interchange between sections 1 and 2. Either one may be the emitter or the receiver. Additional sections may act as shadowers.

Sections 1 and 2 are divided into nodes, possibly in agreement with the surface node zoning made by the FED[2] program. Each node may contain several elemental integration areas. The logic allows automatic do-loop incrementing over the entire range of rows and columns in sections 1 and 2. The program treats each section 1 node to section 2 node interchange as a separate problem.

The number of rows in each node is input as IIRD(1) and IIRD(2) for sections 1 and 2, respectively. The incrementing is made from the beginning rows, IIRB(1) and IIRB(2), to the ending rows, IIRE(1) and IIRE(2). Likewise, the number of columns is input as IICD(1) and IICD(2), and incrementing is made from IICB(1) and IICB(2) to IICE(1) and IICE(2). If the number of rows or column specified in IIRD and IICD is not consistent with the ending row or column numbers, IIRE and IICE, the adjustments are made in the sizes of the last increments. See the cylinder example in Section 2.2 for an example of the use of this option.

The use of the node option automatically generates the card image file. This file contains the two node numbers and the radiative interchange area SS_{1-2} (the product of area and view factor, $SS_{1-2} = A_1F_{1-2} = A_2F_{2-1}$) for each node to node interchange calculated.[5] The format is suitable for input into program GRAY.[3]

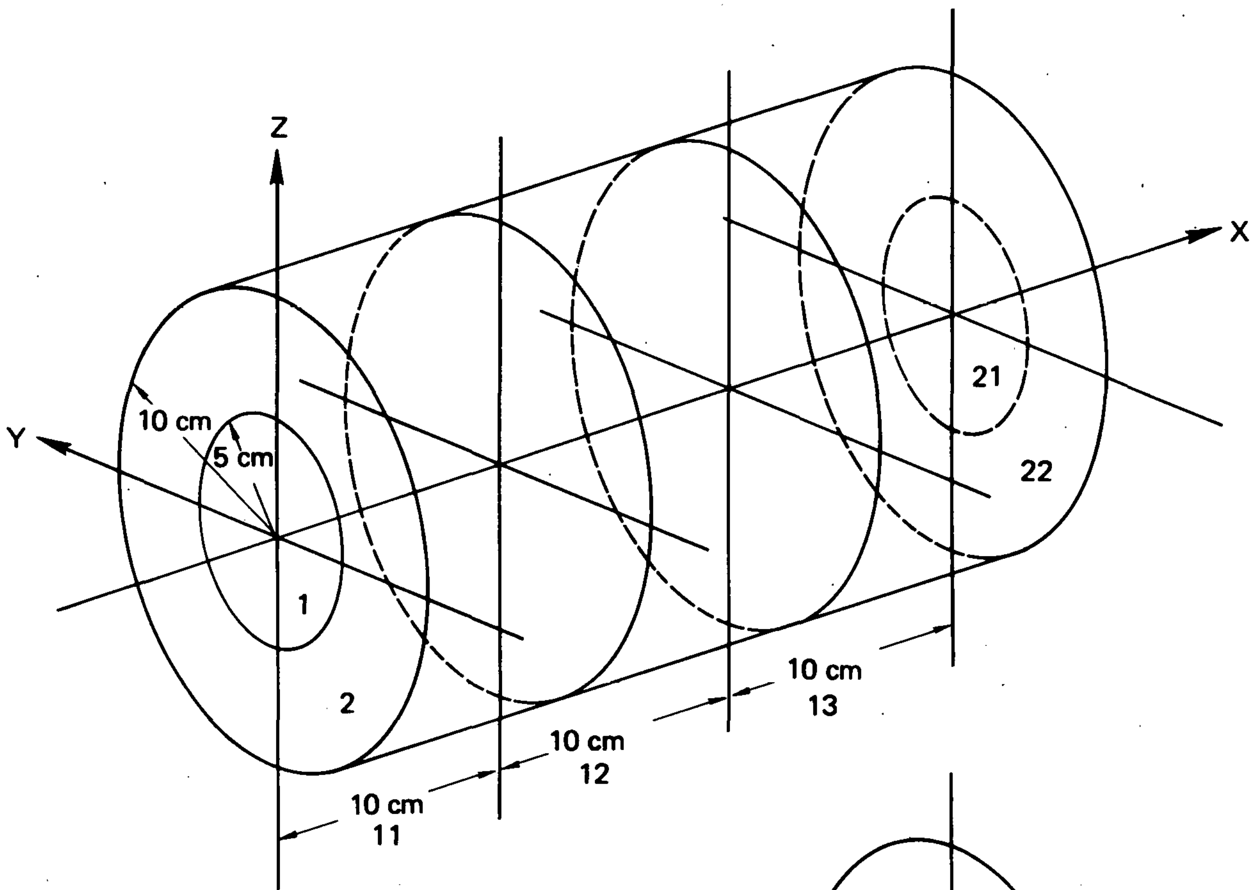
2. EXAMPLES

2.1 VIEW FACTORS WITHIN A CYLINDER

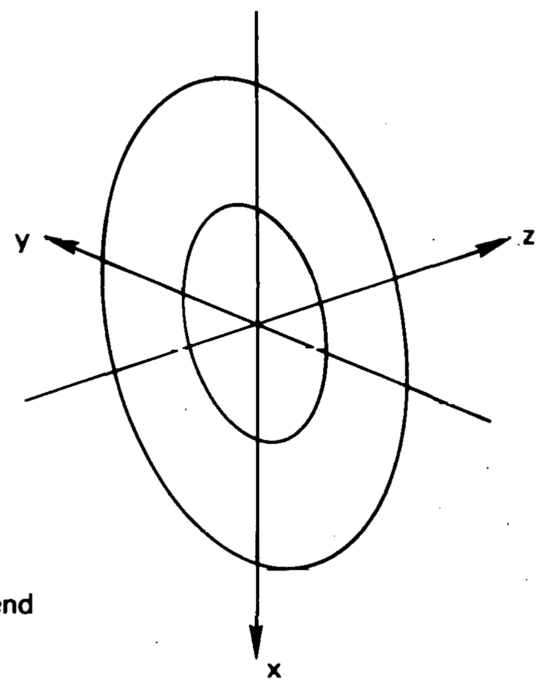
In this axisymmetric problem, it is desired to evaluate the geometric configuration factors inside of the finite cylinder 30-cm-high by 10-cm-radius cylinder shown in Fig. 3. The cylindrical surface is divided into three equal 10-cm-long nodes. The two ends are each divided into a 5-cm-radius node and a 5-cm by 10-cm-radius annular node. The node numbering is indicated by the circled values in Fig. 3(a).

Figure 3(a) shows the base coordinates, X, Y, Z. The coordinates for the cylinderical surface (refer to Fig. A-3) are chosen to correspond with those of the base system. The coordinates for each of the two disk ends (Fig. A 8) are shown in Fig. 3(b). One end is positioned (0,0,0) and the other is at (30,0,0). The pitch, yaw, and roll angles for the disk ends are, respectively, -90°, 0,0.

The input, output, and card image file are shown, respectively, in Figs. 4, 5, and 6. There are four problems. The first one evaluates the disk-to-cylinder view factors. The second and third problems evaluate the



(a) Finite cylinder



(b) Disk end

FIG. 3. Cylinder example.

```
CNVUFAC CYLINDER EXAMPLE: DISK TO CYLINDER
    1    2   50    0    1   11    1    4   50   50
    6   50    1    1    8    1    8    1    0    0
 10.0
 1.0       -90.0       0.0         0.0         0.0         0.0         0.0
    1   50    1   50  150    1  150    0    0    1
 10.0                 30.0
-1.0        0.0        0.0         0.0         0.0         0.0         0.0
CNVUFAC CYLINDER EXAMPLE: CYLINDER TO CYLINDER
    1    2   50    0   11   11    1   50   50   50
    1   50    1    1  150    1  150    1    0    0
 10.0                 30.0
-1.0        0.0        0.0         0.0         0.0         0.0         0.0
    1   50    1   50  150    1  150    0    0    1
 10.0                 30.0
-1.0        0.0        0.0         0.0         0.0         0.0         0.0
CNVUFAC CYLINDER EXAMPLE: CYLINDER TO CYLINDER SEEING ITSELF
    1    2   50    0   11   11    1   50   49   50
    1   50    1    1  150    1  150    1    0    0
 10.0                 30.0
-1.0        0.0        0.0         0.0         0.0         0.0         0.0
    1   50    2   50  150    1  150    0    0    1
 10.0                 30.0
-1.0        0.0        0.0         0.0         0.0         0.0         0.0
CNVUFAC CYLINDER EXAMPLE: DISK TO DISK
    0    2   50    0    1   21    1    4   50    4
    6   50    1    1    8    1    8    1    0    0
 10.0
 1.0       -90.0       0.0         0.0         0.0         0.0         0.0
    6   50    1   50    8    1    8    0    0    1
 10.0
-1.0       -90.0       0.0         0.0        30.0         0.0         0.0    0
```

FIG. 4. Cylinder example: input.

cylinder-to-cylinder view factors. (It is shown below that only the third one is needed.) The fourth problem evaluates the view factors between the two disk ends.

The disk ends are divided into 50 rows and 8 columns (Fig. A-3) so that each node has 25 rows and 8 columns. The cylindrical ends are divided into 50 rows and 150 columns (Fig. A-8) so that each node has 50 rows and 50 columns.

Since the problem is axisymmetric, the symmetric option is used. In all four problems, symmetry with respect to one of the 50 emitter rows is used so that NSYM = 50, and only one row is input. Since section 1 is always chosen as the emitter, IIRB(1) = IIRE(1) = IIRD(1) = 1.

Even though there are two ends, only one end-to-cylinder set of view factors must be evaluated since those from the other end to the cylinder are the same. For input into GRAY, the cards can be duplicated and the node numbers changed.

In the second problem, cylinder-to-cylinder view factors are evaluated by inputting two identical cylinders. However, CNVUFAC will not calculate the view factors of elements of themselves. The program will therefore skip over the calculation for the view factor of nodes of themselves.

```
                                                                                                        PAGE      2
1                                       RADIATION CONFIGURATION FACTORS

CNVUFAC CYLINDER EXAMPLE: DISK TO CYLINDER

IFLAG= 1     L= 2     NSYM=   50    NMI=  0     NODE1=     1
NODE1=    1    NODE2=   11    IIRD(1)=    1     IICD(1)=    4     IIRD(2)=    50     IICD(2)=   50

SECTION 1
    50 ROWS          FIRST ROW      1      LAST ROW      1
     8 COLUMNS    FIRST COLUMN      1   LAST COLUMN      8
KEM=1   KSH=0    KRE=0
DISK             RADIUS= 1.0000E+01

SECTION 2
    50 ROWS          FIRST ROW      1      LAST ROW     50
   150 COLUMNS    FIRST COLUMN      1   LAST COLUMN    150
KEM=0   KSH=0    KRE=1
CYLINDER         RADIUS= 1.0000E+01        LENGTH= 3.0000E+01

SECTION  SWITCH    PIT       YAW       ROL       XO        YO        ZO       FIRST R.   LAST R.  FIRST C.   LAST C.
   1        1    -90.0000       .0        .0        .0        .0        .0        1         1         1         4
   2       -1        .0         .0        .0        .0        .0        .0        1        50         1        50
EMITTER AREA = 7.8540E+01   EMITTER TO RECIEVER VIEW FACTOR= 5.3022E-01   EMITTER NODE NO. =    1
RECEIVER AREA= 6.2832E+02   RECEIVER TO EMITTER VIEW FACTOR= 6.6278E-02   RECEIVER NODE NO.=   11
INTERCHANGE AREA= 4.1643E+01

SECTION  SWITCH    PIT       YAW       ROL       XO        YO        ZO       FIRST R.   LAST R.  FIRST C.   LAST C.
   1        1    -90.0000       .0        .0        .0        .0        .0        1         1         1         4
   2       -1        .0         .0        .0        .0        .0        .0        1        50        51       100
EMITTER AREA = 7.8540E+01   EMITTER TO RECIEVER VIEW FACTOR= 2.7736E-01   EMITTER NODE NO. =    1
RECEIVER AREA= 6.2832E+02   RECEIVER TO EMITTER VIEW FACTOR= 3.4670E-02   RECEIVER NODE NO.=   12
INTERCHANGE AREA= 2.1784E+01

SECTION  SWITCH    PIT       YAW       ROL       XO        YO        ZO       FIRST R.   LAST R.  FIRST C.   LAST C.
   1        1    -90.0000       .0        .0        .0        .0        .0        1         1         1         4
   2       -1        .0         .0        .0        .0        .0        .0        1        50       101       150
EMITTER AREA = 7.8540E+01   EMITTER TO RECIEVER VIEW FACTOR= 9.4605E-02   EMITTER NODE NO. =    1
RECEIVER AREA= 6.2832E+02   RECEIVER TO EMITTER VIEW FACTOR= 1.1826E-02   RECEIVER NODE NO.=   13
INTERCHANGE AREA= 7.4303E+00

SECTION  SWITCH    PIT       YAW       ROL       XO        YO        ZO       FIRST R.   LAST R.  FIRST C.   LAST C.
   1        1    -90.0000       .0        .0        .0        .0        .0        1         1         5         8
   2       -1        .0         .0        .0        .0        .0        .0        1        50         1        50
EMITTER AREA = 2.3562E+02   EMITTER TO RECIEVER VIEW FACTOR= 6.6034E-01   EMITTER NODE NO. =    2
RECEIVER AREA= 6.2832E+02   RECEIVER TO EMITTER VIEW FACTOR= 2.4763E-01   RECEIVER NODE NO.=   11
INTERCHANGE AREA= 1.5559E+02

SECTION  SWITCH    PIT       YAW       ROL       XO        YO        ZO       FIRST R.   LAST R.  FIRST C.   LAST C.
   1        1    -90.0000       .0        .0        .0        .0        .0        1         1         5         8
   2       -1        .0         .0        .0        .0        .0        .0        1        50        51       100
EMITTER AREA = 2.3562E+02   EMITTER TO RECIEVER VIEW FACTOR= 1.8883E-01   EMITTER NODE NO. =    2
RECEIVER AREA= 6.2832E+02   RECEIVER TO EMITTER VIEW FACTOR= 7.0812E-02   RECEIVER NODE NO.=   12
INTERCHANGE AREA= 4.4492E+01

SECTION  SWITCH    PIT       YAW       ROL       XO        YO        ZO       FIRST R.   LAST R.  FIRST C.   LAST C.
   1        1    -90.0000       .0        .0        .0        .0        .0        1         1         5         8
   2       -1        .0         .0        .0        .0        .0        .0        1        50       101       150
EMITTER AREA = 2.3562E+02   EMITTER TO RECIEVER VIEW FACTOR= 7.5166E-02   EMITTER NODE NO. =    2
```

FIG. 5. Cylinder example: output.

```
1
CNVUFAC CYLINDER EXAMPLE: CYLINDER TO CYLINDER

IFLAG= 1     L= 2     NSYM=    50     NMI=  0     NODE1=   11
NODE1=   11     NODE2=   11     IIRD(1)=    1     IICD(1)=   50     IIRD(2)=   50     IICD(2)=   50

SECTION 1
     50 ROWS          FIRST ROW      1      LAST ROW      1
    150 COLUMNS    FIRST COLUMN      1   LAST COLUMN    150
KEM=1   KSH=0   KRE=0
CYLINDER          RADIUS= 1.0000E+01        LENGTH= 3.0000E+01

SECTION 2
     50 ROWS          FIRST ROW      1      LAST ROW     50
    150 COLUMNS    FIRST COLUMN      1   LAST COLUMN    150
KEM=0   KSH=0   KRE=1
CYLINDER          RADIUS= 1.0000E+01        LENGTH= 3.0000E+01

A CALCULATION WAS SKIPPED SINCE AN EMITTER AND A RECEIVER WERE TOUCHING.

SECTION  SWITCH    PIT       YAW       ROL       XO        YO        ZO     FIRST R.  LAST R.  FIRST C.  LAST C.
   1       -1        .0        .0        .0        .0        .0        .0       1         1         1        50
   2       -1        .0        .0        .0        .0        .0        .0       1        50        51       100
EMITTER AREA = 6.2832E+02   EMITTER TO RECIEVER VIEW FACTOR= 2.0381E-01   EMITTER NODE NO. =   11
RECEIVER AREA= 6.2832E+02   RECEIVER TO EMITTER VIEW FACTOR= 2.0381E-01   RECEIVER NODE NO.=   12
INTERCHANGE AREA= 1.2806E+02

SECTION  SWITCH    PIT       YAW       ROL       XO        YO        ZO     FIRST R.  LAST R.  FIRST C.  LAST C.
   1       -1        .0        .0        .0        .0        .0        .0       1         1         1        50
   2       -1        .0        .0        .0        .0        .0        .0       1        50       101       150
EMITTER AREA = 6.2832E+02   EMITTER TO RECIEVER VIEW FACTOR= 6.5244E-02   EMITTER NODE NO. =   11
RECEIVER AREA= 6.2832E+02   RECEIVER TO EMITTER VIEW FACTOR= 6.5244E-02   RECEIVER NODE NO.=   13
INTERCHANGE AREA= 4.0994E+01

SECTION  SWITCH    PIT       YAW       ROL       XO        YO        ZO     FIRST R.  LAST R.  FIRST C.  LAST C.
   1       -1        .0        .0        .0        .0        .0        .0       1         1        51       100
   2       -1        .0        .0        .0        .0        .0        .0       1        50         1        50
EMITTER AREA = 6.2832E+02   EMITTER TO RECIEVER VIEW FACTOR= 2.0381E-01   EMITTER NODE NO. =   12
RECEIVER AREA= 6.2832E+02   RECEIVER TO EMITTER VIEW FACTOR= 2.0381E-01   RECEIVER NODE NO.=   11
INTERCHANGE AREA= 1.2806E+02

A CALCULATION WAS SKIPPED SINCE AN EMITTER AND A RECEIVER WERE TOUCHING.

SECTION  SWITCH    PIT       YAW       ROL       XO        YO        ZO     FIRST R.  LAST R.  FIRST C.  LAST C.
   1       -1        .0        .0        .0        .0        .0        .0       1         1        51       100
   2       -1        .0        .0        .0        .0        .0        .0       1        50       101       150
EMITTER AREA = 6.2832E+02   EMITTER TO RECIEVER VIEW FACTOR= 2.0381E-01   EMITTER NODE NO. =   12
RECEIVER AREA= 6.2832E+02   RECEIVER TO EMITTER VIEW FACTOR= 2.0381E-01   RECEIVER NODE NO.=   13
INTERCHANGE AREA= 1.2806E+02

SECTION  SWITCH    PIT       YAW       ROL       XO        YO        ZO     FIRST R.  LAST R.  FIRST C.  LAST C.
   1       -1        .0        .0        .0        .0        .0        .0       1         1       101       150
   2       -1        .0        .0        .0        .0        .0        .0       1        50         1        50
EMITTER AREA = 6.2832E+02   EMITTER TO RECIEVER VIEW FACTOR= 6.5244E-02   EMITTER NODE NO. =   13
RECEIVER AREA= 6.2832E+02   RECEIVER TO EMITTER VIEW FACTOR= 6.5244E-02   RECEIVER NODE NO.=   11
INTERCHANGE AREA= 4.0994E+01

SECTION  SWITCH    PIT       YAW       ROL       XO        YO        ZO     FIRST R.  LAST R.  FIRST C.  LAST C.
   1       -1        .0        .0        .0        .0        .0        .0       1         1       101       150


      RECEIVER AREA= 6.2832E+02   RECEIVER TO EMITTER VIEW FACTOR= 2.8187E-02   RECEIVER NODE NO.=   13
      INTERCHANGE AREA= 1.7711E+01
```

FIG. 5. (con't.) Cylinder example: output.

```
1
CNVUFAC CYLINDER EXAMPLE: CYLINDER TC CYLINDER SEEING ITSELF

IFLAG= 1      L= 2      NSYM=    50     NMI=  0      NODE1=    11
NODE1=    11      NODE2=    11      IIRD(1)=     1      IICD(1)=    50      IIRD(2)=    49      IICD(2)=    50

SECTION 1
    50 ROWS          FIRST ROW       1       LAST ROW      1
   150 COLUMNS    FIRST COLUMN      1    LAST COLUMN    150
KEM=1   KSH=0    KRE=0
CYLINDER         RADIUS= 1.0000E+01        LENGTH= 3.0000E+01

SECTION 2
    50 ROWS          FIRST ROW       2       LAST ROW     50
   150 COLUMNS    FIRST COLUMN      1    LAST COLUMN    150
KEM=0   KSH=0    KRE=1
CYLINDER         RADIUS= 1.0000E+01        LENGTH= 3.0000E+01

SECTION  SWITCH     PIT        YAW        ROL        XO         YO         ZO      FIRST R.   LAST R.  FIRST C.    LAST C.
   1       -1         .0         .0         .0         .0         .0         .0       1          1          1          50
   2       -1         .0         .0         .0         .0         .0         .0       2         50          1          50
EMITTER AREA = 6.2832E+02   EMITTER TO RECIEVER VIEW FACTOR= 3.8166E-01   EMITTER NODE NO. =    11
RECEIVER AREA= 6.1575E+02   RECEIVER TO EMITTER VIEW FACTOR= 3.8945E-01   RECEIVER NODE NO.=    11
INTERCHANGE AREA= 2.3980E+02

SECTION  SWITCH     PIT        YAW        ROL        XO         YO         ZO      FIRST R.   LAST R.  FIRST C.    LAST C.
   1       -1         .0         .0         .0         .0         .0         .0       1          1          1          50
   2       -1         .0         .0         .0         .0         .0         .0       2         50         51         100
EMITTER AREA = 6.2832E+02   EMITTER TO RECIEVER VIEW FACTOR= 2.0381E-01   EMITTER NODE NO. =    11
RECEIVER AREA= 6.1575E+02   RECEIVER TO EMITTER VIEW FACTOR= 2.0797E-01   RECEIVER NODE NO.=    12
INTERCHANGE AREA= 1.2806E+02

SECTION  SWITCH     PIT        YAW        ROL        XO         YO         ZO      FIRST R.   LAST R.  FIRST C.    LAST C.
   1       -1         .0         .0         .0         .0         .0         .0       1          1          1          50
   2       -1         .0         .0         .0         .0         .0         .0       2         50        101         150
EMITTER AREA = 6.2832E+02   EMITTER TO RECIEVER VIEW FACTOR= 6.5244E-02   EMITTER NODE NO. =    11
RECEIVER AREA= 6.1575E+02   RECEIVER TO EMITTER VIEW FACTOR= 6.6575E-02   RECEIVER NODE NO.=    13
INTERCHANGE AREA= 4.0994E+01

SECTION  SWITCH     PIT        YAW        ROL        XO         YO         ZO      FIRST R.   LAST R.  FIRST C.    LAST C.
   1       -1         .0         .0         .0         .0         .0         .0       1          1         51         100
   2       -1         .0         .0         .0         .0         .0         .0       2         50          1          50
EMITTER AREA = 6.2832E+02   EMITTER TO RECIEVER VIEW FACTOR= 2.0381E-01   EMITTER NODE NO. =    12
RECEIVER AREA= 6.1575E+02   RECEIVER TO EMITTER VIEW FACTOR= 2.0797E-01   RECEIVER NODE NO.=    11
INTERCHANGE AREA= 1.2806E+02

SECTION  SWITCH     PIT        YAW        ROL        XO         YO         ZO      FIRST R.   LAST R.  FIRST C.    LAST C.
   1       -1         .0         .0         .0         .0         .0         .0       1          1         51         100
   2       -1         .0         .0         .0         .0         .0         .0       2         50         51         100
EMITTER AREA = 6.2832E+02   EMITTER TO RECIEVER VIEW FACTOR= 3.8166E-01   EMITTER NODE NO. =    12
RECEIVER AREA= 6.1575E+02   RECEIVER TO EMITTER VIEW FACTOR= 3.8945E-01   RECEIVER NODE NO.=    12
INTERCHANGE AREA= 2.3980E+02

SECTION  SWITCH     PIT        YAW        ROL        XO         YO         ZO      FIRST R.   LAST R.  FIRST C.    LAST C.
   1       -1         .0         .0         .0         .0         .0         .0       1          1         51         100
   2       -1         .0         .0         .0         .0         .0         .0       2         50        101         150
EMITTER AREA = 6.2832E+02   EMITTER TO RECIEVER VIEW FACTOR= 2.0381E-01   EMITTER NODE NO  =    12
RECEIVER AREA= 6.1575E+02   RECEIVER TO EMITTER VIEW FACTOR= 2.0797E-01   RECEIVER NODE NO.=    13
INTERCHANGE AREA= 1.2806E+02
```

FIG. 5. (con't.) Cylinder example: output.

```
1
CNVUFAC CYLINDER EXAMPLE: DISK TO DISK

IFLAG= 0     L= 2     NSYM=   50     NMI=  0     NODEI=    1
NODEI=    1     NODE2=   21     IIRD(1)=    1     IICD(1)=    4     IIRD(2)=   50     IICD(2)=    4

SECTION 1
    50 ROWS          FIRST ROW      1       LAST ROW      1
     8 COLUMNS    FIRST COLUMN      1    LAST COLUMN      8
KEM=1   KSH=0    KRE=0
DISK             RADIUS= 1.0000E+01

SECTION 2
    50 ROWS          FIRST ROW      1       LAST ROW     50
     8 COLUMNS    FIRST COLUMN      1    LAST COLUMN      8
KEM=0   KSH=0    KRE=1
DISK             RADIUS= 1.0000E+01

SECTION  SWITCH     PIT         YAW         ROL         XO          YO          ZO      FIRST R.   LAST R.  FIRST C.   LAST C.
   1        1    -90.0000        .0          .0          .0          .0          .0          1          1         1          4
   2       -1    -90.0000        .0          .0     30.0000          .0          .0          1         50         1          4
EMITTER AREA = 7.8540E+01   EMITTER TO RECIEVER VIEW FACTOR= 2.6376E-02   EMITTER NODE NO. =    1
RECEIVER AREA= 7.8540E+01   RECEIVER TO EMITTER VIEW FACTOR= 2.6376E-02   RECEIVER NODE NO.=   21
INTERCHANGE AREA= 2.0716E+00

SECTION  SWITCH     PIT         YAW         ROL         XO          YO          ZO      FIRST R.   LAST R.  FIRST C.   LAST C.
   1        1    -90.0000        .0          .0          .0          .0          .0          1          1         1          4
   2       -1    -90.0000        .0          .0     30.0000          .0          .0          1         50         5          8
EMITTER AREA = 7.8540E+01   EMITTER TO RECIEVER VIEW FACTOR= 7.1555E-02   EMITTER NODE NO. =    1
RECEIVER AREA= 2.3562E+02   RECEIVER TO EMITTER VIEW FACTOR= 2.3852E-02   RECEIVER NODE NO.=   22
INTERCHANGE AREA= 5.6199E+00

SECTION  SWITCH     PIT         YAW         ROL         XO          YO          ZO      FIRST R.   LAST R.  FIRST C.   LAST C.
   1        1    -90.0000        .0          .0          .0          .0          .0          1          1         5          8
   2        1    -90.0000        .0          .0     30.0000          .0          .0          1         50         1          4
EMITTER AREA = 2.3562E+02   EMITTER TO RECIEVER VIEW FACTOR= 2.3852E-02   EMITTER NODE NO. =    2
RECEIVER AREA= 7.8540E+01   RECEIVER TO EMITTER VIEW FACTOR= 7.1555E-02   RECEIVER NODE NO.=   21
INTERCHANGE AREA= 5.6199E+00

SECTION  SWITCH     PIT         YAW         ROL         XO          YO          ZO      FIRST R.   LAST R.  FIRST C.   LAST C.
   1        1    -90.0000        .0          .0          .0          .0          .0          1          1         5          8
   2       -1    -90.0000        .0          .0     30.0000          .0          .0          1         50         5          8
EMITTER AREA = 2.3562E+02   EMITTER TO RECIEVER VIEW FACTOR= 6.5890E-02   EMITTER NODE NO. =    2
RECEIVER AREA= 2.3562E+02   RECEIVER TO EMITTER VIEW FACTOR= 6.5890E-02   RECEIVER NODE NO.=   22
INTERCHANGE AREA= 1.5525E+01
```

FIG. 5. (con't.) Cylinder example: output.

```
SECTION  SWITCH    PIT        YAW       ROL       XO        YO         ZO     FIRST R.   LAST R.  FIRST C.   LAST C.
   1       -1          .0        .0        .0        .0        .0         .0      1          1       101        150
   2       -1          .0        .0        .0        .0        .0         .0      2         50         1         50
EMITTER AREA = 6.2832E+02   EMITTER TO RECIEVER VIEW FACTOR= 6.5244E-02   EMITTER NODE NO. =   13
RECEIVER AREA= 6.1575E+02   RECEIVER TO EMITTER VIEW FACTOR= 6.6575E-02   RECEIVER NODE NO.=   11
INTERCHANGE AREA= 4.0994E+01

SECTION  SWITCH    PIT        YAW       ROL       XO        YO         ZO     FIRST R.   LAST R.  FIRST C.   LAST C.
   1       -1          .0        .0        .0        .0        .0         .0      1          1       101        150
   2       -1          .0        .0        .0        .0        .0         .0      2         50        51        100
EMITTER AREA = 6.2832E+02   EMITTER TO RECIEVER VIEW FACTOR= 2.0381E-01   EMITTER NODE NO. =   13
RECEIVER AREA= 6.1575E+02   RECEIVER TO EMITTER VIEW FACTOR= 2.0797E-01   RECEIVER NODE NO.=   12
INTERCHANGE AREA= 1.2806E+02

SECTION  SWITCH    PIT        YAW       ROL       XO        YO         ZO     FIRST R.   LAST R.  FIRST C.   LAST C.
   1       -1          .0        .0        .0        .0        .0         .0      1          1       101        150
   2       -1          .0        .0        .0        .0        .0         .0      2         50       101        150
EMITTER AREA = 6.2832E+02   EMITTER TO RECIEVER VIEW FACTOR= 3.8166E-01   EMITTER NODE NO. =   13
RECEIVER AREA= 6.1575E+02   RECEIVER TO EMITTER VIEW FACTOR= 3.8945E-01   RECEIVER NODE NO.=   13
INTERCHANGE AREA= 2.3980E+02



   2       -1          .0        .0        .0        .0        .0         .0      1         50        51        100
EMITTER AREA = 6.2832E+02   EMITTER TO RECIEVER VIEW FACTOR= 2.0381E-01   EMITTER NODE NO. =   13
RECEIVER AREA= 6.2832E+02   RECEIVER TO EMITTER VIEW FACTOR= 2.0381E-01   RECEIVER NODE NO.=   12
INTERCHANGE AREA= 1.2806E+02

A CALCULATION WAS SKIPPED SINCE AN EMITTER AND A RECEIVER WERE TOUCHING.
```

FIG. 5 (con't.) Cylinder example: output.

```
1
CNVUFAC CYLINDER EXAMPLE: DISK TO CYLINDER
   EMITTER  RECEIVER INT. AREA
         1        11 4.164E+01
         1        12 2.178E+01
         1        13 7.430E+00
         2        11 1.556E+02
         2        12 4.449E+01
         2        13 1.771E+01
CNVUFAC CYLINDER EXAMPLE: CYLINDER TO CYLINDER
   EMITTER  RECEIVER INT. AREA
        11        12 1.281E+02
        11        13 4.099E+01
        12        11 1.281E+02
        12        13 1.281E+02
        13        11 4.099E+01
        13        12 1.281E+02
CNVUFAC CYLINDER EXAMPLE: CYLINDER TO CYLINDER SEEING ITSELF
   EMITTER  RECEIVER INT  AREA
        11        11 2.398E+02
        11        12 1.281E+02
        11        13 4.099E+01
        12        11 1.281E+02
        12        12 2.398E+02
        12        13 1.281E+02
        13        11 4.099E+01
        13        12 1.281E+02
        13        13 2.398E+02
CNVUFAC CYLINDER EXAMPLE: DISK TO DISK
   EMITTER  RECEIVER INT. AREA
         1        21 2.072E+00
         1        22 5.620E+00
         2        21 5.620E+00
         2        22 1.552E+01
         0         0     .0E+00
```

FIG. 6. Cylinder example: card image output.

This difficulty is resolved in the third problem. Here, two identical cylinders are again input. However, the row in the receiver cylinder that corresponds to the one row input from the emitter cylinder is eliminated. Specifically, since the symmetry option requires that only row 1 need be input from the emitter cylinder (section 1), row 1 is eliminated from the receiver cylinder (section 2). Note that the receiver cylinder only uses rows 2 through 50. The errors using this procedure can be minimized by sufficiently fine zoning.

For this particular problem, the procedure introduces no errors into any of the cylinder-to-cylinder emitters to receiver view factors since the eliminated receiver row cannot see the one emitter row used. There are 2% errors in the receiver-to-emitter view factors. Since the interchange areas are calculated from the emitter area and the emitter-to-receiver view factors, these values (which are the used in the card image file) also contain no additional errors.

In the output file (Figs. 7, 8, and 9) the program first prints the row and the column values for the entire sections. As each node-to-node interchange is calculated, the program prints the row and column numbers for the particular nodes considered. Values of area, view factor, interchange area, and node numbers are also printed for the particular interchange.

The image file (Fig. 6) contains values of node number and interchange area. After the label cards are eliminated, the format is suitable for input into program GRAY.

This example required 0.78 minute to execute. For the 2.1×10^6 elements calculated, the element calculated, the element calculation rate on the CDC7600 was 2.7×10^6 elements per minute.

Choosing this simple geometry, the view factors can be checked with exact solutions.[6,8] These comparisons are shown in Table 1. Generally, the errors are less than 1 percent. Neglecting the errors due to eliminating the receiver row, the only interchange having a larger error is that between nodes 11 and 2. Note that these two nodes are adjacent to one another.

This brings up an important point. Generally, the closer the two surfaces are to one another, the more inaccurate is the elemental integration technique used. The next example evaluates the error in the calculation of two identical opposed disks as the spacing is changed.

```
1       0
CNVUFAC PARALLEL DISK ERROR TEST. H/D=0.1-2.0
    0    2   50   19
    6   50    1    :    8    1    8 ,  1    0    0
 0.5
 1.0      -90.0      0.0      C.0      0.0      0.0      0.0
 0.0       0.0       0.0      C.0      0.0      0.0
    6   50    1   50    8    1    8    0    0    1
 0.5
-1.0      -90.0      0.0      C.0      0.1      0.0      0.0
 0.0       0.0       0.0      C.1      0.0      0.0
```

FIG. 7. Opposed disks example: input.

2.2 ERROR IN TWO OPPOSED DISKS

This example illustrates the use of the matrix incrementing option and evaluates the error as a function of disk spacing. The two identical opposed disks are parallel and are both centered on the X axis. The orientation is the same as that for the two ends in the previous cylinder example. The row and column divisions are also identical. The disk diameter is set at 1.0.

1 RADIATION CONFIGURATION FACTORS

```
CNVUFAC PARALLEL DISK ERROR TEST, H/D=0.1-2.0

IFLAG= 0     L= 2     NSYM=   50     NMI= 19     NODE1=   -0

SECTION 1
    50 ROWS          FIRST ROW      1      LAST ROW      1
     8 COLUMNS    FIRST COLUMN      1   LAST COLUMN      8
KEM=1   KSH=0    KRE=0
DISK             RADIUS= 5.0000E-01

SECTION 2
    50 ROWS          FIRST ROW      1      LAST ROW     50
     8 COLUMNS    FIRST COLUMN      1   LAST COLUMN      8
KEM=0   KSH=0    KRE=1
DISK             RADIUS= 5.0000E-01

SECTION 1
DPI=       .0  DYA=       .0  DRL=       .0  DXO=       .0  DYO=       .0  DZO=       .0

SECTION 2
DPI=       .0  DYA=       .0  DRL=       .0  DXO=    .1000  DYO=       .0  DZO=       .0

SECTION  SWITCH     PIT        YAW       ROL       XO        YO        ZO     FIRST R.   LAST R.  FIRST C.   LAST C.
   1        1    -90.0000       .0        .0        .0        .0        .0        1         1         1         8
   2       -1    -90.0000       .0        .0     .1000        .0        .0        1        50         1         8
EMITTER AREA = 7.8540E-01   EMITTER TO RECIEVER VIEW FACTOR= 8.2775E-01
RECEIVER AREA= 7.8540E-01   RECEIVER TO EMITTER VIEW FACTOR= 8.2775E-01
INTERCHANGE AREA= 6.5012E-01

SECTION  SWITCH     PIT        YAW       ROL       XO        YO        ZO     FIRST R.   LAST R.  FIRST C.   LAST C.
   1        1    -90.0000       .0        .0        .0        .0        .0        1         1         1         8
   2       -1    -90.0000       .0        .0     .2000        .0        .0        1        50         1         8
EMITTER AREA = 7.8540E-01   EMITTER TO RECIEVER VIEW FACTOR= 6.7641E-01
RECEIVER AREA= 7.8540E-01   RECEIVER TO EMITTER VIEW FACTOR= 6.7641E-01
INTERCHANGE AREA= 5.3125E-01

SECTION  SWITCH     PIT        YAW       ROL       XO        YO        ZO     FIRST R.   LAST R.  FIRST C.   LAST C.
   1        1    -90.0000       .0        .0        .0        .0        .0        1         1         1         8
   2        1    -90.0000       .0        .0     .3000        .0        .0        1        50         1         8
EMITTER AREA = 7.8540E-01   EMITTER TO RECIEVER VIEW FACTOR= 5.5650E-01
RECEIVER AREA= 7.8540E-01   RECEIVER TO EMITTER VIEW FACTOR= 5.5650E-01
INTERCHANGE AREA= 4.3707E-01

SECTION  SWITCH     PIT        YAW       ROL       XO        YO        ZO     FIRST R.   LAST R.  FIRST C.   LAST C.
   1        1    -90.0000       .0        .0        .0        .0        .0        1         1         1         8
   2       -1    -90.0000       .0        .0     .4000        .0        .0        1        50         1         8
EMITTER AREA = 7.8540E-01   EMITTER TO RECIEVER VIEW FACTOR= 4.6046E-01
RECEIVER AREA= 7.8540E-01   RECEIVER TO EMITTER VIEW FACTOR= 4.6046E-01
INTERCHANGE AREA= 3.6164E-01

SECTION  SWITCH     PIT        YAW       ROL       XO        YO        ZO     FIRST R.   LAST R.  FIRST C.   LAST C.
   1        1    -90.0000       .0        .0        .0        .0        .0        1         1         1         8
   2       -1    -90.0000       .0        .0     .5000        .0        .0        1        50         1         8
EMITTER AREA = 7.8540E-01   EMITTER TO RECIEVER VIEW FACTOR= 3.8349E-01
RECEIVER AREA= 7.8540E-01   RECEIVER TO EMITTER VIEW FACTOR= 3.8349E-01
INTERCHANGE AREA= 3.0119E-01
```

FIG. 8. Opposed disks example: output.

```
SECTION  SWITCH    PIT        YAW        ROL        XO         YO         ZO    FIRST R.  LAST R.  FIRST C.  LAST C.
   1        1    -90.0000      .0         .0         .0         .0        .0       1         1         1         8
   2       -1    -90.0000      .0         .0        .6000       .0        .0       1        50         1         8
EMITTER AREA = 7.8540E-01   EMITTER TO RECIEVER VIEW FACTOR= 3.2170E-01
RECEIVER AREA= 7.8540E-01   RECEIVER TO EMITTER VIEW FACTOR= 3.2170E-01
INTERCHANGE AREA= 2.5266E-01

SECTION  SWITCH    PIT        YAW        ROL        XO         YO         ZO    FIRST R.  LAST R.  FIRST C.  LAST C.
   1        1    -90.0000      .0         .0         .0         .0        .0       1         1         1         8
   2       -1    -90.0000      .0         .0        .7000       .0        .0       1        50         1         8
EMITTER AREA = 7.8540E-01   EMITTER TO RECIEVER VIEW FACTOR= 2.7192E-01
RECEIVER AREA= 7.8540E-01   RECEIVER TO EMITTER VIEW FACTOR= 2.7192E-01
INTERCHANGE AREA= 2.1357E-01

SECTION  SWITCH    PIT        YAW        ROL        XO         YO         ZO    FIRST R.  LAST R.  FIRST C.  LAST C.
   1        1    -90.0000      .0         .0         .0         .0        .0       1         1         1         8
   2       -1    -90.0000      .0         .0        .8000       .0        .0       1        50         1         8
EMITTER AREA = 7.8540E-01   EMITTER TO RECIEVER VIEW FACTOR= 2.3163E-01
RECEIVER AREA= 7.8540E-01   RECEIVER TO EMITTER VIEW FACTOR= 2.3163E-01
INTERCHANGE AREA= 1.8192E-01

SECTION  SWITCH    PIT        YAW        ROL        XO         YO         ZO    FIRST R.  LAST R.  FIRST C.  LAST C.
   1        1    -90.0000      .0         .0         .0         .0        .0       1         1         1         8
   2       -1    -90.0000      .0         .0        .9000       .0        .0       1        50         1         8
EMITTER AREA = 7.8540E-01   EMITTER TO RECIEVER VIEW FACTOR= 1.9883E-01
RECEIVER AREA= 7.8540E-01   RECEIVER TO EMITTER VIEW FACTOR= 1.9883E-01
INTERCHANGE AREA= 1.5616E-01

SECTION  SWITCH    PIT        YAW        ROL        XO         YO         ZO    FIRST R.  LAST R.  FIRST C.  LAST C.
   1        1    -90.0000      .0         .0         .0         .0        .0       1         1         1         8
   2       -1    -90.0000      .0         .0       1.0000       .0        .0       1        50         1         8
EMITTER AREA = 7.8540E-01   EMITTER TO RECIEVER VIEW FACTOR= 1.7194E-01
RECEIVER AREA= 7.8540E-01   RECEIVER TO EMITTER VIEW FACTOR= 1.7194E-01
INTERCHANGE AREA= 1.3504E-01

SECTION  SWITCH    PIT        YAW        ROL        XO         YO         ZO    FIRST R.  LAST R.  FIRST C.  LAST C.
   1        1    -90.0000      .0         .0         .0         .0        .0       1         1         1         8
   2       -1    -90.0000      .0         .0       1.1000       .0        .0       1        50         1         8
EMITTER AREA = 7.8540E-01   EMITTER TO RECIEVER VIEW FACTOR= 1.4975E-01
RECEIVER AREA= 7.8540E-01   RECEIVER TO EMITTER VIEW FACTOR= 1.4975E-01
INTERCHANGE AREA= 1.1762E-01

SECTION  SWITCH    PIT        YAW        ROL        XO         YO         ZO    FIRST R.  LAST R.  FIRST C.  LAST C.
   1        1    -90.0000      .0         .0         .0         .0        .0       1         1         1         8
   2       -1    -90.0000      .0         .0       1.2000       .0        .0       1        50         1         8
EMITTER AREA = 7.8540E-01   EMITTER TO RECIEVER VIEW FACTOR= 1.3131E-01
RECEIVER AREA= 7.8540E-01   RECEIVER TO EMITTER VIEW FACTOR= 1.3131E-01
INTERCHANGE AREA= 1.0313E-01

SECTION  SWITCH    PIT        YAW        ROL        XO         YO         ZO    FIRST R.  LAST R.  FIRST C.  LAST C.
   1        1    -90.0000      .0         .0         .0         .0        .0       1         1         1         8
   2       -1    -90.0000      .0         .0       1.3000       .0        .0       1        50         1         8
EMITTER AREA = 7.8540E-01   EMITTER TO RECIEVER VIEW FACTOR= 1.1586E-01
RECEIVER AREA= 7.8540E-01   RECEIVER TO EMITTER VIEW FACTOR= 1.1586E-01
INTERCHANGE AREA= 9.0998E-02

SECTION  SWITCH    PIT        YAW        ROL        XO         YO         ZO    FIRST R.  LAST R.  FIRST C.  LAST C.
   1        1    -90.0000      .0         .0         .0         .0        .0       1         1         1         8
   2       -1    -90.0000      .0         .0       1.4000       .0        .0       1        50         1         8
```

FIG. 8. (con't.) Opposed disks example: output.

```
EMITTER AREA = 7.8540E-01   EMITTER TO RECIEVER VIEW FACTOR= 1.0284E-01
RECEIVER AREA= 7.8540E-01   RECEIVER TO EMITTER VIEW FACTOR= 1.0284E-01
INTERCHANGE AREA= 8.0772E-02

SECTION  SWITCH    PIT        YAW        ROL        XO         YO         ZO    FIRST R.  LAST R.  FIRST C.  LAST C.
   1        1    -90.0000     .0         .0         .0         .0         .0       1         1        1         8
   2       -1    -90.0000     .0         .0       1.5000       .0         .0       1        50        1         8
EMITTER AREA = 7.8540E-01   EMITTER TO RECIEVER VIEW FACTOR= 9.1789E-02
RECEIVER AREA= 7.8540E-01   RECEIVER TO EMITTER VIEW FACTOR= 9.1789E-02
INTERCHANGE AREA= 7.2091E-02

SECTION  SWITCH    PIT        YAW        ROL        XO         YO         ZO    FIRST R.  LAST R.  FIRST C.  LAST C.
   1        1    -90.0000     .0         .0         .0         .0         .0       1         1        1         8
   2       -1    -90.0000     .0         .0       1.6000       .0         .0       1        50        1         8
EMITTER AREA = 7.8540E-01   EMITTER TO RECIEVER VIEW FACTOR= 8.2347E-02
RECEIVER AREA= 7.8540E-01   RECEIVER TO EMITTER VIEW FACTOR= 8.2347E-02
INTERCHANGE AREA= 6.4675E-02

SECTION  SWITCH    PIT        YAW        ROL        XO         YO         ZO    FIRST R.  LAST R.  FIRST C.  LAST C.
   1        1    -90.0000     .0         .0         .0         .0         .0       1         1        1         8
   2       -1    -90.0000     .0         .0       1.7000       .0         .0       1        50        1         8
EMITTER AREA = 7.8540E-01   EMITTER TO RECIEVER VIEW FACTOR= 7.4229E-02
RECEIVER AREA= 7.8540E-01   RECEIVER TO EMITTER VIEW FACTOR= 7.4229E-02
INTERCHANGE AREA= 5.8300E-02

SECTION  SWITCH    PIT        YAW        ROL        XO         YO         ZO    FIRST R.  LAST R.  FIRST C.  LAST C.
   1        1    -90.0000     .0         .0         .0         .0         .0       1         1        1         8
   2       -1    -90.0000     .0         .0       1.8000       .0         .0       1        50        1         8
EMITTER AREA = 7.8540E-01   EMITTER TO RECIEVER VIEW FACTOR= 6.7211E-02
RECEIVER AREA= 7.8540E-01   RECEIVER TO EMITTER VIEW FACTOR= 6.7211E-02
INTERCHANGE AREA= 5.2787E-02

SECTION  SWITCH    PIT        YAW        ROL        XO         YO         ZO    FIRST R.  LAST R.  FIRST C.  LAST C.
   1        1    -90.0000     .0         .0         .0         .0         .0       1         1        1         8
   2       -1    -90.0000     .0         .0       1.9000       .0         .0       1        50        1         8
EMITTER AREA = 7.8540E-01   EMITTER TO RECIEVER VIEW FACTOR= 6.1107E-02
RECEIVER AREA= 7.8540E-01   RECEIVER TO EMITTER VIEW FACTOR= 6.1107E-02
INTERCHANGE AREA= 4.7994E-02

SECTION  SWITCH    PIT        YAW        ROL        XO         YO         ZO    FIRST R.  LAST R.  FIRST C.  LAST C.
   1        1    -90.0000     .0         .0         .0         .0         .0       1         1        1         8
   2       -1    -90.0000     .0         .0       2.0000       .0         .0       1        50        1         8
EMITTER AREA = 7.8540E-01   EMITTER TO RECIEVER VIEW FACTOR= 5.5773E-02
RECEIVER AREA= 7.8540E-01   RECEIVER TO EMITTER VIEW FACTOR= 5.5773E-02
INTERCHANGE AREA= 4.3804E-02
```

FIG. 8. (con't.) Opposed disks example:, output.

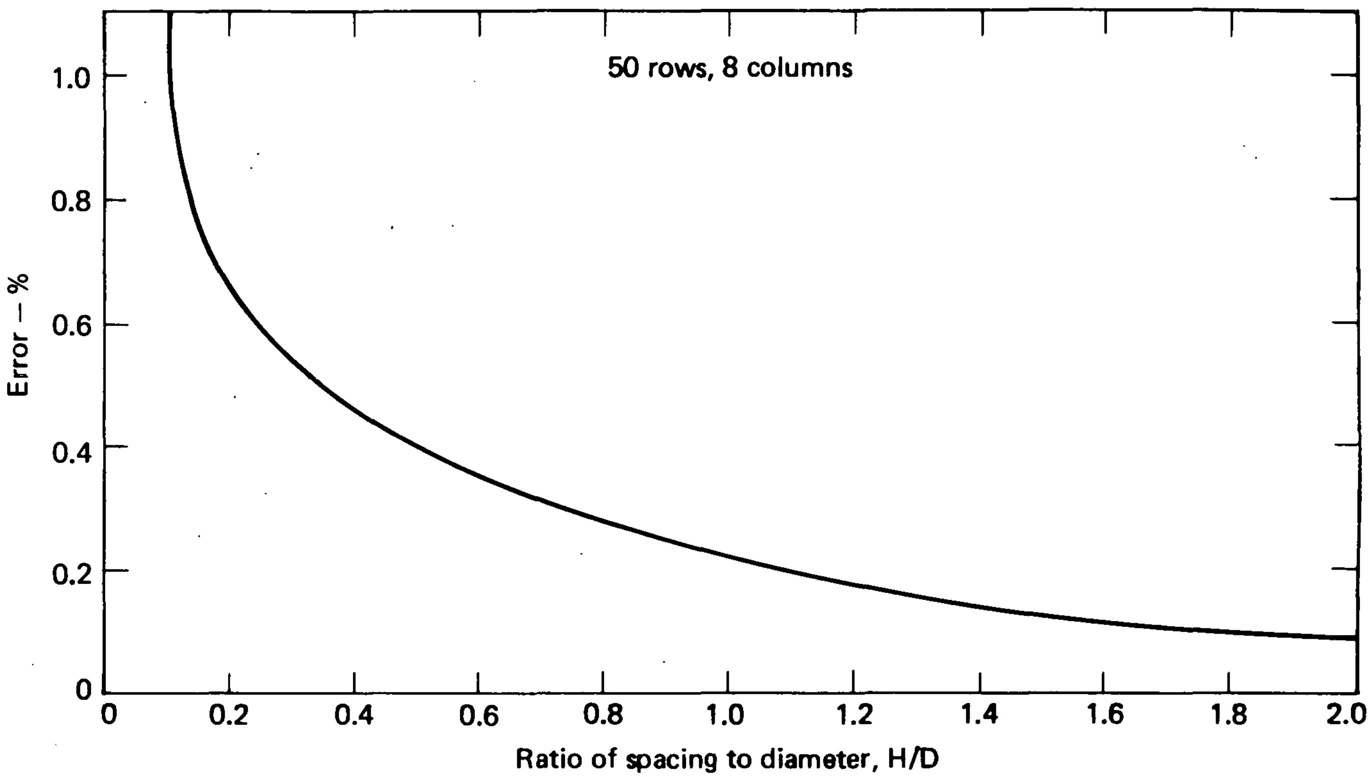


FIG. 9. Error in calculation of two identical opposed disks.

Figures 7 and 8 show the input and output files, respectively. Setting NMI = 19 and DXO(2) = 0.1 automatically increments the spacing from 0.1 to 2.0 in increments of 0.1. The calculation required 0.037 minute or 1.7×10^6 elements per minute.

Figure 9 shows the percent error in the calculation when compared to the exact value. The error is climbing rapidly as the spacing becomes less than H/D = 0.2, but even at H/D = 0.1, the error is only 1.07 percent.

2.3 DISK TO SLIT SHADOWED BY CYLINDER

To illustrate the use of the shadowing option, this example shows a calculation used on an LLL laser isotope separation experiment. The geometry is shown in Fig. 10. It was desired to calculate the view factor from the disk to the rectangular slit. The view factor is shadowed by the cylinder.

TABLE 1. Cylinder Example: Comparison with Exact Solutions.

From node	To node	View factor: CNYUFAC	View factor: Exact	Error percentage
11	1	6.6278×10^{-2}	6.6391×10^{-2}	- 0.170
12	1	3.4670×10^{-2}	3.4579×10^{-2}	0.263
13	1	1.1826×10^{-2}	1.1805×10^{-2}	0.178
11	2	2.4763×10^{-1}	2.4263×10^{-1}	2.061
12	2	7.0812×10^{-2}	7.0617×10^{-2}	0.276
13	2	2.8187×10^{-2}	2.8145×10^{-2}	0.149
11	11	3.8166×10^{-1}	3.8197×10^{-1}	- 0.081
11	12	2.0381×10^{-1}	2.0382×10^{-1}	- 0.005
11	13	6.5244×10^{-2}	6.5247×10^{-2}	- 0.005
11	11	3.8945×10^{-1}	3.8197×10^{-1}	1.958[a]
11	12	2.0797×10^{-1}	2.0382×10^{-1}	2.036[a]
11	13	6.6575×10^{-2}	6.5247×10^{-2}	2.035[a]
21	1	2.6376×10^{-2}	2.6334×10^{-2}	0.159
22	1	2.3852×10^{-2}	2.3820×10^{-2}	0.134
21	2	7.1555×10^{-2}	7.1460×10^{-2}	0.133
22	2	6.5890×10^{-2}	6.5813×10^{-2}	0.117

[a]These values are receiver to emitter view factors include a 2% receiver area error due to eliminating one receiver row. See text.

In Fig. 10, the base coordinates are labeled as X, Y, Z. The disk (section 1) coordinates, x_1, y_1, z_1, are subjected to a yaw and roll of -90° and 90°, respectively. The cylinder (section 2) coordinates, x_2, y_2, z_2, are subjected to an X displacement of 2.08 cm. The rectangular slit (section 3) coordinates, x_3, y_3, z_3, are subjected to a pitch and a roll of -90° and 90°, respectively. In addition, these coordinates have Y and Z displacements of 2.06 and 0.2 cm, respectively.

Figure 11 shows the input and output. The calculation time was 1.08 minutes. Counting only the elements in the emitter and the receiver, the calculation rate is only 222 elements per minute. This is about four orders of magnitude slower than the previous two examples due to the shadowing in the calculation.

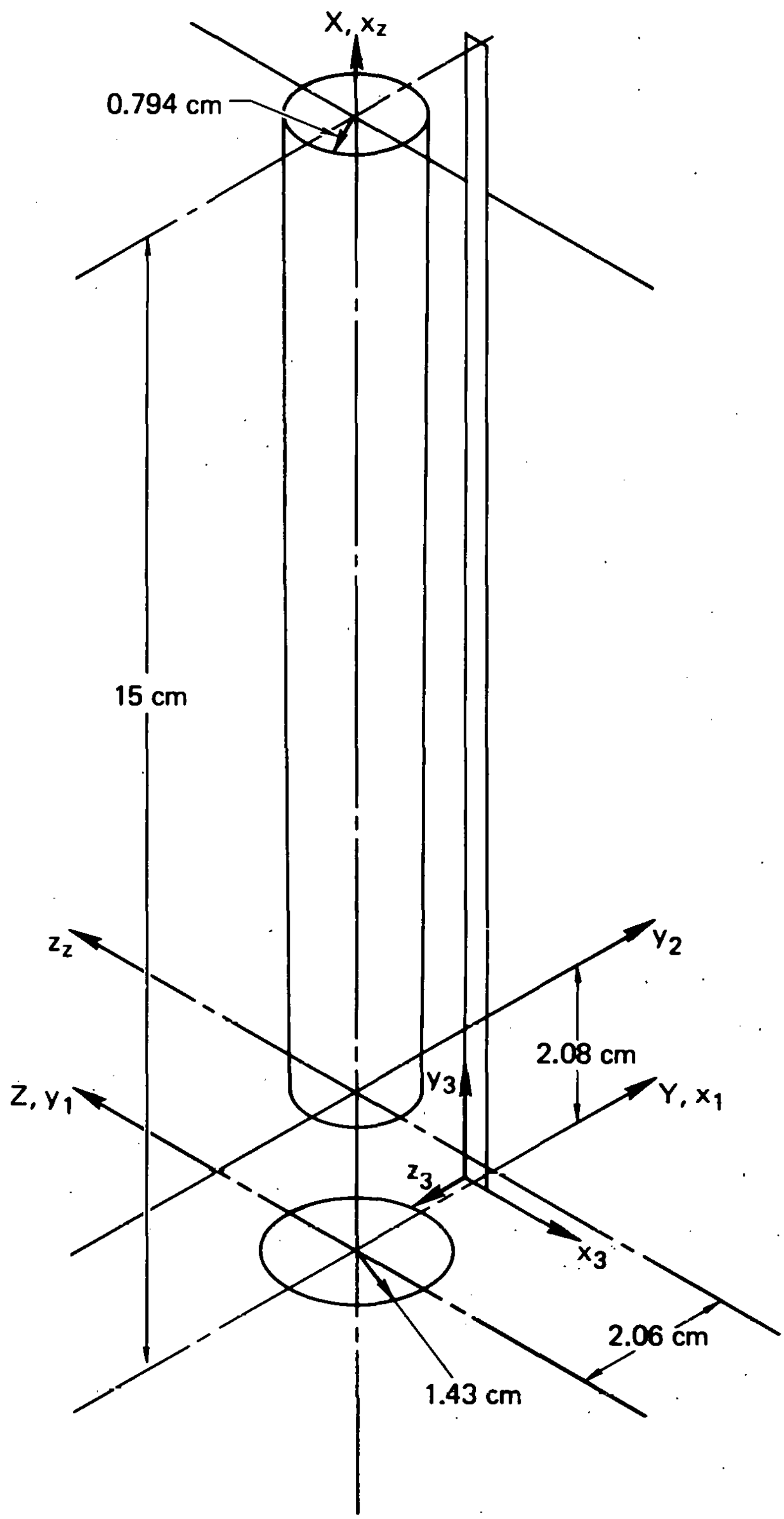


FIG. 10. Disk to slit shadowed by cylinder.

```
SPP2 ELECTRODE TO SLIT VIEW FACTOR SHADOWED BY BOAT
    0      3      1
    6     20      1     20      9      1      9      1      0      0
 1.43
 1.0          0.0         -90.0        90.0         0.0         0.0         0.0
    1     20      1     20     30      1     30      0      1      0
 0.794                     12.92
 1.0          0.0          0.0          0.0         2.08        0.0         0.0
    5      2      1      2     30      1     30      0      0      1
                           0.4                                 15.0
 1.0         -90.0         0.0         90.0         0.0         2.06        0.2
```

(a) Input

```
1                                    RADIATION CONFIGURATION FACTORS

SPP2 ELECTRODE TO SLIT VIEW FACTOR SHADOWED BY BOAT


IFLAG= 0     L= 3     NSYM=     1     NMI= -0     NODE1=    -0

SECTION 1
    20 ROWS         FIRST ROW      1      LAST ROW     20
     9 COLUMNS   FIRST COLUMN      1   LAST COLUMN      9
KEM=1   KSH=0    KRE=0
DISK            RADIUS= 1.4300E+00

SECTION 2
    20 ROWS         FIRST ROW      1      LAST ROW     20
    30 COLUMNS   FIRST COLUMN      1   LAST COLUMN     30
KEM=0   KSH=1    KRE=0
CYLINDER        RADIUS= 7.9400E-01       LENGTH= 1.2920E+01

SECTION 3
     2 ROWS         FIRST ROW      1      LAST ROW      2
    30 COLUMNS   FIRST COLUMN      1   LAST COLUMN     30
KEM=0   KSH=0    KRE=1
FLAT PLATE      LENGTH= 4.0000E-01        WIDTH= 1.5000E+01

SECTION  SWITCH     PIT        YAW        ROL        XO         YO         ZO     FIRST R.   LAST R.  FIRST C.   LAST C.
   1        1          .0  -90.0000   90.0000        .0         .0         .0       1          20        1          9
   2        1          .0        .0        .0    2.0800         .0         .0       1          20        1         30
   3        1    -90.0000        .0   90.0000        .0     2.0600      .2000       1           2        1         30
EMITTER AREA = 6.4242E+00   EMITTER TO RECIEVER VIEW FACTOR= 2.7788E-02
RECEIVER AREA= 6.0000E+00   RECEIVER TO EMITTER VIEW FACTOR= 2.9754E-02
INTERCHANGE AREA= 1.7852E-01
```

(b) Output

FIG. 11. Examples of disk to slit shadowed by cylinder.

REFERENCES

1. A. L. Edwards, *TRUMP: A Computer Program for Transient and Steady-State Temperature Distributions in Multidimensional Systems*, Lawrence Livermore Laboratory, Livermore, Calif., UCRL-14754, Rev. 3 (September 1, 1972).
2. D. A. Schauer, *FED: A Computer Program to Generate Geometric Input for the Heat-Transfer Code TRUMP*, Lawrence Livermore Laboratory, Livermore, Calif., UCRL-50816, Rev. 1 (January 12, 1973).
3. R. L. Wong, *GRAY, A Program to Calculate Gray Body Radiation Heat Transfer View Factors From Black Body View Factors*, Lawrence Livermore Laboratory, Livermore, Calif., UCID-17277 (June 14, 1976).
4. R. Siegel and J. R. Howell, *Thermal Radiation Heat Transfer* (McGraw-Hill Book Company Inc., New York, 1972).
5. H. C. Hottel and A. F. Sarofim, *Radiative Transfer* (McGraw-Hill Book Company, Inc., New York, 1967).
6. J. C. Oglebay, personal communication, NASA, Lewis Research Center, Cleveland, Ohio.
7. R. S. Dummer and W. T. Breckenridge, Jr., *Radiation Configuration Factors*, General Dynamics Corp., Astronautics Div., Rept. ERR-AN-244 (February, 1963).
8. A. V. Bushman, Jr., and C. M. Pittman, *Configuration Factors for Exchange of Radiant Energy Between Axisymmetrical Sections of Cylinders, Cones, and Hemispheres and Their Bases*, NASA, Tech. Note D-944 (October 1961), available from MTIS, Rept. No. AD-865186.

RHM/cg

LLL:1980/1

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

APPENDIX A

PROGRAM DESCRIPTION

The material on pages 31 through 51 is from an original report "Radiation Configuration Factors," authored by General Dynamics Corporation and is used with permission of General Dynamics. General Dynamics makes no warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein; or that the use of information disclosed herein may not infringe privately owned rights; or assumes any responsibility for liability or damage which may result from the use of any information disclosed herein.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

A.1 DESCRIPTION OF THE PROBLEM

A.1.1 Heat Exchange Between Two Area Elements. It may be shown that the heat exchanged between two elemental areas, as shown in Figure A-1, is expressed by,

$$d^2Q_b = \frac{\cos\beta_1 \cos\beta_2}{s^2} dA_1 \, dA_2 \frac{\sigma}{\pi} (T_1{}^4 - T_2{}^4). \tag{1}$$

Since the emissive powers of the elemental areas are $e_{b1} = \sigma T_1{}^4$ and $e_{b2}, = \sigma T_2{}^4$, it is possible to develop a "view factor" of element 1 for element 2 which is dependent only on the geometry of the situation. Thus,

$$dF_{1-2} = \frac{\cos\beta_1 \cos\beta_2}{\pi s^2} dA_2. \tag{2}$$

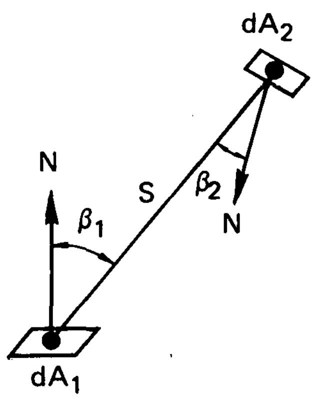


Figure A-1. Geometry of Heat Exchange Between Elemental Areas

Equation (1) may now be written as

$$d^2Q_b = \sigma dF_{1-2} \, dA_1 \, (T_1{}^4 - T_2{}^4). \tag{3}$$

(This equation is valid only for blackbodies.)

A.1.2 Heat Exchange Between Finite Areas. Heat exchange between bodies whose surface dimensions are not small when compared to the distance between them may be computed by division of the surfaces involved into many elemental areas (which meet the smallness criterion) and summation (integration) of Equation (1) for all of the elemental areas of surface E with respect to all of the elements of surface R (from Figure A-2). The same concept of view factor may be utilized to produce Equations (4) and (5).

$$F_{e-r} = \frac{1}{A_e} \sum_{A_e} \sum_{A_r} \frac{\cos\beta_1 \cos\beta_2}{\pi s^2} \, dA_r \, dA_e \tag{4}$$

$$Q_b = F_{e-r} A_e \sigma (T_e^4 - T_r^4) \tag{5}$$

Here we will call F_{e-r} a "configuration" or "shape" factor.

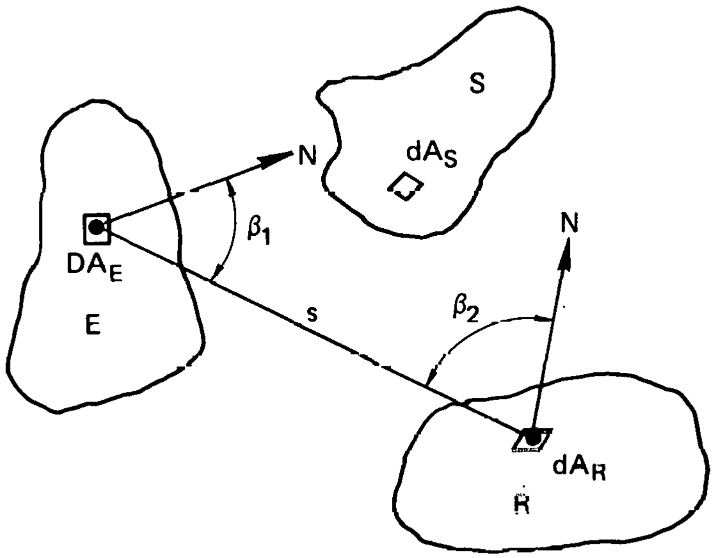


Figure A-2. Basic Geometry for Configuration Factor Analysis

It is to be noted that the preceding equations apply only to the situation of blackbodies, where multiple reflections do not occur, and to isotropic emitters, where the cosine law prevails.

The value of a shape factor is now readily seen. Once the shape factor is calculated by integration of Equation (4), heat exchange between isothermal bodies may be computed by evaluating Equation (5) without repeated integration, as long as the geometry of the situation does not change.

A.2 PROGRAM CONCEPT. The computer program documented here solves Equation (4) for a wide variety of basic shapes. The shapes chosen are: cylinder, cone, sphere, ellipsoid, flat rectangular plane, circular disk, toroid, and polynomial of revolution. The geometries of each of these shapes are shown in Figure A-3 through A-10.

The surfaces of the configurations are divided into "rows and columns"; that is, the surface is mapped by an arbitrary arrangement of planes intersecting the surface and producing elements of the surface, designated by row and column numbers. Elemental area derivation for each type of configuration is discussed in Subsection A.3. Computationally, each element henceforth will be treated as a plane located in the right-handed, orthogonal reference system of that section by the coördinates of its center and the direction cosines of its normal. An elemental area and a test radius are also stored for each element in each configuration section. Program input is designed to permit consideration of all or part of each of the above configurations by "inputting" the limits of row number and column number for consideration in each section. Any of the sections called for by program input may be designated as receiver (KRE), emitter (KEM), or shadower (KSH). Also, several sections may be designated as emitters and several as receivers. Sections may be designated as shadowers only; or, either receiving or emitting sections may be designated as shadowers of themselves.

By matrix transform algebra, all section information is moved from each section system to a base system, so that all sections have a common frame of reference. This is necessary since each section is permitted to have any attitude (pitch, yaw, roll) and location in relation to the base system. Matrix transformation, matrix incrementation, and point translation are discussed in Subsection A.4.

With all information regarding each element of each subsection now in a common system, the process of numerical integration is begun. All sections are examined in ascending numerical order until one designated "emitter" is encountered. The first element of the region of interest, as indicated by "column beginning" and "row beginning", is then selected. Again, all sections are examined in ascending order until one designated "receiver" is encountered; and, the first element of the region of interest is selected in a like manner. With two elements now so designated, the cosines of the angles between the two perpendiculars and a line connecting their centers are examined for sign. If either cosine is negative, the two elements cannot "see" each other and the next element of the receiver is examined. If, however, both signs are positive, the elements may "see" each other if the line-of-sight is not interrupted. To determine this, the sections are again examined in ascending numerical order until one designated "shadower" is encountered. Then, all elements of this section and of subsequent sections so designated are examined for shadowing until a shadowing element is found, or until all possible shadowing elements have been eliminated. The technique for the shadowing calculation is discussed in Subsection A.5. If shadowing does not occur, the program computes

$$\Delta SFX = \frac{\cos\theta_e \cos\theta_r}{\left(|\vec{er}|\right)^2} \quad A^{(ME)}_{(ie,je)} \quad A^{(MR)}_{(ir,jr)} \tag{6}$$

The terms θ_e and θ_r are the β_1 and β_2 terms from Fig. A-2; $A^{(ME)}_{(ie,je)}$ and $A^{(MR)}_{(ir,jr)}$ are the dA_e and dA_r for the particular rows, columns, and sections involved; and $|\vec{er}|$ is the s term in Fig. A-2, or the scalar length of the vector joining the centers of the two elemental areas. ΔSFX is added to a running sum of these values (called SFX), and the calculations proceed, evaluating all receiver elements which "see" each emitter element for shadowing until all sections are complete. The configuration factor of the emitter for the receiver is computed by dividing the total SFX by π and the area of the emitter. The configuration factor of the receiver for the emitter is computed by dividing the total SFX by π and the area of the receiver.

The use of the words emitter and receiver in this report are for mnemonic value only. In reality, both objects radiate energy and receive energy according to their temperatures, and the balance is determined by the sign of the expression $(T_e^4 - T_r^4)$ in Equation (5).

A.3 ELEMENTAL AREA DERIVATION. In this subsection the mapping of each of the configuration surfaces is discussed. The mapping and designation of areas, by row and column number, is as shown in Figure A-3 through A-10. The number of surface divisions and surface region of interest are chosen by the program user.

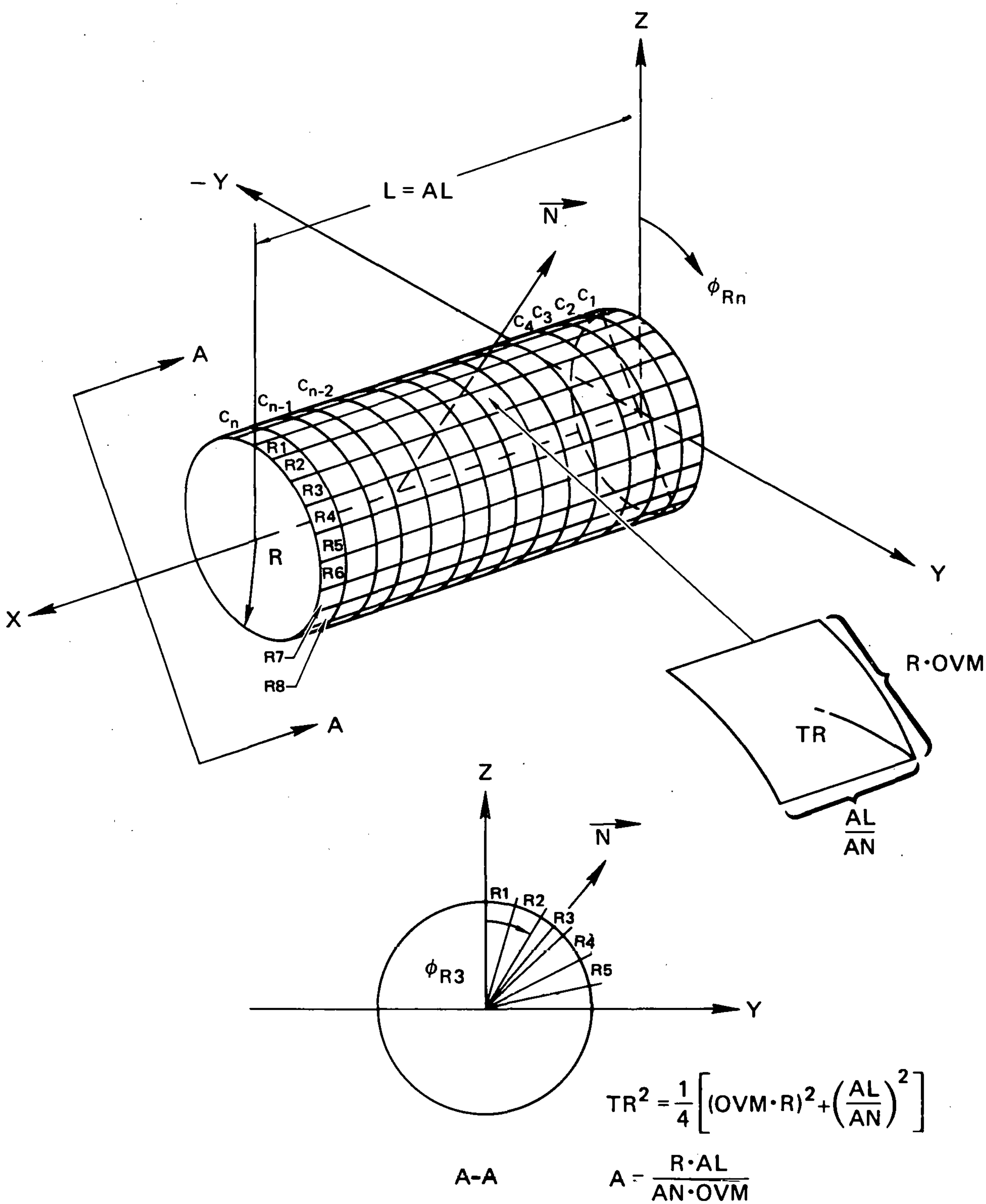


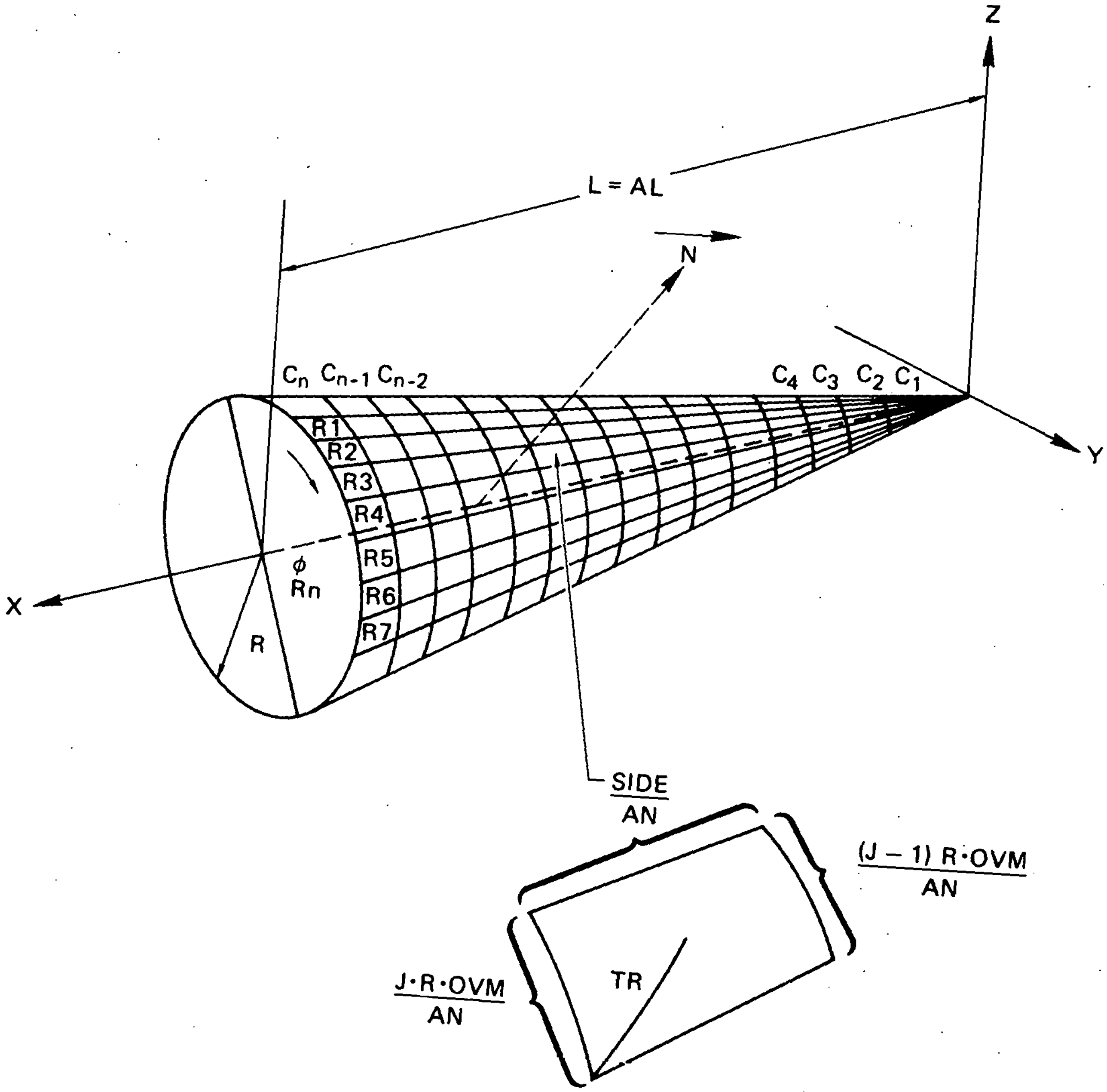
Figure A-3. Geometry of the Cylinder Configuration

The direction cosines, spatial position, test radius, and area are computed for each surface element on each section as functions of the indices I and J, which designate row and column numbers. The derivation and computation of these quantities can best be seen by reference to the corresponding diagram and flow chart.

Information regarding a particular section is contained on two specification cards. The first of these cards contains the section number, a code number (1 through 8) defining the shape, two numbers designating the number of rows and columns into which the section is to be divided, four numbers designating the region of interest by row numbers (beginning and ending) and column numbers (beginning and ending), and by three switches (KEM, KSH, KRE) which are set as either 1 or 0, depending on whether or not the section in question is an emitter, shadower, or receiver. The second card relates to a particular type of section and is discussed below under each section type description.

A.3.1 Cylinder Configuration. The cylinder configuration is shown in Figure A-3. Rows run along the cylinder lengthwise and are designated R1, R2, etc. Columns run around the cylinder and are designated C1, C2, C3, etc. The numbering for rows begins at the positive Z-axis and increases in a clockwise sense for an observer standing at the origin and looking along the negative X-axis of the cylinder reference system. Column numbers start at the origin and increase with the positive X-axis. The second of the two specification cards for the cylinder contains two numbers: R, the radius of the cylinder; and L = AL, the length of the cylinder.

A.3.2 Cone Configuration. The cone configuration is shown in Figure A-4. Rows run lengthwise along the cone from the apex to the base and are designated R1, R2, etc., starting at the positive Z-axis and increasing in a clockwise sense for an observer at the origin looking along the negative X-axis of the cone reference system. Columns run around the cone and are designated C1, C2, etc. Numbering begins at the apex and proceeds along the X-axis as shown in Figure A-4. As with the cylinder, the second of the two specification cards for the cone contains two numbers: R, the radius of the cone; and L = AL, the length of the cone.



$$TR^2 = \frac{1}{4}\left[\left(\frac{SIDE}{AN}\right)^2 + \left(\frac{R \cdot OVM \cdot J}{AN}\right)^2\right]$$

$$A = \frac{SIDE \cdot R \cdot OVM\left(J - \frac{1}{2}\right)}{AN^2}$$

Figure A-4. Geometry of the Cone Configuration

A.3.3 <u>Sphere Configuration</u>. One quarter of the sphere configuration is shown in Figure A-5. The sphere is mapped by semicircular arrows which run half-way around the circumference of the sphere, from the positive to the negative Z-axis, crossing the equator (X-Y plane) perpendicularly. Numbering starts at the positive X-axis and increases in a clockwise manner for an observer at the origin looking along the positive Z-axis of the sphere reference system. Columns are full circles running around the outside of the sphere parallel to the equator; numbering starts at the point where the sphere intersects the positive Z-axis and increases along the Z-axis in a negative direction. The second of the two specification cards for the sphere contains one number: R, the radius of the sphere.

A.3.4 <u>Ellipsoid Configuration</u>. This configuration is shown in Figure A-6. Rows and columns are numbered as described in the figure notes. The second of the two specification cards for the ellipsoid contains two numbers: a = SMOLLA, the semi-axis lying along the configuration X-axis; and B, the semi-axis which is rotated about the configuration X-axis.

A.3.5 <u>Flat Plate Configuration</u>. The flat plate configuration is shown in Figure A-7. The flat surface is divided into rectangular elements with the rows running parallel to the Y-axis, starting at the origin and increasing with the positive X. Columns run parallel to the X-axis, increasing in the direction of positive Y. The second of the two specification cards for the flat plate contains two numbers: L = AL, the length of the plate along the configuration X-axis; and W, the width of the plate along the configuration Y-axis.

A.3.6 <u>Disk Configuration</u>. The disk configuration is shown in Figure A-8. Rows are taken as pie-cuts of the disk and numbering starts at the X-Z plane and runs, in ascending order, counterclockwise (in the direction of ϕ in the figure). Columns start at the origin as concentric circles with the origin as center and run outward to the edge of the disk. The second specification card for the disk contains one number: R, the radius of the disk.

A.3.7 <u>Toroid Configuration</u>. This configuration is shown in Figure A-9. Columns run around the toroid as shown in the figure and are numbered, starting

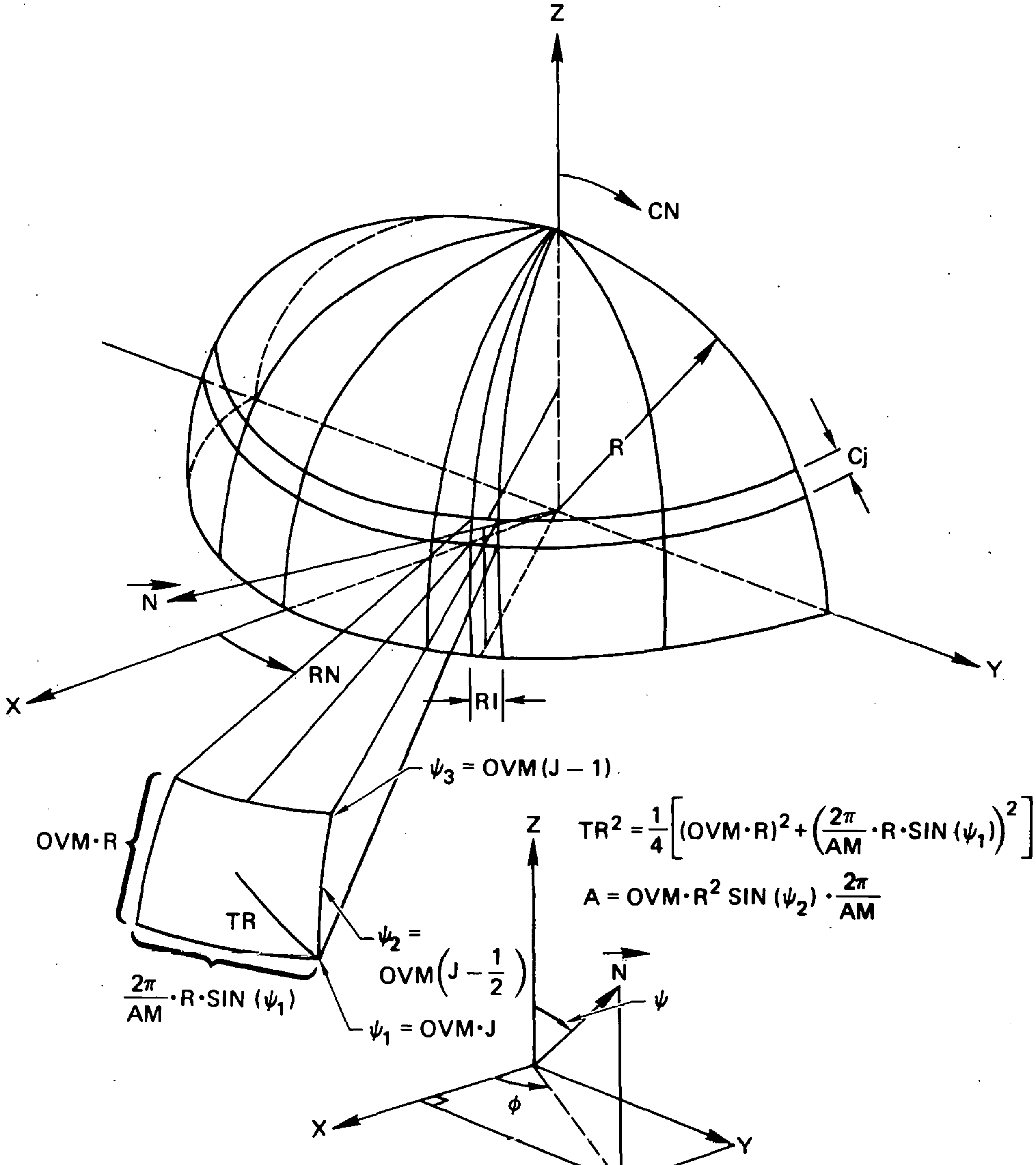
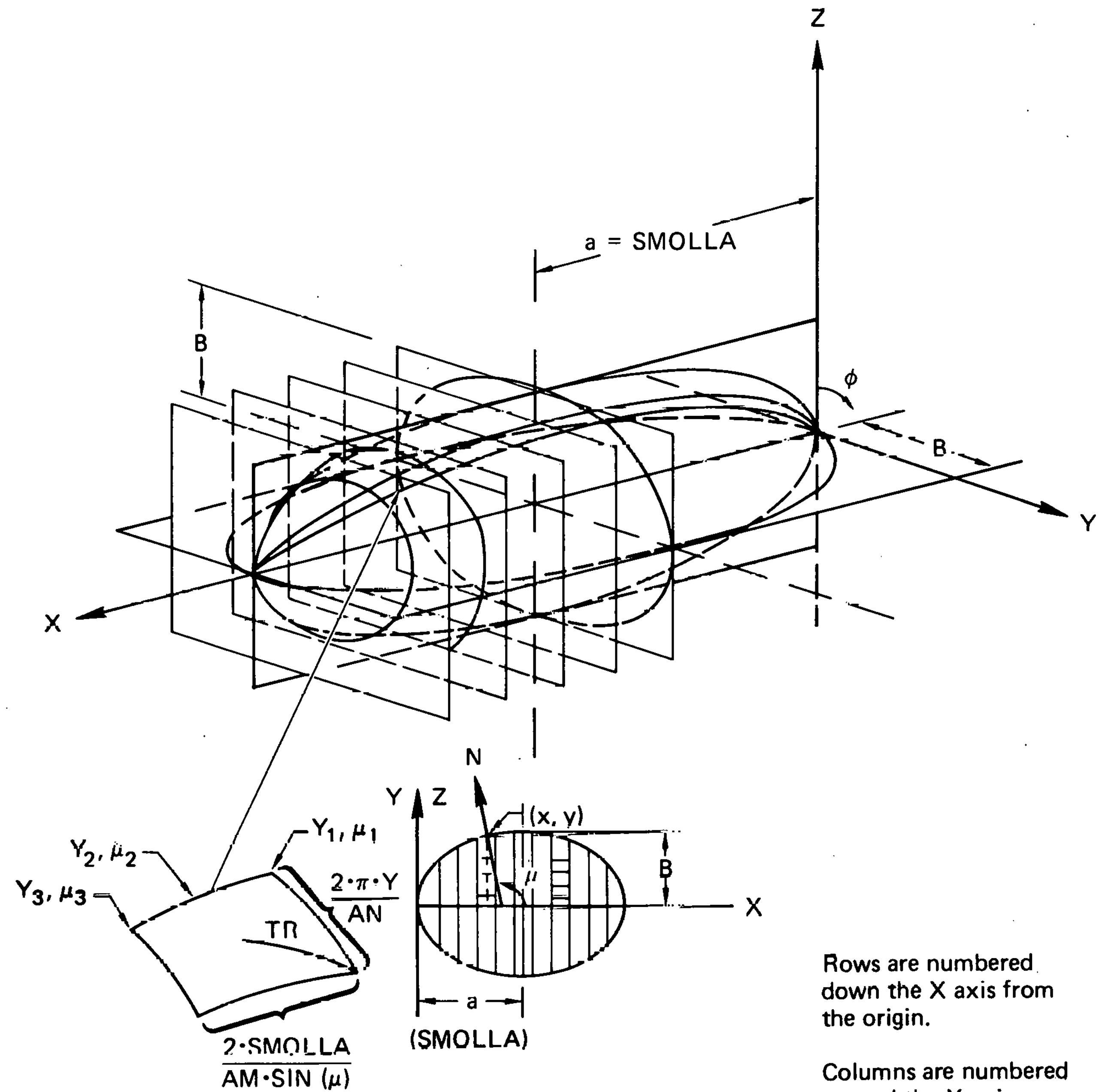


Figure A-5. Geometry of the Sphere Configuration



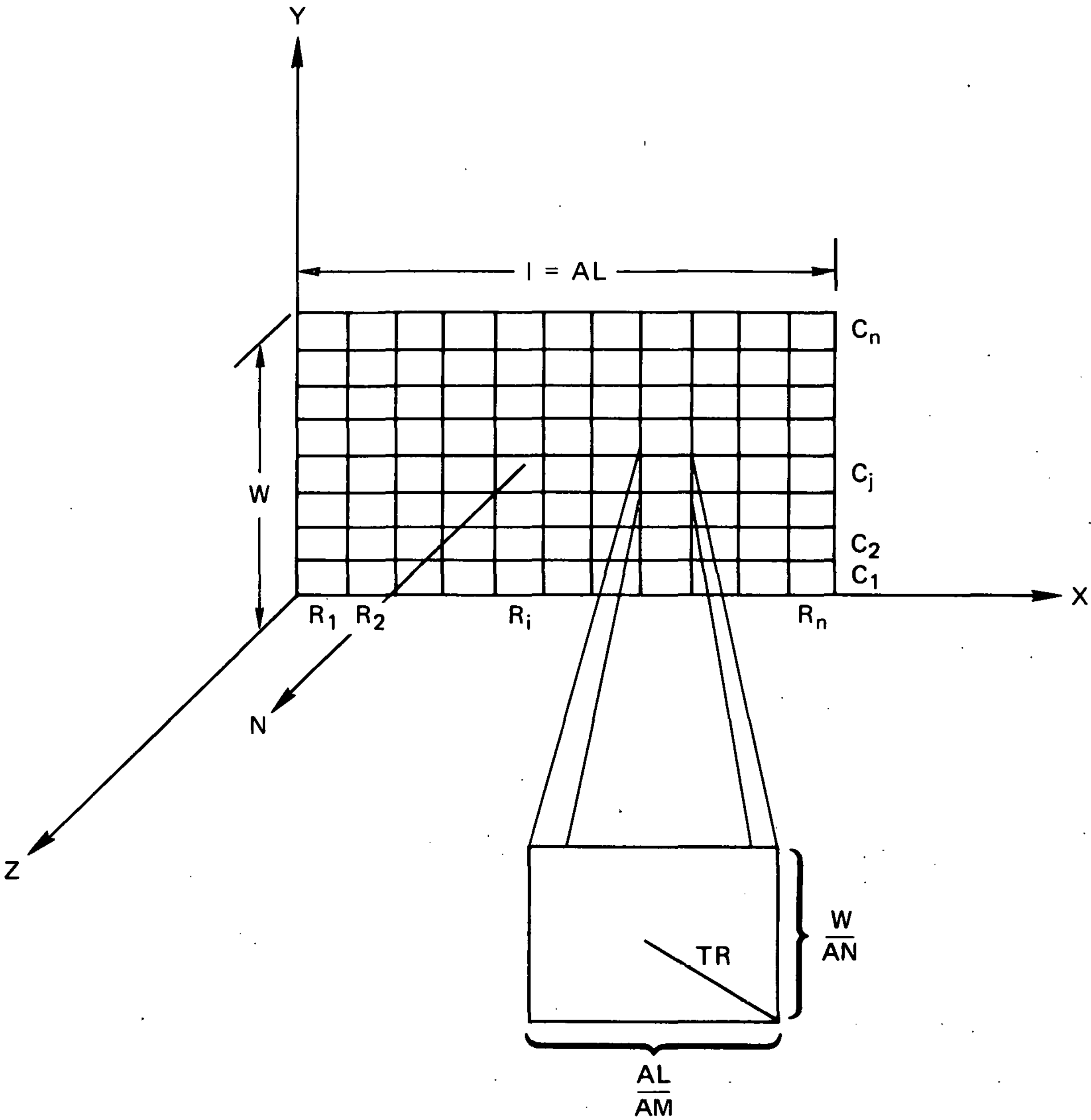
$$TR^2 = \left(\frac{\pi \cdot Y_1}{AN}\right)^2 + \left(\frac{SMOLLA}{AM \cdot SIN\ (\mu_2)}\right)^2$$

$$A = \frac{4\pi \cdot SMOLLA \cdot Y_2}{AM \cdot AN \cdot SIN\ (\mu_2)}$$

Rows are numbered down the X axis from the origin.

Columns are numbered around the X axis starting from the X-Z plane in the direction of ϕ.

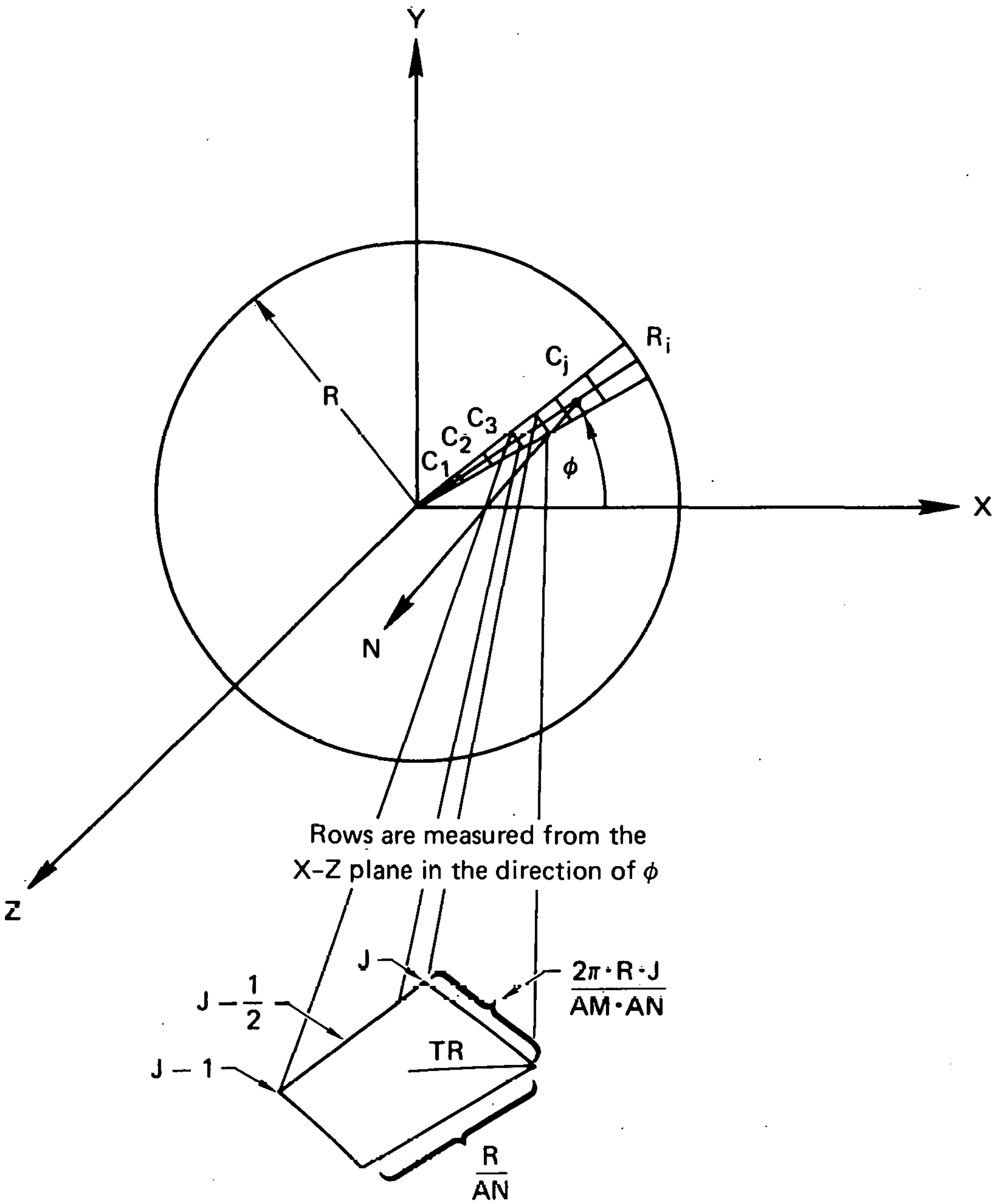
Figure A-6. Geometry of the Ellipsoid Configuration



$$TR^2 = \frac{1}{4}\left[\left(\frac{AL}{AM}\right)^2 + \left(\frac{W}{AN}\right)^2\right]$$

$$A = \frac{AL \cdot W}{AM \cdot AN}$$

Figure A-7. Geometry of the Flat Plate Configuration



$$TR^2 = \left(\frac{\pi \cdot R \cdot J}{AM \cdot AN}\right)^2 + \left(\frac{R}{2AN}\right)^2$$

$$A = \frac{2\pi \cdot R^2 \left(J - \frac{1}{2}\right)}{AN^2 \cdot AM}$$

Figure A-8. Geometry of the Disk Configuration

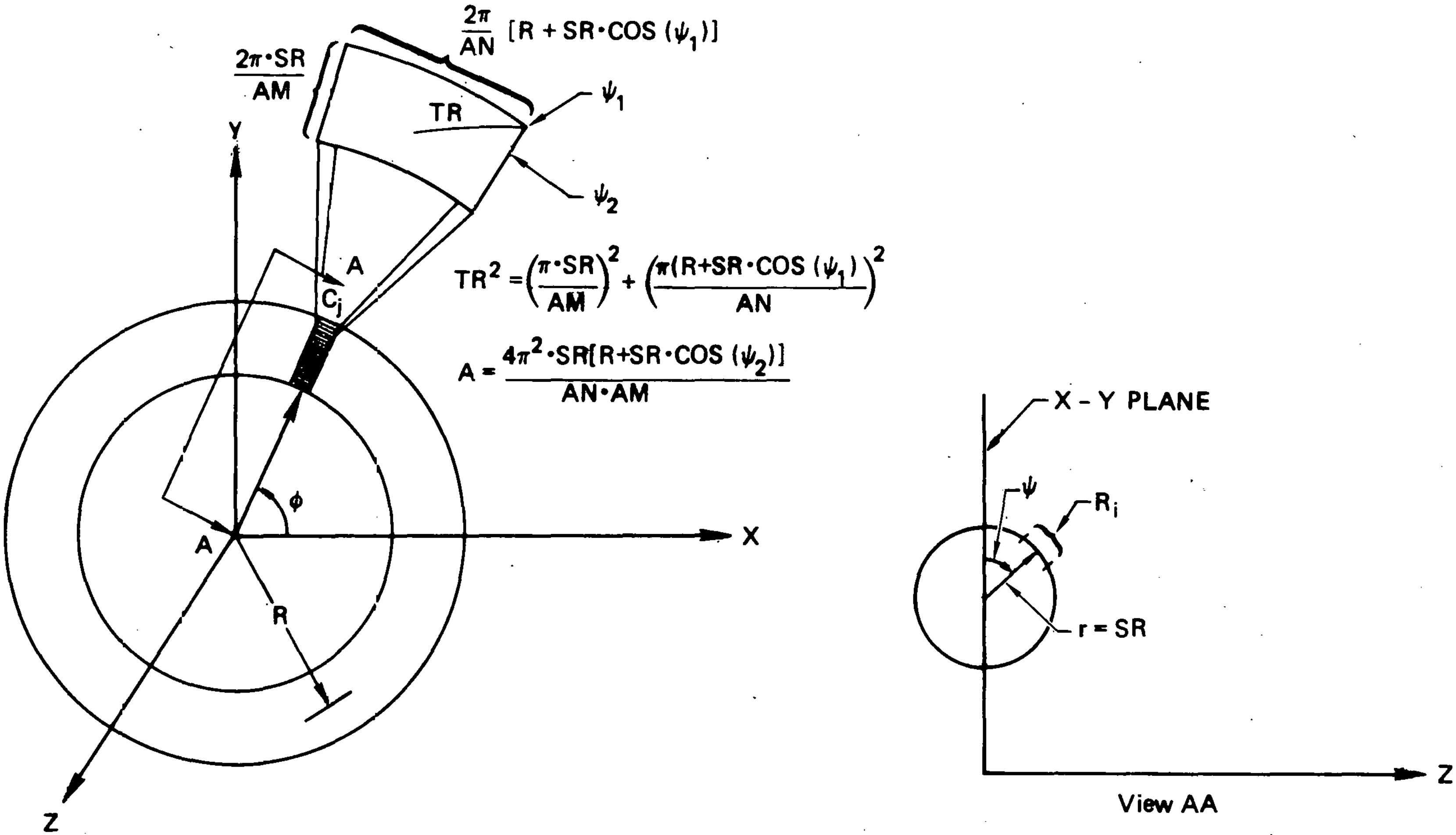


Figure A-9. Geometry of the Toroid Configuration at the X-Z plane and increasing counterclockwise (in the direction of ϕ in the figure). Rows are taken as increments of arc on the surface of the columns and are numbered from the X-Y plane in the direction of increasing ψ. The second specification card for the toroid contains two numbers: r = SR, the minor radius of the toroid, and R, the major radius of the toroid.

A.3.8 Polynomial-of-Revolution Configuration. This configuration is shown in Figure A-10. Columns run around the polynomial of revolution, and numbering starts at the Y-Z plane and increases along the positive X-axis. Rows run lengthwise and are numbered from the X-Y plane in the direction of ϕ in Figure A-10. The second specification card for this configuration contains seven numbers: l, the "x" limit of the polynomial, L = AL, and A_o = AO through A_5 = A5 the coefficients of the powers of "x" of a polynomial of the form $Y = \sum_{i=o} A_i x^i$.

A.4 MATRIX TRANSFORMATION AND INCREMENTATION

A.4.1 Transformation and Translation. As described in Subsection A.3, each section is defined originally by direction cosines, spatial position, and test radius in its own configuration reference system. However, for computation it is necessary to have all section information in an arbitrary but common base reference system. To move section information to this base system, ortho-normal transformation matrices are used. These are arrays of numbers of dimension 3 × 3, composed of the direction cosines of each of the configuration axes (X_c, Y_c, Z_c) in the base system. To illustrate the transformation matrix, a "rotation box" is shown below:

	X_c	Y_c	Z_c	$\odot_c$
X_b	m_{11}	m_{12}	m_{13}	x_{co}
Y_b	m_{21}	m_{22}	m_{23}	y_{co}
Z_b	m_{31}	m_{32}	m_{33}	z_{co}
$\odot_b$	x_{bo}	y_{bo}	z_{bo}	

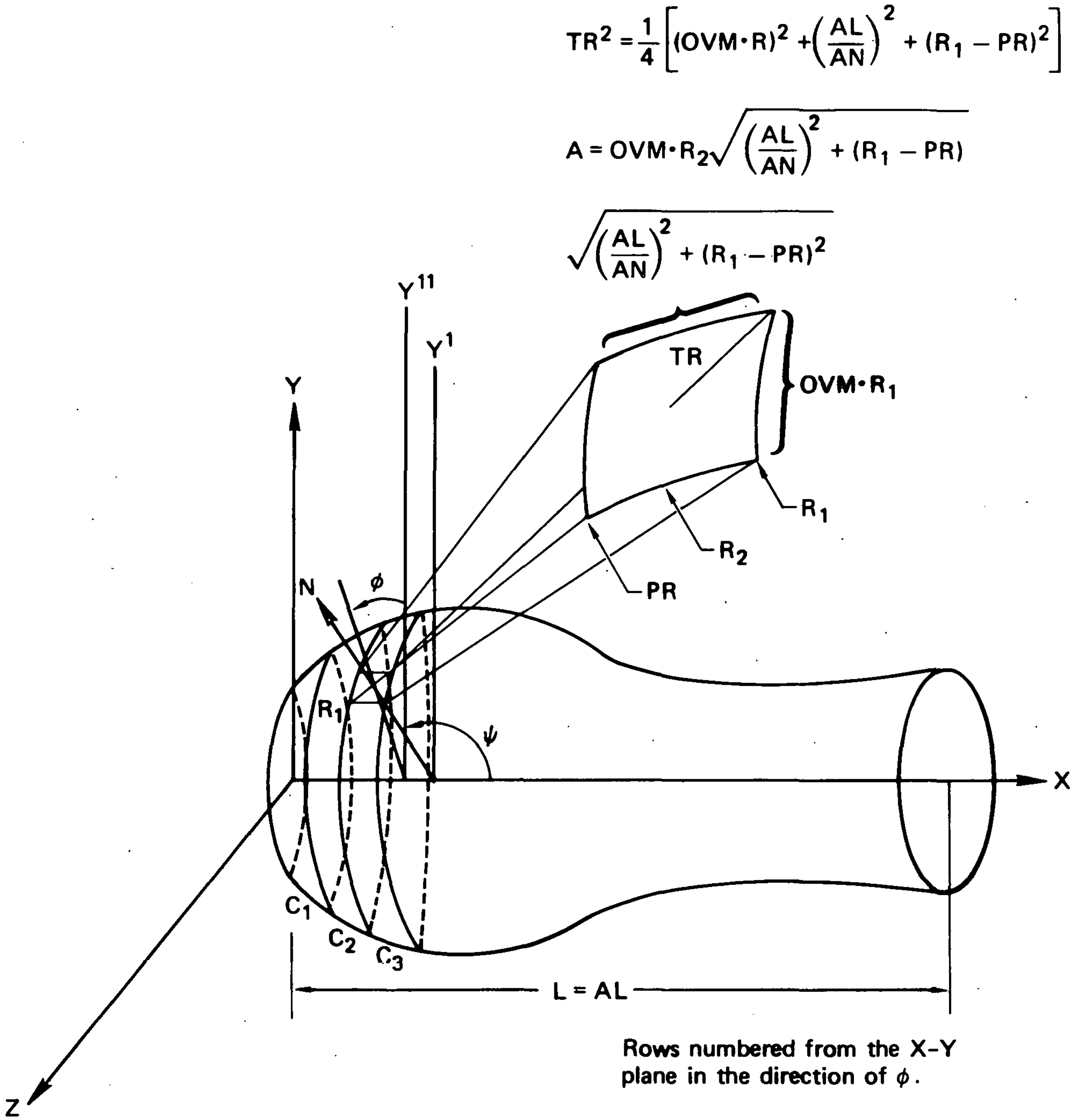


Figure A-10. Geometry of the Polynomial of Revolution Configuration

The nine numbers inside the double lines of the box are the elements of the matrix, M. The two subscripts denote row and column, in that order. Thus (m_{12}) is the element in row 1, column 2 of the matrix. The numbers in column 1 are the direction cosines of the configuration X-axis in the base system, the numbers in column 2 are the direction cosines of the configuration Y-axis in the base system, and those in column 3 are for the Z-axis. The rows, in turn, are the direction cosines of the base axes in the configuration system. Since the numbers are direction cosines, each row or column is of unit length. Since for Cartesian systems the axes are at right angles to each other, the inner product (dot product) of one row and any other row is zero; the same is true for the dot product of columns. Since the systems with which we deal are right-handed ("X" crosses with "Y" to form "Z", "Y" with "Z" to form "X", etc.), the elements of "Z" may be computed from the elements of "X" and "Y" by the determinants

$$m_{31} = \begin{vmatrix} m_{12} & m_{13} \\ m_{22} & m_{23} \end{vmatrix}, \quad m_{32} = -\begin{vmatrix} m_{11} & m_{13} \\ m_{31} & m_{33} \end{vmatrix}, \text{ and } m_{33} = \begin{vmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{vmatrix}.$$

In a like manner, the elements of "X" may be determined from "Y" and "Z", and so on.

The six other numbers (outside the double lines) in the box are the vector translation of the origins from one system to the other. The column under $\odot_c$ is the origin of the configuration system in the base system: the row opposite $\odot_b$ is the base origin in the configuration system. To find the location of a point expressed in the configuration system by x_c, y_c, and z_c in the base system, one computes:

$$x_b = m_{11}\, x_c + m_{12}\, y_c + m_{13}\, z_c + x_{co}$$

$$y_b = m_{21}\, x_c + m_{22}\, y_c + m_{23}\, z_c + y_{co}$$

and likewise for z_b.

This operation is expressed in matrix notation as follows:

$$\begin{pmatrix} x_b \\ y_b \\ z_b \end{pmatrix} = M \begin{pmatrix} x_c \\ y_c \\ z_c \end{pmatrix} + \begin{pmatrix} x_{co} \\ y_{co} \\ z_{co} \end{pmatrix}$$

The inverse transformation goes:

$$\begin{pmatrix} x_c \\ y_c \\ z_c \end{pmatrix} = M^T \begin{pmatrix} x_b \\ y_b \\ z_b \end{pmatrix} + \begin{pmatrix} x_{b1} \\ y_{b2} \\ z_{b3} \end{pmatrix}$$

For ortho-normal matrices the transpose is the inverse matrix.

As a means of relating the various configurations to a base system, we have chosen to think of each of the configurations as a vehicle and then relate it to an arbitrary base set of axes by the concepts of pitch, yaw, and roll. The X_c-axis is chosen as the vehicle centerline with the arrow pointing forward, and the Y_c-axis may be thought of as a left wing. In this case the Z_C-axis points up. Positive pitch is "nose-up", positive yaw is "nose-right", and positive roll is "left wing up". To position any configuration correctly in relation to a base system, the order: yaw, pitch, and roll must be observed. The angle between the X_c-axis and the base X-Y plane is the pitch angle; the angle between the projection of the X_c-axis on the base X-Y plane and the base X_b-axes is the yaw angle; roll is measured in a plane normal to the X_c-axis and is the angle between the trace of the normal plane on the X-Y plane and the Y_c-axis. When these definitions of yaw, pitch, and roll are used, the following general matrix can be constructed

$$M = \begin{pmatrix} \cos p \cos y & \begin{matrix}\cos r \sin y \\ -\sin p \cos y \sin r\end{matrix} & \begin{matrix}-\sin y \sin r \\ -\sin p \cos y \cos r\end{matrix} \\ -\cos p \sin y & \begin{matrix}\cos y \cos r \\ +\sin p \sin y \sin r\end{matrix} & \begin{matrix}-\cos y \sin r \\ +\sin p \sin y \cos r\end{matrix} \\ \sin p & \cos p \sin r & \cos p \cos r \end{pmatrix}$$

This matrix results from the multiplication of the three simple matrices

$$\left[\underset{\text{Yaw}}{\begin{pmatrix} \cos y & +\sin y & 0 \\ -\sin y & \cos p & 0 \\ 0 & 0 & 1 \end{pmatrix}} \underset{\text{Pitch}}{\begin{pmatrix} \cos p & 0 & -\sin p \\ 0 & 1 & 0 \\ +\sin p & 0 & +\cos p \end{pmatrix}}\right] \underset{\text{Roll}}{\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos r & -\sin r \\ 0 & \sin r & \cos r \end{pmatrix}}$$

Since the vector normals to each elemental area of each configuration are free vectors, only the matrix transformation need be applied to them; so

$$\begin{pmatrix} \lambda_{1b} \\ \lambda_{2b} \\ \lambda_{3b} \end{pmatrix} = M \begin{pmatrix} \lambda_{1c} \\ \lambda_{2c} \\ \lambda_{3c} \end{pmatrix}$$

However, for the point "centers" of the elemental areas, both matrix transformation and translation are required:

$$\begin{pmatrix} x_b \\ y_b \\ z_b \end{pmatrix} = M \begin{pmatrix} x_c \\ y_c \\ z_c \end{pmatrix} + \begin{pmatrix} x_{co} \\ y_{co} \\ z_{co} \end{pmatrix}$$

At the beginning of a program run, after the elemental information is computed in the various configuration systems, the transformation and translation matrices are developed. At this time all pertinent elemental information is moved from the various configuration systems to the common base system, and the data is stored back in the same cells from which they were taken. For this reason, in the driver flow chart, where this logic is shown, the designations for values in both the configuration system and the base system are identical.

A.4.2 <u>Matrix Transformation -- Incrementation</u>. Figure A-11 is a schematic diagram depicting the way in which the transformation matrix, TM, is incremented for each section of a body. Before each matrix increment is computed, the matrix transform, BMT, is computed, to transform the original

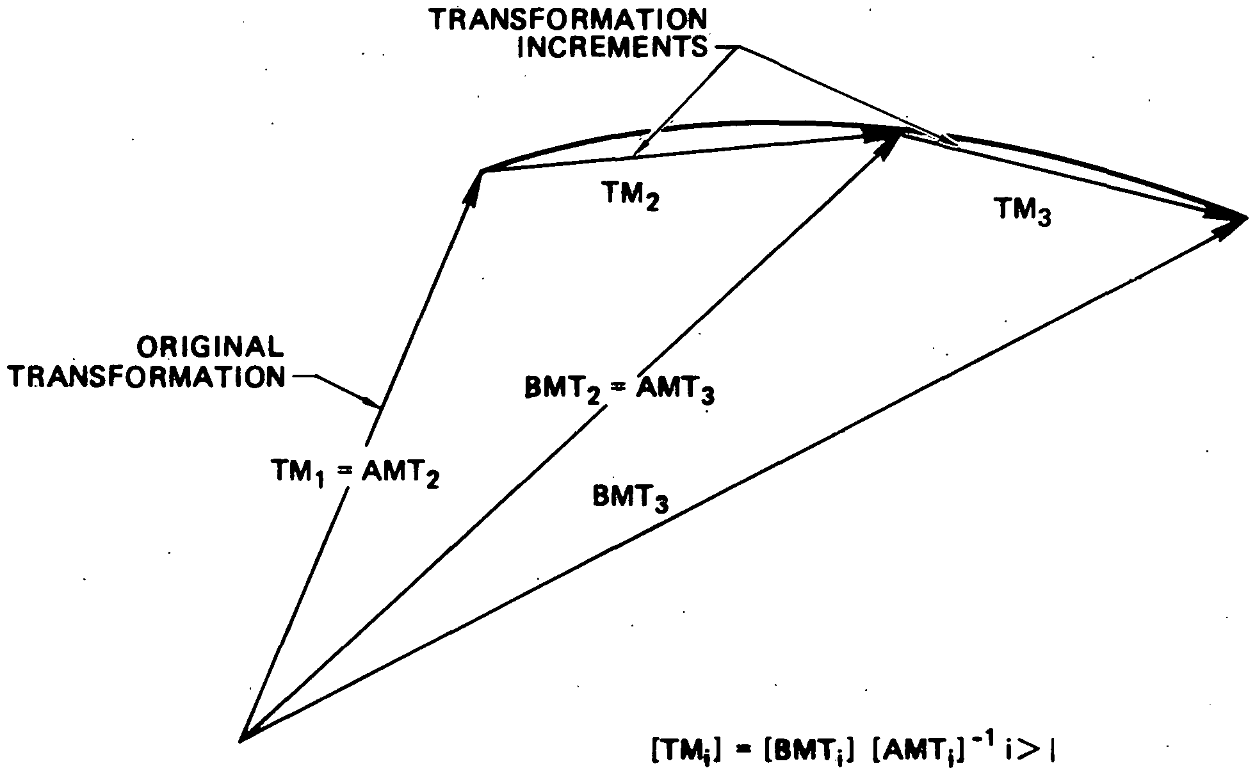


Figure A-11. Transformation Incrementation Schematic

configuration data to the base coordinate system but increased by an incremented amount each time. This matrix transform, BMT, is combined with the inverse of the previous such matrix transform, AMT. The result is the matrix transform, TM, from the previous orientation to the incremented orientation. This matrix transform will then increment the data properly for a particular section. The same mathematics is also used when, instead of incrementations for pitch, yaw, and roll, new values of pitch, yaw, and roll are given for the same configuration, thus avoiding the recomputation of the elemental information.

A.5 INTERSECTION OF LINE AND PLANE FOR SHADOWING CALCULATIONS. Shadowing is determined by the following logical procedures. The line of interest is defined by the spatial positions of emitting and receiving elements. The direction numbers of this line are obtained by differencing the vectors $\vec{C}_r$ and $\vec{C}_e$. These are the vectors from the origin to the receiver and from the origin to the emitter, respectively. The difference forms the vector $\vec{er}$, which establishes the direction of the line. The vector $\vec{C}_e$ establishes the spatial position of the line, since its end point (the center of the emitting element) is on the line. The equation of the line may now be written as:

$$\frac{x - \vec{C}_{e(1)}}{\vec{er}_{(1)}} = \frac{y - \vec{C}_{e(2)}}{\vec{er}_{(2)}} = \frac{z - \vec{C}_{e(3)}}{\vec{er}_{(3)}}$$

The plane of interest is determined by the shadowing element under consideration. It may be written as,

$$\vec{\lambda}^{(MS)}_{(is,js)} \cdot \overrightarrow{(x,y,z)} = D,$$

the normal form of the equation, where

$$D = \vec{\lambda}^{(MS)}_{(is,js)} \cdot \vec{C}_{SH},$$

the normal distance from the element to the origin of the base system. Simultaneous solution of the equations for line and plane produces the expressions for XP, YP, and ZP. The point of intersection is now compared with the test radius (T_r) to find whether it is within or without this circle. Tests are then performed to ascertain if the point of intersection lies spatially between the emitting and receiving elements. If these conditions are met, shadowing occurs and the receiver elements are incremented without the addition of a ΔSFX to the sum; if not, shadowing elements are incremented until all have been examined. In the event none shadows, ΔSFX is added to the sum (SFX).

The accuracies of shadowing calculations are again determined by the smallness criterion, with accuracy directly proportional to the number of shadower elemental areas. As can be seen in the diagrams of the configurations, the test radius is the distance from the center of the configuration to the farthest corner of a surface element. Hence, the area of influence of a shadower element is larger than the area of the surface element which it represents. This prevents holes from existing in a shadower. It also creates an edge effect for the shadower. For example, the outer edge of a shadower disk will really be a series of small areas shading an area beyond the edge of the disk.

This boundary inaccuracy is lessened for the closed, three-dimensional surfaces discussed, since at the boundary of a closed solid the view of a surface element is foreshortened. It is suggested that the user proceed with caution in shadowing calculations, choosing fairly square shadowing elements and large elemental areas at first, until experience determines an optimum size for balancing computer costs with run accuracy.

A.6 <u>SWITCH — CONFIGURATION NORMAL VECTOR REVERSAL</u>. Because the program user may at times require configuration factors for the reverse side of the surfaces shown (in Figures A-3 through A-10), a switch (SWITCH) is used in connection with the matrix transform logic. Where SWITCH is designated on the appropriate transformation input card, as (-1.0), the sense of the normal vector as shown in Figures A-3 through A-10 is reversed. When the SWITCH position is left blank, SWITCH is automatically set to +1.0 and the program treats the vector N as it is shown in the figures.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

APPENDIX B

LIST OF PROGRAM SYMBOLS

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

LIST OF SYMBOLS USED IN PROGRAM CNVUFAC

A. GENERAL TERMS

CONFIGURATION-THE PARTICULAR SHAPE PICTURED ON THE CONFIGURATION DRAWINGS.
SECTION-THE GENERALIZED TERM FOR CONFIGURATIONS. A BODY MAY BE COMPOSED OF MORE SECTIONS THAN CONFIGURATIONS, SINCE TWO OR MORE OF THE CONFIGURATIONS MAY BE THE SAME TYPE.
BODY -THE BODY IS COMPOSED OF SECTIONS.
EMITTER-A SECTION ON THE BODY THAT IS RADIATING A NET AMOUNT OF ENERGY TO THE RECEIVER.
RECEIVER-A SECTION ON THE BODY THAT IS RECEIVING A NET AMOUNT OF ENERGY FROM THE EMITTER.
SHADOWER-A SECTION OF A BODY THAT MAY STOP PART OR ALL OF THE FLOW OF RADIANT ENERGY BETWEEN EMITTERS AND RECEIVERS. A SHADOWER MAY BE AN EMITTER OR A RECEIVER OR ONLY A SHADOWER.
FLAT PLATE ELEMENT OR ELEMENT-A PLANE AREA WHOSE AREA EQUALS THE AREA OF ONE OF THE LITTLE ELEMENTAL DIVISIONS PICTURED ON THE CONFIGURATION DRAWINGS AND WHOSE NORMAL IS THE SAME AS THE NORMAL TO SAID DIVISION AT ITS CENTER.
NODE -FINITE DIFFERENCE SURFACE AREA (IN TRUMP THERMAL ANALYZER ZONING)

IN SECTION 1 OR 2. A NODE CAN BE COMPOSED OF 1 OR MORE FLAT PLATE ELEMENTS. AUTOMATIC NODE INCREMENTING IN SECTIONS 1 AND 2 IS PROVIDED FOR.

TEST RADIUS-THE APPROXIMATE DISTANCE FROM THE CENTER OF THE FURTHEST CORNER OF ONE OF THE LITTLE ELEMENTAL DIVISIONS PICTURED ON THE CONFIGURATION DRAWINGS.

B. PROGRAM QUANTITIES

A -THE AREA OF A FLAT PLATE ELEMENT IN SQUARE FEET.

A0,A1,A2,A3,A4,A5-CONSTANTS USED TO DESCRIBE THE POLYNOMIAL OF REVOLUTION CONFIGURATION.

AL -THE LENGTH IN FEET ALONG THE CONFIGURATION COORDINATE SYSTEM X AXIS OF THE CYLINDER, CONE, FLAT PLATE, OR POLYNOMIAL OF REVOLUTION CONFIGURATION.

ALAM1 -THE X DIRECTION COSINE OF A NORMAL TO A FLAT PLATE ELEMENT WITH RESPECT TO EITHER THE CONFIGURATION COORDINATE SYSTEM OR THE BASE COORDINATE SYSTEM.

ALAM2 -THE Y DIRECTION COSINE OF A NORMAL TO A FLAT PLATE ELEMENT WITH RESPECT TO EITHER THE CONFIGURATION COORDINATE SYSTEM OR THE BASE COORDINATE SYSTEM.

ALAM3 -THE Z DIRECTION COSINE OF A NORMAL TO A FLAT PLATE ELEMENT WITH RESPECT TO EITHER THE CONFIGURATION CORDINATE SYSTEM OF THE BASE COORDINATE SYSTEM.

AM -THE NUMBER OF FLAT PLATE ELEMENTS AROUND A CYLINDER, CONE, SPHERE, DISK, OR POLYNOMIAL OF REVOLUTION CONFIGURATION. THE NUMBER OF DIVISIONS AROUND A SECTION OF THE TOROID CONFIGURATION. THE NUMBER OF X AXIS DIVISIONS ALONG THE ELLIPSOID CONFIGURATION. THE NUMBER OF DIVISIONS LENGTHWISE ON THE FLAT PLATE CONFIGURATION.

AN -THE NUMBER OF DIVISIONS LENGTHWISE ON A CYLINDER, CONE, OR POLYNOMIAL OF REVOLUTION CONFIGURATION. THE NUMBER OF DIVISIONS WIDTHWISE ON THE FLAT PLATE CONFIGURATION. THE NUMBER OF DIVISIONS RADIALLY ON THE DISK CONFIGURATION. THE NUMBER OF DIVISIONS AROUND THE ELLIPSOID OR TOROID CONFIGURATION.

AREA -THE AREA OF A FLAT PLATE IN SQUARE FEET.

AREAE -THE AREA OF THE EMITTER IN SQUARE FEET.

AREAET-NSYM*AREAE TOTAL EMITTER AREA WHEN SYMMETRY OPTION IS USED.

AREAR -THE AREA OF THE RECEIVER IN SQUARE FEET.

B -SEMI-AXIS OF THE ELLIPSOID CONFIGURATION IN FEET WHICH IS NOT ALONG THE CONFIGURATION X AXIS.

BMT -THE TRANSFORM MATRIX USED TO TRANSFORM THE GEOMETRY IN A CONFIGURATION COORDINATE SYSTEM TO THE BASE COORDINATE SYSTEM.

COM1,COM2,COM3,COM4-COMMON CELLS.

COSCON-COSINE OF THE SEMI-APEX ANGLE OF THE CONE CONFIGURATION.

COSE -COSINE OF THE ANGLE BETWEEN THE NORMAL TO A FLAT PLATE ELEMENT ON THE EMITTER AND THE VECTOR FROM THE CENTER OF THAT ELEMENT TO THE CENTER OF AN ELEMENT ON THE RECEIVER.

COSP -COS(PHI) OR COS(PIT).

COSPSI-COS(PSI) FOR TOROID AND POLYNOMIAL OF REVOLUTION CONFIGURATIONS.

COSR -THE COSINE OF THE ANGLE BETWEEN THE NORMAL TO A RECEIVER ELEMENT AND THE LINE SEGMENT JOINING THE CENTERS OF THAT RECEIVER ELEMENT AND AN EMITTER ELEMENT. ALSO COS(ROL).

COSU -COS(U) FOR THE ELLIPSOID.

COSY -COS(YAW)

COY -COMMON CELL.

DPI -THE INCREMENT TO PITCH IN DEGREES IN THE BASE COORDINATE SYSTEM.

DRL -THE INCREMENT TO ROLL IN DEGREES IN THE BASE COORDINATE SYSTEM.

DSFX -THE INCREMENT TO SFX. THIS CELL IS ACTUALLY USED TO STORE THE LOW ORDER VALUE OF SFX.

DXO -THE INCREMENT TO THE BASE X COORDINATE OF ALL FLAT PLATE ELEMENTS

```
       IN A CONFIGURATION.
DYO   -THE INCREMENT TO THE BASE Y COORDINATE OF ALL FLAT PLATE ELEMENTS
       IN A CONFIGURATION.
DYA   -THE INCREMENT TO YAW IN DEGREES IN THE BASE COORDINATE SYSTEM.
DZO   -THE INCREMENT TO THE BASE Z COORDINATE OF ALL FLAT PLATE ELEMENTS
       IN A CONFIGURATION.
FI    -I.
FJ    -J.
I     -DESIGNATES THE ROW.
IC1   -COLUMN NUMBER FROM SECTION 1 INCREMENTED IN NODE DO LOOP.
IC2   -COLUMN NUMBER FROM SECTION 2 INCREMENTED IN NODE DO LOOP.
ICB   -THE NUMBER OF THE FIRST COLUMN TO BE CONSIDERED ON A CONFIGURATION.
ICBE  -ICB FOR THE EMITTER.
ICBR  -ICB FOR THE RECEIVER.
ICBS  -ICB FOR THE SHADOWER.
ICBSAV-SAVED VALUE OF IICB IN NODE INCREMENTING.
ICD   -AN INDICATOR DESIGNATING THE CONFIGURATION TO BE CONSIDERED.
       1-CYLINDER, 2-CONE, 3-SPHERE, 4-ELLIPSOID, 5-FLAT PLATE, 6-DISK,
       7-TOROID, 8-POLYNOMIAL OF REVOLUTION.
ICE   -THE NUMBER OF THE LAST COLUMN TO BE CONSIDERED ON A CONFIGURATION.
ICEE  -ICE FOR THE EMITTER.
ICER  -ICE FOR THE RECEIVER.
ICES  -ICE FOR THE SHADOWER.
ICESAV-SAVED VALUE OF IICE IN NODE INCREMENTING.
IDC   -CONFIGURATION DATA INDICATOR.  0-ORIGINAL CONFIGURATION DATA,
       1-MODIFIED CONFIGURATION DATA.
IFLAG -A FLAG TO DETERMINE IF A ANOTHER PROBLEM FOLLOWS.  0-NO PROBLEM
       FOLLOWS, 1-ANOTHER PROBLEM FOLLOWS.
IE    -DESIGNATES THE ROW ON THE EMITTER.
IICB  -THE NUMBER OF THE FIRST COLUMN TO BE CONSIDERED ON A CONFIGURATION.
IICB1 -BEGINNING COLUMN NUMBER FROM SECTION 1 IN NODE DO LOOP.
IICB2 -BEGINNING COLUMN NUMBER FROM SECTION 2 IN NODE DO LOOP.
IICD  -THE NUMBER OF COLUMNS TO BE INCREMENTED IN NODE DO LOOP.
IICD1 -IICD FOR SECTION 1.
IICD2 -IICD FOR SECTION 2.
IICE  -THE NUMBER OF THE LAST COMUMN TO BE CONSIDERED ON A CONFIGURATION.
IICE1 -ENDING COLUMN NUMBER FROM SECTION 1 IN NODE DO LOOP.
IICE2 -ENDING COLUMN NUMBER FROM SECTION 2 IN NODE DO LOOP.
IIRB  -THE NUMBER OF THE FIRST ROW TO BE CONSIDERED ON A CONFIGURATION.
IIRB1 -BEGINNING ROW NUMBER FROM SECTION 1 IN NODE DO LOOP.
IIRB2 -BEGINNING ROW NUMBER FROM SECTION 2 IN NODE DO LOOP.        0
IIRD  -THE NUMBER OF ROWS TO BE INCREMENTED IN NODE DO LOOP.
IIRD1 -IIRD FOR SECTION 1.
IIRD2 -IIRD FOR SECTION 2.
IIRE  -THE NUMBER OF THE LAST ROW TO BE CONSIDERED ON A CONFIGURATION.
IIRE1 -ENDING ROW NUMBER FROM SECTION 1 IN NODE DO LOOP.
IIRE2 -ENDING ROW NUMBER FROM SECTION 2 IN NODE DO LOOP.
INDEX -NM(IS-1)+N*(I-IRB)+J-ICB+1  INDEX IS THE VALUE OF THE INDEX REG-
       ISTER USED TO DESIGNATE THE CELL LOCATION OF CERTAIN 3-DIMENSIONED
       QUANTITIES.  IT REPLACES THE 3 INDEXES I, J, AND IS.
INDEXE-INDEX FOR THE EMITTER.
INDEXR-INDEX FOR THE RECEIVER.
INDEXS-INDEX FOR THE SHADOWER.
INOD1 -NODE NUMBER FOR SECTION 1.
INOD2 -NODE NUMBER FOR SECTION 2.
IR    -DESIGNATES THE ROW ON THE RECEIVER.
IR1   -ROW NUMBER FROM SECTION 1 INCREMENTED IN NODE DO LOOP.
IR2   -ROW NUMBER FROM SECTION 2 INCREMENTED IN NODE DO LOOP.
IRB   -THE NUMBER OF THE FIRST ROW TO BE CONSIDERED ON A CONFIGURATION.
IRBE  -IRB FOR THE EMITTER.
```

IRBR -IRB FOR THE RECEIVER.

IRBS -IRB FOR THE SHADOWER.

IRBSAV-SAVED VALUE OF IIRB IN NODE INCREMENTING.

IRE -THE NUMBER OF THE LAST ROW TO BE CONSIDERED ON A CONFIGURATION.

IREE -IRE FOR THE EMITTER.

IRER -IRE FOR THE RECEIVER.

IRES -IRE FOR THE SHADOWER.

IRESAV-SAVED VALUE OF IIRE IN NODE INCREMENTING.

IS -DESIGNATES THE ROW ON THE SHADOWER. DESIGNATES THE SECTION NUMBER.

ISS -DESIGNATES THE SECTION NUMBER OF A SECTION (USED TO CHECK CONSISTANCY BETWEEN GROUPS OF DATA CARDS AND TO DETECT TWO CARDS FOR THE SAME SECTION.

J -DESIGNATES THE COLUMN.

JE -DESIGNATES THE COLUMN ON THE EMITTER.

JR -DESIGNATES THE COLUMN ON THE RECEIVER.

JS -DESIGNATES THE COLUMN ON THE SHADOWER.

KEM -EMITTER INDICATOR. 0-SECTION IS NOT AN EMITTER, 1-SECTION IS AN EMITTER.

KPNT -PRINT CONTROL FOR SECTION INFORMATION PRINTOUT.

KRE -RECEIVER INDICATOR. 0-SECTION IS NOT A RECEIVER, 1-SECTION IS A RECEIVER.

KSH -SHADOWER INDICATOR. 0-SECTION IS NOT A SHADOWER, 1-SECTION IS A SHADOWER.

KSHF -THE TOTAL NUMBER OF SHADOWER SECTIONS.

L -THE NUMBER OF SECTIONS.

M -THE NUMBER OF ROWS CONSIDERED ON A SECTION.

ME -DESIGNATES THE EMITTER SECTION NUMBER.

MR -DESIGNATES THE RECEIVER SECTION NUMBER.

MS -DESIGNATES THE SHADOWER SECTION NUMBER.

N -THE NUMBER OF COLUMNS CONSIDERED ON A SECTION.

NM -THE NUMBER OF FLAT PLATES CONSIDERED ON ALL SECTIONS WHOSE SECTION NUMBER IS LOWER THAN OR EQUAL TO THE PRESENTLY CONSIDERED SECTION.

NMZERO-NM(0)=0

NMI -THE NUMBER OF MATRIX INCREMENTATIONS.

NMIX -COUNTS THE NUMBER OF MATRIX INCREMENTATIONS.

NODE -NODE NUMBER FOR SECTION 1 OR 2.

NODE1 -STARTING NODE NUMBER IN SECTION 1.

NODE2 -STARTING NODE NUMBER IN SECTION 2.

NODEE -EMITTER NODE NUMBER.

NODER -RECEIVER NODE NUMBER.

NSYM -THE NUMBER OF SYMMETRIC VIEW FACTORS FROM ONE SEGMENT OF THE EMITTER TO THE ENTIRE RECEIVER (WHERE A SEGMENT MAY BE ONE ROW OR COLUMN).

OVM -2.*PI/AM THE ANGULAR WIDTH OF ROWS FOR ALL CONFIGURATIONS EXCEPT THE SPHERE. THE ANGULAR WIDTH OF COLUMNS OF A SPHERE.

PHI -DEFINED ON THE CONFIGURATION GEOMETRY DRAWINGS.

PI -3.14159265

PIT -PITCH ANGLE IN DEGREES OF A CONFIGURATION X AXIS IN THE BASE COORDINATE SYSTEM. PIT IS THE ANGLE BETWEEN THE CONFIGURATION COORDINATE SYSTEM X AXIS AND THE X-Y PLANE OF THE BASE COORDINATE SYSTEM.

PIX -PITCH IN RADIANS.

PR -PRECEEDING VALUE OF R IN THE POLYNOMIAL OF REVOLUTION CONFIGURATION.

PSI -DEFINED ON THE CONFIGURATION GEOMETRY DRAWINGS.

R -THE RADIUS OF THE POLYNOMIAL OF REVOLUTION ABOUT THE X AXIS FOR A PARTICULAR VALUE OF X. THE RADIUS OF THE TOROID MEASURED FROM THE Z AXIS TO THE CENTER OF A CROSS SECTION WHOSE PLANE CONTAINS THE Z-AXIS.

RAD -180./PI

RLX -ROLL IN RADIANS.

ROL -ROLL ANGLE. THE ANGLE, MEASURED IN A PLANE NORMAL TO THE CONFIGURATION X AXIS, FROM THE BASE COORDINATE SYSTEM X-Y PLANE TO THE CONFIGURATION COORDINATE SYSTEM +Y AXIS. ROLL IS MEASURED POSATIVELY AROUND THE CONFIGURATION X AXIS IN A CLOCKWISE DIRECTION AS VIEWED FROM THE CONFIGURATION COORDINATE SYSTEM ORIGIN AND LOOKING TOWARD THE +X CONFIGURATION AXIS.
S -DISTANCE FROM EMITTING TO RECEIVING ELEMENT.
SFER -SHAPE OR CONFIGURATION FACTOR FOR EMITTER OF RECEIVER.
SFRE -SHAPE OR CONFIGURATION FACTOR FOR RECEIVER OF EMITTER.
SFX -PART OF SFER AND SFRE.
SIDE -THE LENGTH OF THE SIDE OF THE CONE CONFIGURATION.
SINCON-THE SINE OF THE HALF-ANGLE OF THE CONE CONFIGURATION.
SINP -SIN(PHI) OR SIN(PIT).
SINPSI-SIN(PSI)
SINR -SIN(ROL)
SINU -SIN(U) IN THE ELLIPSOID CONFIGURATION.
SINY -SIN(YAW).
SIY -COMMON CELL.
SMOLLA-THE SEMI-AXIS OF THE ELLIPSOID CONFIGURATION IN FEET ALONG THE CONFIGURATION X AXIS.
SR -THE RADIUS OF A CROSS SECTION OF THE TOROID WHOSE PLANE CONTAINS THE Z AXIS.
SS -AREAET*SFER=AREAR*SFRE RADIATION INTERCHANGE AREA.
SUMA -THE AREA IN SQUARE FEET OF THE PART OF A CONFIGURATION THAT A PARTICULAR RUN IS CONCERNED WITH.
SWITCH-AN INDICATOR TELLING WHICH SIDE OF A CONFIGURATION WE ARE CONSIDERING. THE NORMAL SIDE IS THE OUTSIDE, EXCEPT IN THE CASE OF THE FLAT PLATE AND DISK CONFIGURATIONS WHERE THE NORMAL SIDE IS THE SIDE OF THE +Z AXIS. SWITCH NEED NOT BE SET FOR THOSE SECTIONS WHICH ARE ONLY SHADOWERS. +1. FOR THE NORMAL SIDE, -1. FOR THE REVERSE SIDE.
TANPSI-TAN(PSI).
TESTR2-TEST RADIUS SQUARED OF A FLAT PLATE ELEMENT ON A SHADOWER.
TITLE -PROBLEM TITLE CARD.
TM -THE TRANSFORM MATRIX USED TO TRANSFORM THE GEOMETRY IN A CONFIGURATION COORDINATE SYSTEM TO THE BASE COORDINATE SYSTEM OR TO ROTATE THE CONFIGURATION GEOMETRY IN THE BASE COORDINATE SYSTEM.
TMS -THE ARRAY OF STORED PAST VALUES OF ROTATION MATRICES TRANSFORMING FROM EACH CONFIGURATION COORDINATE SYSTEM TO THE BASE COORDINATE SYSTEM.
TR2 -TEST RADIUS SQUARED OF A FLAT PLATE ELEMENT ON A SHADOWER.
VALAM -THE UNIT VECTOR NORMAL TO A FLAT PLATE ELEMENT. ITS DIRECTION IS DETERMINED BY SWITCH.
VC -THE VECTOR POINTING FROM THE CONFIGURATION COORDINATE SYSTEM ORIGIN TO THE CENTER OF A FLAT PLATE ELEMENT.
VCOM -COMMON VECTOR.
VER -THE VECTOR POINTING FROM THE CENTER OF AN EMITTER FLAT PLATE ELEMENT TO THE CENTER OF A RECEIVER FLAT PLATE ELEMENT.
VLEI -THE UNIT VECTOR NORMAL TO AN EMITTER ELEMENT. ITS DIRECTION IS DETERMINED BY SWITCH.0
VLRI -THE UNIT VECTOR NORMAL TO A RECEIVER ELEMENT. ITS DIRECTION IS DETERMINED BY SWITCH.
W -WIDTH OF THE FLAT PLATE.
X -THE X COORDINATE.
XO -THE X COORDINATE OF A CONFIGURATION COORDINATE SYSTEM ORIGIN IN THE BASE COORDINATE SYSTEM.
XC -THE X COORDINATE OF THE CENTER OF A FLAT PLATE ELEMENT IN EITHER THE CONFIGURATION COORDINATE SYSTEM OR THE BASE COORDINATE SYSTEM MEASURED IN FEET.
XP -THE X COORDINATE OF THE POINT COMMON TO VER AND THE PLANE OF A

SHADOWER ELEMENT.

Y	-THE Y COORDINATE.
YO	-THE Y COORDINATE OF A CONFIGURATION COORDINATE SYSTEM ORIGIN IN THE BASE COORDINATE SYSTEM.
YAW	-YAW ANGLE IN DEGREES OF A CONFIGURATION X AXIS IN THE BASE COORDINATE SYSTEM. YAW IS THE ANGLE BETWEEN THE PROJECTION OF THE CONFIGURATION COORDINATE SYSTEM X AXIS ON THE BASE COORDINATE SYSTEM X-Y PLANE AND THE BASE COORDINATE SYSTEM X AXIS, MEASURING FROM THE BASE X AXIS TOWARD THE -Y BASE AXIS.
YAX	-YAW IN RADIANS.
YC	-THE Y COORDINATE OF THE CENTER OF A FLAT PLATE ELEMENT IN EITHER THE CONFIGURATION COORDINATE SYSTEM OR THE BASE COORDINATE SYSTEM MEASURED IN FEET.
YP	-THE Y COORDINATE OF THE POINT COMMON TO VER AND THE PLANE OF A SHADOWER ELEMENT.
ZO	-THE Z COORDINATE OF A CONFIGURATION COORDINATE SYSTEM ORIGIN IN THE BASE COORDINATE SYSTEM.
ZC	-THE Z COORDINATE OF THE CENTER OF A FLAT PLATE ELEMENT IN EITHER THE CONFIGURATION COORDINATE SYSTEM OR THE BASE COORDINATE SYSTEM MEASURED IN FEET.
ZP	-THE Z COORDINATE OF THE POINT COMMON TO VER AND THE PLANE OF A SHADOWER ELEMENT.

APPENDIX C

PROGRAM LISTING

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

```
      PROGRAM CNVUFAC(TAPE5,TAPE6,TAPE7)
C
C     GENERAL DYNAMICS PROGRAM OBTAINED FROM JON C. OGLEBAY, NASA LEWIS
C     RESEARCH CENTER, CLEVELAND, OHIO, FEBRUARY 1976.
C     ORIGINAL PROGRAM MODIFIED BY OGLEBAY FOR NAME LIST INPUT.
C
C     ORIGINAL REPORT:  R.S. DRUMMER AND W.T. BRECKENRIDGE, JR.,
C     ΔRADIATION CONFIGURATION FACTORS PROGRAMΔ, REPT. NO. ERR-AN-224,
C     SPACE SCIENCE LABORATORY, GENERAL DYNAMICS/ASTRONAUTICS,
C     FEBRUARY 1963.
C
C     MODIFIED FOR LLL CDC7600 PUTT COMPILER BY R.L. WONG, MAY 1976.
C     MODIFICATIONS INCLUDE CHANGING OGLEBAY'S NAME LIST INPUT TO
C     FORMATED INPUT AND INCLUDING LOGIC FOR A NODE INCREMENTING
C     OPTION.
C
C     THE NAMES OF THE OUTPUT FILES ARE OBTAINED BY APPENDING THE
C     FIRST 3 CHARACTERS (OR ALL CHARACTERS IF 3 OR LESS) OF
C     THE INPUT FILE AS FOLLOWS:  IF INPUT FILE IS XXXIN,
C     THE OUTPUT FILE IS XXXOUT,
C     THE VIEW FACTOR PUNCH FILE IS XXXCARD (GENERATED WHEN NODE
C     INCREMENTING OPTION IS USED BUT NOT AUTOMATICALLY PUNCHED).
C     THE DEFAULT FOR XXX IS VUF.
C
C     ************************************************************
C
C     RADIATION CONFIGURATION FACTORS
C
C     NO MORE THAN 10 SECTIONS MAY BE USED.
C     THE TOTAL NUMBER OF ELEMENTAL AREAS OR FLAT PLATES ON ALL SECTIONS
C     MUST NOT EXCEED 2800.
C     AN INDEX CANNOT HAVE A VALUE GREATER THAN 32768.
C
C     ************************************************************
C
C     NMZERO MUST PRECEED NM IN COMMON.  IT IS ESSENTIALLY NM(0) IN THE
C     CALCULATION.
C     NOTE THAT A COMMON ZEROING DO LOOP HAS BEEN REMOVED.  IT IS NOT
C     REQUIRED SINCE THE CDC7600 ZEROS ALL ARRAYS.  IT MAY HAVE TO BE
C     INCLUDED AGAIN FOR OTHER COMPUTERS.
C
      COMMON A(2800),A0(10),A1(10),A2(10),A3(10),A4(10),A5(10),AL(10),AL
     1AM1(2800),ALAM2(2800),ALAM3(2800),AMT(3,3),B(10),BMT(3,3),DPI(10),
     2DRL(10),DXO(10),DYA(10),DYO(10),DZO(10),ICD(10),IICB(10),IICE(10),
     3IIRB(10),IIRE(10),ISS(10),ISS1(10),ISS2(10),KEM(10),KRE(10),KSH(10
     4),MA(10),NA(10),NMZERO,NM(10),PIT(10),R(10),ROL(10),SMOLLA(10),SR(
     510),SUMA(10),SWITCH(10),TM(3,3),TMS(3,3,10),TR2(2800),VALAM(3),VC(
     63),VCOM(3),VER(3),VES(3),VES1(3),VLE1(3),VLR1(3),VLS1(3),VRS(3),VR
     7S1(3),W(10),XC(2800),XO(10),YAW(10),YC(2800),YO(10),ZC(2800),ZO(10
     8),TITLE(8),FNAME(2),LG(2),IIRD(2),IICD(2),IRBSAV(10),IRESAV(10),
     9ICBSAV(10),ICESAV(10),NODE(2)
      DATA NZERO/0/,ZERO/0.0/
C
C     SET UP FILES.
C
C     READ INPUT FILE NAME FROM TELETYPE.
C
      ITY=59
      CALL GOB(1503B,IER,700B,KKK)
      IF(IER.EQ.0) GO TO 10
```

```
      WRITE (ITY,1801)
C
C     FNAMEI=INPUT FILE NAME.  THE FIRST 3 CHARACTERS (OR ALL
C     CHARACTERS IF 3 OR LESS) ARE APPENDED TO THE BEGINNING OF ALL
C     OUTPUT FILES.  THE DEFAULT FOR FNAMEI IS VUFIN.
C
10    READ(ITY,1800) FNAMEI
C
C     CHECK OF FNAMEI IS BLANK OR CONTAINS LESS THAN 3 CHARACTERS.
C
      IF(FNAMEI.EQ.1H ) FNAMEI=5HVUFIN
      IIS=0
      IBYTE=LBYT(FNAMEI,48,6)
      IF(IBYTE.NE.1R ) GO TO 12
      IIS=12
      GO TO 13
12    IBYTE=LBYT(FNAMEI,42,6)
      IF(IBYTE.NE.1R ) GO TO 13
      IIS=6
13    DO 15 L=1,3
      FNAME(L)=FNAMEI
15    CONTINUE
      CALL SBYT(FNAME(1),IIS,42,7ROUT     )
      CALL SBYT(FNAME(2),IIS,42,7RCARD    )
      WRITE (ITY,1802) FNAME
C
C     OPEN INPUT FILE.
C
      IEE=-2
      CALL OPENFN(FNAMEI,5,LGIN,IEE)
      IF(IEE.EQ.0) GO TO 16
      WRITE (ITY,1803) IEE,FNAMEI
      CALL EXIT
C
C     OPEN AND CREATE OUTPUT FILES.
C
16    DO 17 LL=1,2
      IEE=-5
      LG(1)=500008
      LG(2)=100008
      NT=LL+5
      CALL OPENFN(FNAME(LL),NT,LG(LL),IEE)
      IF(IEE.EQ.0) GO TO 17
      WRITE (ITY,1803) IEE,FNAME(LL)
      CALL EXIT
17    CONTINUE
C
      PI=3.14159265
      WRITE (6,1520)
      RAD=57.2957795
      NMZERO=0
C
C     INPUT
C
C     TITLE=HEADING CARD, BEGIN NEW PROBLEM.
22    READ (5,1820) TITLE
C
C     IFLAG=0 IF THIS IS LAST PROBLEM, =1 IF ANOTHER PROBLEM FOLLOWS.
C     L=NUMBER OF SECTIONS CONSIDERED (MAXIMUM=10).
C     NSYM=EMITTER AREA MULTIPLIER WHEN GEOMETRY PERMITS ASSUMPTION OF
```

```
C     SYMMETRIC EMITTER SEGMENT TO RECEIVER VIEW FACTORS.  ONLY ONE
C     SYMMETRIC EMITTER SEGMENT NEED BE INPUT SAVING COMPUTER TIME.  THE
C     TOTAL EMITTER TO RECIEVER VIEW FACTOR IS EQUAL TO THAT FROM THE
C     EMITTER SEGMENT TO THE RECEIVER.   THE TOTAL EMITTER AREA IS
C     OBTAINED BY MULTIPLYING BY NSYM AND THE RECEIVER TO EMITTER VIEW
C     FACTOR AND THE INTERCHANGE AREA ARE FOR THE TOTAL EMITTER.  IF
C     THERE IS NO SYMMETRY, NSYM=1.
C     NMI=NUMBER OF MATRIX INCREMENTATIONS IN MATRIX INCREMENTING
C     OPTION.  NMI=0 FOR NO MATRIX INCREMENTING OPTION.
C     NODE1=BEGINNING NODE NUMBER FOR SECTION 1 WHEN THE NODE
C     INCREMENTING OPTION IS USED.  THIS OPTION PERMITS AUTOMATIC
C     NODE INCREMENTING FOR SECTIONS 1 AND 2.  NODE1=0 FOR NO NODE
C     INCREMENTING OPTION.  THE FOLLOWING INPUT ARE FOR THE NODE
C     INCREMENTING OPTION AND ARE IGNORED WHEN THE OPTION IS NOT USED.
C     THIS OPTION AUTOMATICALLY GENERATES A PUNCH FILE OF NODE NUMBERS
C     AND INTERCHANGE AREAS.
C     NODE2=BEGINNING NODE NUMBER FOR SECTION 2.
C     IIRD=NUMBER OF ELEMENT ROWS PER NODE  IN SECTIONS 1 AND 2.
C     IICD=NUMBER OF ELEMENT COLUMNS PER NODE  IN SECTIONS 1 AND 2.
      READ (5,1821) IFLAG,L,NSYM,NMI,NODE1,NODE2,(IIRD(IS),IICD(IS),
     1IS=1,2)
C
C     THE FOLLOWING CARDS MUST BE INPUT FOR EACH SECTION.
C
      DO 27 IS=1,L
C
C     ICD=CONFIGURATION INDICATOR.  1=CYLINDER, 2=CONE, 3=SPHERE,
C     4=ELLIPSOID, 5=FLAT PLATE, 6=DISK, 7=TOROID, 8=POLYNOMIAL OF
C     REVOLUTION.
C     MA=NUMBER OF ELEMENT ROWS.
C     IIRB=FIRST ROW NUMBER CONSIDERED FOR THE SECTION.
C     IIRE=LAST ROW NUMBER CONSIDERED FOR THE SECTION.
C     NA=NUMBER OF ELEMENT COLUMNS.
C     IICB=FIRST COLUMN NUMBER CONSIDERED FOR THE SECTION.
C     IICE=LAST COLUMN NUMBER CONSIDERED FOR THE SECTION.
C     KEM=1 IF AN EMITTER, =0 IF NOT AN EMITTER.
C     KSH=1 IF A SHADOWER, =0 IF NOT A SHADOWER.
C     KRE=1 IF A RECEIVER, =0 IF NOT A RECEIVER.
      READ (5,1821) ICD(IS),MA(IS),IIRB(IS),IIRE(IS),NA(IS),IICB(IS),
     1IICE(IS),KEM(IS),KSH(IS),KRE(IS)
C
C     EITHER OF THE NEXT 2 CARDS IS READ DEPENDING IF ICD=8 OR NOT.
C
      IF(ICD(IS).EQ.8) GO TO 25
C
C     R=RADIUS OF CYLINDER, CONE, SPHERE, DISK, OR MAJOR RADIUS OF
C     TORIOD.
C     SR=MINOR RADIUS OF TOROID.
C     AL=LENGTH ALONG X-AXIS OF CYLINDER, CONE, FLAT PLATE.
C     SMOLLA=SEMI-AXIS ALONG X-AXIS OF ELLIPSOID.
C     B=SEMI-AXIS (RADIUS) PERPENDICULAR TO X-AXIS OF ELLIPSOID.
C     W=WIDTH ALONG Y-AXIS OF FLAT PLATE.
      READ (5,1822) R(IS),SR(IS),AL(IS),SMOLLA(IS),B(IS),W(IS)
      GO TO 26
C
C     AL=LENGTH ALONG X-AXIS OF POLYNOMIAL OF REVOLUTION.
C     A0,A1,A2,A3,A4,A5=CONSTANTS FOR POLYNOMIAL OF REVOLUTION.
25    READ (5,1822) AL(IS),A0(IS),A1(IS),A2(IS),A3(IS),A4(IS),A5(IS)
C
C     SWITCH=1.0 TO CONSIDER NORMAL SIDE OF CONFIGURATION SURFACE,
```

```
C       =-1.0 TO CONSIDER REVERSE SIDE.
C       PIT=CONFIGURATION PITCH ANGLE.
C       YAW=CONFIGURATION YAW ANGLE.
C       ROL=CONFIGURATION ROLL ANGLE.
C       XO=X-COORDINATE OF CONFIGURATION.
C       YO=Y-COORDINATE OF CONFIGURATION.
C       ZO=Z-COORDINATE OF CONFIGURATION.
26      READ (5,1822) SWITCH(IS),PIT(IS),YAW(IS),ROL(IS),XO(IS),YO(IS),
       1ZO(IS)
C
C       THE FOLLOWING CARD IS READ IN ONLY IF THE MATRIX INCREMENTING
C       OPTION IS USED, (NMI.GT.0).
C
        IF(NMI.LE.0) GO TO 27
C       DPI=PIT INCREMENT.
C       DYA=YAW INCREMENT.
C       DRL=ROL INCREMENT.
C       DXO=XO INCREMENT.
C       DYO=YO INCREMENT.
C       DZO=ZO INCREMENT.
        READ (5,1822) DPI(IS),DYA(IS),DRL(IS),DXO(IS),DYO(IS),DZO(IS)
27      CONTINUE
C
        WRITE (6,1804) TITLE
        WRITE (6,1530) IFLAG,L,NSYM,NMI,NODE1
        IF(NODE1.GT.0) WRITE (6,1531) NODE1,NODE2,(IIRD(IS),IICD(IS),
       2IS=1,2)
        DO 30 IS=1,2
        IF(IIRD(IS).LE.(IIRE(IS)-IIRB(IS)+1)) GO TO 29
        WRITE (6,1685) IS,IS,IS
        CALL EXIT
29      IF(IICD(IS).LE.(IICE(IS)-IICB(IS)+1)) GO TO 30
        WRITE (6,1686) IS,IS,IS
        CALL EXIT
30      CONTINUE
        FNMI=NMI
        NMIX=0
        KPNT=0
C
C       ENTER CALCULATION, BEGIN MATRIX INCREMENTING LOOP
C
C       SET UP NODE INCREMENTING DO LOOPS FOR SECTIONS 1 AND 2
C
31      DO 32 IS=1,10
        IRBSAV(IS)=IIRB(IS)
        IRESAV(IS)=IIRE(IS)
        ICBSAV(IS)=IICB(IS)
        ICESAV(IS)=IICE(IS)
32      CONTINUE
        IF(NODE1.EQ.0) GO TO 40
        WRITE (7,1820) TITLE
        WRITE (7,1806)
        IIRB1=IIRB(1)
        IIRB2=IIRB(2)
        INC=(IIRE(1)-IIRB(1)+1)/IIRD(1)
        IIRE1=IIRB(1)+IIRD(1)*(INC-1)
        INC=(IIRE(2)-IIRB(2)+1)/IIRD(2)
        IIRE2=IIRB(2)+IIRD(2)*(INC-1)
        IIRD1=IIRD(1)
        IIRD2=IIRD(2)
```

```
      IICB1=IICB(1)
      IICB2=IICB(2)
      INC=(IICE(1)-IICB(1)+1)/IICD(1)
      IICE1=IICB(1)+IICD(1)*(INC-1)
      INC=(IICE(2)-IICB(2)+1)/IICD(2)
      IICE2=IICB(2)+IICD(2)*(INC-1)
      IICD1=IICD(1)
      IICD2=IICD(2)
      INOD1=-1
      INOD2=-1
      DO 1426 IR1=IIRB1,IIRE1,IIRD1
      IIRB(1)=IR1
      IIRE(1)=IR1+IIRD(1)-1
35    DO 1424 IC1=IICB1,IICE1,IICD1
      IICB(1)=IC1
      IICE(1)=IC1+IICD(1)-1
36    INOD1=INOD1+1
      NODE(1)=NODE1+INOD1
      DO 1422 IR2=IIRB2,IIRE2,IIRD2
      IIRB(2)=IR2
      IIRE(2)=IR2+IIRD(2)-1
37    DO 1420 IC2=IICB2,IICE2,IICD2
      IICB(2)=IC2
      IICE(2)=IC2+IICD(2)-1
38    INOD2=INOD2+1
      NODE(2)=NODE2+INOD2
C
C     COMPUTE CONFIGURATION INFORMATION
C
40    INDEX=0
      KSHF=0
      DO 540 IS=1,L
      KSHF=KSHF+KSH(IS)
      IF (KPNT.EQ.0) WRITE (6,1580) IS,MA(IS),IRBSAV(IS),IRESAV(IS),
     2NA(IS),ICBSAV(IS),ICESAV(IS),KEM(IS),KSH(IS),KRE(IS)
      IRB=IIRB(IS)
      IRE=IIRE(IS)
      ICB=IICB(IS)
      ICE=IICE(IS)
      M=IRE-IRB+1
      N=ICE-ICB+1
      IF (M-MA(IS)) 60,60,50
50    WRITE (6,1590) IS
      CALL EXIT
60    IF (N-NA(IS)) 80,80,70
70    WRITE (6,1600) IS
      CALL EXIT
80    NM(IS)=NM(IS-1)+N*M
      IF (NM(IS).LE.2800) GO TO 90
      WRITE (6,1710) IS,NM(IS)
      CALL EXIT
90    SUMA(IS)=0.
      K=ICD(IS)
      AM=MA(IS)
      AN=NA(IS)
      GO TO (100,120,140,210,300,320,340,400),K
C
C     CYLINDER CONFIGURATION(1)
C
100   IF (KPNT.EQ.0) WRITE (6,1610) R(IS),AL(IS)
```

```
      OVM=2.*PI/AM
      AREA=OVM*R(IS)/AN*AL(IS)
      TESTR2=((OVM*R(IS))**2+(AL(IS)/AN)**2)/4.
      DO 110 I=IRB,IRE
      PHI=OVM*(FLOAT(I)-.5)
      SINP=SIN(PHI)
      COSP=COS(PHI)
      DO 110 J=ICB,ICE
      INDEX=INDEX+1
      ALAM1(INDEX)=0.
      ALAM2(INDEX)=SINP
      ALAM3(INDEX)=COSP
      XC(INDEX)=AL(IS)/AN*(FLOAT(J)-.5)
      YC(INDEX)=R(IS)*SINP
      ZC(INDEX)=R(IS)*COSP
      TR2(INDEX)=TESTR2
110   A(INDEX)=AREA
      SUMA(IS)=FLOAT(N*M)*AREA
      GO TO 500
C
C     CONE CONFIGURATION(2)
C
120   IF (KPNT.EQ.0) WRITE (6,1620) R(IS),AL(IS)
      SIDE=SQRT(R(IS)**2+AL(IS)**2)
      COSCON=AL(IS)/SIDE
      SINCON=-R(IS)/SIDE
      OVM=2.*PI/AM
      COM2=R(IS)/AN*OVM/2.
      COM3=SIDE/AN*R(IS)/AN*OVM
      COM4=(SIDE/AN/2.)**2
      DO 130 I=IRB,IRE
      PHI=OVM*(FLOAT(I)-.5)
      SINP=SIN(PHI)
      COSP=COS(PHI)
      DO 130 J=ICB,ICE
      INDEX=INDEX+1
      ALAM1(INDEX)=SINCON
      ALAM2(INDEX)=COSCON*SINP
      ALAM3(INDEX)=COSCON*COSP
      FJ=FLOAT(J)
      XC(INDEX)=AL(IS)/AN*(FJ-.5)
      YC(INDEX)=XC(INDEX)/AL(IS)*R(IS)*SINP
      ZC(INDEX)=XC(INDEX)/AL(IS)*R(IS)*COSP
      TR2(INDEX)=COM4+(COM2*FJ)**2
      A(INDEX)=COM3*(FJ-.5)
130   SUMA(IS)=SUMA(IS)+A(INDEX)
      GO TO 600
C
C     SPHERE CONFIGURATION(3)
C
140   IF (KPNT.EQ.0) WRITE (6,1630) R(IS)
      OVM=PI/AN
      COM1=(OVM*R(IS))**2
      COM2=2.*PI/AM
      DO 200 J=ICB,ICE
      FJ=FLOAT(J)
      IF (KSH(IS)) 150,190,150
150   IF (J-IFIX(AN)/2) 160,160,170
160   PSI=OVM*FJ
      GO TO 180
```

```
170   PSI=OVM*(FJ-1.)
180   TESTR2=(COM1+(COM2*R(IS)*SIN(PSI))**2)/4.
190   PSI=OVM*(FJ-.5)
      SINPSI=SIN(PSI)
      AREA=OVM*COM2*R(IS)**2*SINPSI
      SUMA(IS)=SUMA(IS)+FLOAT(M)*AREA
      DO 200 I=IRB,IRE
      INDEX=NM(IS-1)+N*(I-IRB)+J-ICB+1
      PHI=COM2*(FLOAT(I)-0.5)
      ALAM1(INDEX)=SINPSI*COS(PHI)
      ALAM2(INDEX)=SINPSI*SIN(PHI)
      ALAM3(INDEX)=COS(PSI)
      XC(INDEX)=R(IS)*ALAM1(INDEX)
      YC(INDEX)=R(IS)*ALAM2(INDEX)
      ZC(INDEX)=R(IS)*ALAM3(INDEX)
      TR2(INDEX)=TESTR2
200   A(INDEX)=AREA
      GO TO 500
C
C     ELLIPSOID CONFIGURATION(4)
C
210   IF (KPNT.EQ.0) WRITE (6,1640) SMOLLA(IS),B(IS)
      COM1=4.*PI/AM*SMOLLA(IS)/AN*B(IS)
      COM2=2.*PI/AN
      DO 290 I=IRB,IRE
      COY=FLOAT(2*I-1)/AM-1.
      SIY=SQRT(1.-COY**2)
      TANU=SMOLLA(IS)/B(IS)*SIY/COY
      COSU=1./SQRT(TANU**2+1.)
      IF (COY) 220,230,230
220   COSU=-COSU
230   SINU=COSU*TANU
      AREA=COM1*SIY/SINU
      FI=FLOAT(I)
      IF (KSH(IS)) 240,280,240
240   IF (I-IFIX(AM)/2) 250,250,260
250   X=SMOLLA(IS)/AM*FI*2.
      GO TO 270
260   X=2.*SMOLLA(IS)/AM*(FI-1.)
270   Y=B(IS)*SQRT((X/SMOLLA(IS))*(2.-(X/SMOLLA(IS))))
      TESTR2=((Y*COM2/2.)**2+(SMOLLA(IS)/AM/SINU)**2)
280   X=2.*SMOLLA(IS)/AM*(FI-.5)
      Y=B(IS)*SQRT((X/SMOLLA(IS))*(2.-(X/SMOLLA(IS))))
      DO 290 J=ICB,ICE
      INDEX=INDEX+1
      PHI=COM2*(FLOAT(J)-.5)
      SINP=SIN(PHI)
      COSP=COS(PHI)
      ALAM1(INDEX)=COSU
      ALAM2(INDEX)=SINU*SINP
      ALAM3(INDEX)=SINU*COSP
      XC(INDEX)=X
      YC(INDEX)=Y*SINP
      ZC(INDEX)=Y*COSP
      TR2(INDEX)=TESTR2
      A(INDEX)=AREA
290   SUMA(IS)=SUMA(IS)+A(INDEX)
      GO TO 500
C
C     FLAT PLATE CONFIGURATION(5)
```

```
C
C     THE VECTOR REPRESENTING THE FLAT PLATE CONFIGURATION POINTS IN THE
C     +Z DIRECTION, UNLESS SWITCH=-1.
C
300   IF (KPNT.EQ.0) WRITE (6,1650) AL(IS),W(IS)
      TESTR2=((AL(IS)/AM)**2+(W(IS)/AN)**2)/4.
      AREA=AL(IS)/AM*W(IS)/AN
      DO 310 I=IRB,IRE
      DO 310 J=ICB,ICE
      INDEX=INDEX+1
      ALAM1(INDEX)=0.
      ALAM2(INDEX)=0.
      ALAM3(INDEX)=1.
      XC(INDEX)=AL(IS)/AM*(FLOAT(I)-.5)
      YC(INDEX)=W(IS)/AN*(FLOAT(J)-.5)
      ZC(INDEX)=0.
      TR2(INDEX)=TESTR2
310   A(INDEX)=AREA
      SUMA(IS)=FLOAT(N*M)*AREA
      GO TO 500
C
C     DISK CONFIGURATION(6)
C
C     THE VECTOR REPRESENTING THE DISK CONFIGURATION POINTS IN THE +Z
C     DIRECTION, UNLESS SWITCH=-1.
C
320   IF (KPNT.EQ.0) WRITE (6,1660) R(IS)
      COM2=(R(IS)/2./AN)**2
      COM3=2.*PI/AM*R(IS)/AN
      DO 330 I=IRB,IRE
      PHI=2.*PI/AM*(FLOAT(I)-.5)
      SINP=SIN(PHI)
      COSP=COS(PHI)
      DO 330 J=ICB,ICE
      INDEX=INDEX+1
      ALAM1(INDEX)=0.
      ALAM2(INDEX)=0.
      ALAM3(INDEX)=1.
      FJ=FLOAT(J)
      COM1=R(IS)/AN*(FJ-.5)
      XC(INDEX)=COM1*COSP
      YC(INDEX)=COM1*SINP
      ZC(INDEX)=0.
      A(INDEX)=COM1*COM3
      SUMA(IS)=SUMA(IS)+A(INDEX)
330   TR2(INDEX)=(PI/AM*R(IS)/AN*FJ)**2+COM2
      GO TO 500
C
C     TOROID CONFIGURATION(7)
C
340   IF (KPNT.EQ.0) WRITE (6,1670) SR(IS),R(IS)
      COM1=4.*PI**2*SR(IS)/AN/AM
      COM2=(PI/AM*SR(IS))**2
      DO 390 J=ICB,ICE
      PHI=2.*PI/AN*(FLOAT(J)-.5)
      SINP=SIN(PHI)
      COSP=COS(PHI)
      DO 390 I=IRB,IRE
      INDEX=NM(IS-1)+N*(I-IRB)+J-ICB+1
      FI=FLOAT(I)
```

```
      PSI=2.*PI/AM*(FI-.5)
      COSPSI=COS(PSI)
      ALAM1(INDEX)=COSPSI*COSP
      ALAM2(INDEX)=COSPSI*SINP
      ALAM3(INDEX)=SIN(PSI)
      XC(INDEX)=COSP*(R(IS)+SR(IS)*COSPSI)
      YC(INDEX)=SINP*(R(IS)+SR(IS)*COSPSI)
      ZC(INDEX)=SR(IS)*ALAM3(INDEX)
      A(INDEX)=COM1*(R(IS)+SR(IS)*COSPSI)
      SUMA(IS)=SUMA(IS)+A(INDEX)
      IF (KSH(IS)) 350,390,350
350   IF (I-IFIX(AM)/2) 370,370,360
360   PSI=2.*PI/AM*FI
      GO TO 380
370   PSI=2.*PI/AM*(FI-1.)
380   TR2(INDEX)=COM2+(PI/AN*(R(IS)+SR(IS)*COSPSI))**2
390   CONTINUE
      GO TO 500
C
C     POLYNOMIAL OF REVOLUTION CONFIGURATION(8)
C
400   IF (KPNT.EQ.0) WRITE (6,1680) AL(IS),A0(IS),A1(IS),A2(IS),
     1A3(IS),A4(IS),A5(IS)
      OVM=2.*PI/AM
      X=AL(IS)/AN*FLOAT(ICB-1)
      PR=A0(IS)+A1(IS)*X+A2(IS)*X**2+A3(IS)*X**3+A4(IS)*X**4+A5(IS)*X**5
      DO 490 J=ICB,ICE
      FJ=FLOAT(J)
      X=AL(IS)/AN*FJ
      R(IS)=A0(IS)+A1(IS)*X+A2(IS)*X**2+A3(IS)*X**3+A4(IS)*X**4+A5(IS)*X
     1**5
      IF (R(IS)-PR) 420,410,420
410   SINPSI=1.
      COSPSI=0.
      GO TO 450
420   TANPSI=AL(IS)/AN/(PR-R(IS))
      COSPSI=1./SQRT(1.+TANPSI**2)
      IF (TANPSI) 430,440,440
430   COSPSI=-COSPSI
440   SINPSI=TANPSI*COSPSI
450   COM1=(OVM*PR)**2
      COM2=(OVM*R(IS))**2
      COM3=(AL(IS)/AN)**2+(R(IS)-PR)**2
      IF (R(IS)-PR) 460,470,470
460   TESTR2=(COM1+COM3)/4.
      GO TO 480
470   TESTR2=(COM2+COM3)/4.
480   PR=R(IS)
      X=AL(IS)/AN*(FJ-.5)
      R(IS)=A0(IS)+A1(IS)*X+A2(IS)*X**2+A3(IS)*X**3+A4(IS)*X**4+A5(IS)*X
     1**5
      AREA=OVM*R(IS)*SQRT(COM3)
      SUMA(IS)=SUMA(IS)+AREA*FLOAT(IRE-IRB+1)
      DO 490 I=IRB,IRE
      INDEX=NM(IS-1)+N*(I-IRB)+J-ICB+1
      PHI=OVM*(FLOAT(I)-.5)
      SINP=SIN(PHI)
      COSP=COS(PHI)
      ALAM1(INDEX)=COSPSI
      ALAM2(INDEX)=SINPSI*COSP
```

```
      ALAM3(INDEX)=SINPSI*SINP
      XC(INDEX)=X
      YC(INDEX)=R(IS)*COSP
      ZC(INDEX)=R(IS)*SINP
      TR2(INDEX)=TESTR2
490   A(INDEX)=AREA
500   IF (IRE-IFIX(AM)) 520,520,510
510   WRITE (6,1690) IS
      CALL EXIT
520   IF (ICE-IFIX(AN)) 540,540,530
530   WRITE (6,1700) IS
      CALL EXIT
540   CONTINUE
      IF (NM(L)-2800) 560,560,550
550   WRITE (6,1710) L,NM(L)
      CALL EXIT
560   IDC=0
      IF (NMI.EQ.0.OR.KPNT.GT.0) GO TO 570
      WRITE (6,1720) (IS,DPI(IS),DYA(IS),DRL(IS),DXO(IS),DYO(IS),
     1DZO(IS), IS=1,L)
570   DO 610 IS=1,L
      IF (SWITCH(IS)) 580,590,590
580   SWITCH(IS)=-1.
      GO TO 600
590   SWITCH(IS)=1.
600   ISS(IS)=0
610   CONTINUE
C
C     SET UP MATRIX TRANSFORMS
C
      INDEX=0
      DO 700 IS=1,L
      PIX=PIT(IS)/RAD
      YAX=YAW(IS)/RAD
      RLX=ROL(IS)/RAD
      SINP=SIN(PIX)
      COSP=COS(PIX)
      SINY=SIN(YAX)
      COSY=COS(YAX)
      SINR=SIN(RLX)
      COSR=COS(RLX)
      IF (IDC) 620,640,620
620   DO 630 I=1,3
      DO 630 J=1,3
630   AMT(I,J)=TMS(I,J,IS)
640   TMS(1,1,IS)=COSP*COSY
      TMS(1,2,IS)=COSR*SINY-SINP*COSY*SINR
      TMS(1,3,IS)=-SINR*SINY-SINP*COSY*COSR
      TMS(2,1,IS)=-COSP*SINY
      TMS(2,2,IS)=COSY*COSR+SINP*SINY*SINR
      TMS(2,3,IS)=-COSY*SINR+SINP*SINY*COSR
      TMS(3,1,IS)=SINP
      TMS(3,2,IS)=COSP*SINR
      TMS(3,3,IS)=COSP*COSR
      IF (IDC) 670,650,670
650   DO 660 I=1,3
      DO 660 J=1,3
660   TM(I,J)=TMS(I,J,IS)
      GO TO 690
670   DO 680 I=1,3
```

```
      DO 680 J=1,3
680   BMT(I,J)=TMS(I,J,IS)
      CALL MTR (BMT(1,1),AMT(1,1),TM(1,1))
C
C     TRANSFORM ALL CONFIGURATION INFORMATION TO THE BASE COORDINATE
C     SYSTEM
C
690   IRB=IIRB(IS)
      IRE=IIRE(IS)
      ICB=IICB(IS)
      ICE=IICE(IS)
      DO 700 I=IRB,IRE
      DO 700 J=ICB,ICE
      INDEX=INDEX+1
      VALAM(1)=ALAM1(INDEX)
      VALAM(2)=ALAM2(INDEX)
      VALAM(3)=ALAM3(INDEX)
      CALL MVM (TM(1,1),VALAM(1),VALAM(1))
      VALAM(1)=VALAM(1)*SWITCH(IS)
      VALAM(2)=VALAM(2)*SWITCH(IS)
      VALAM(3)=VALAM(3)*SWITCH(IS)
      ALAM1(INDEX)=VALAM(1)
      ALAM2(INDEX)=VALAM(2)
      ALAM3(INDEX)=VALAM(3)
      VC(1)=XC(INDEX)
      VC(2)=YC(INDEX)
      VC(3)=ZC(INDEX)
      CALL MVM (TM(1,1),VC(1),VC(1))
      XC(INDEX)=VC(1)+XO(IS)
      YC(INDEX)=VC(2)+YO(IS)
      ZC(INDEX)=VC(3)+ZO(IS)
700   CONTINUE
C
C      COMPUTE CONFIGURATION FACTOR
C
      AREAE=0.
      AREAR=0.
      SFX=0.
      DSFX=0.
      DO 1390 ME=1,L
      IF (KRE(ME)) 710,720,710
710   AREAR=AREAR+SUMA(ME)
720   IF (KEM(ME)) 730,1390,730
730   AREAE=AREAE+SUMA(ME)
      IRBE=IIRB(ME)
      IREE=IIRE(ME)
      ICBE=IICB(ME)
      ICEE=IICE(ME)
      INDEXE=NM(ME-1)
      DO 1380 IE=IRBE,IREE
      DO 1370 JE=ICBE,ICEE
      INDEXE=INDEXE+1
      DO 1360 MR=1,L
      IF (KRE(MR)) 740,1360,740
740   IRBR=IIRB(MR)
      IRER=IIRE(MR)
      ICBR=IICB(MR)
      ICER=IICE(MR)
      INDEXR=NM(MR-1)
      DO 1350 IR=IRBR,IRER
```

```
      DO 1340 JR=ICBR,ICER
      INDEXR=INDEXR+1
      VER(1)=XC(INDEXR)-XC(INDEXE)
      VER(2)=YC(INDEXR)-YC(INDEXE)
      VER(3)=ZC(INDEXR)-ZC(INDEXE)
      IF (ABS(VER(1))+ABS(VER(2))+ABS(VER(3))) 750,750,760
750   WRITE (6,1730)
      GO TO 1400
760   VLEI(1)=ALAM1(INDEXE)
      VLEI(2)=ALAM2(INDEXE)
      VLEI(3)=ALAM3(INDEXE)
      VLRI(1)=ALAM1(INDEXR)
      VLRI(2)=ALAM2(INDEXR)
      VLRI(3)=ALAM3(INDEXR)
      VCOM(1)=0.
      VCOM(2)=0.
      VCOM(3)=0.
      AMVER=SQRT(VER(1)**2+VER(2)**2+VER(3)**2)
      IF (VER(1).NE.0.) VCOM(1)=VER(1)/AMVER
      IF (VER(2).NE.0.) VCOM(2)=VER(2)/AMVER
      IF (VER(3).NE.0.) VCOM(3)=VER(3)/AMVER
      COSE=VCOM(1)*VLEI(1)+VCOM(2)*VLEI(2)+VCOM(3)*VLEI(3)
      IF (COSE) 1340,1340,770
770   COSR=-VCOM(1)*VLRI(1)-VCOM(2)*VLRI(2)-VCOM(3)*VLRI(3)
      IF (COSR) 1340,1340,780
780   IF (KSHF) 790,1330,790
790   DO 1320 MS=1,L
      IF ((KSH(MS))) 800,1320,800
C                                   ADJACENT ELEMENT SHADOWING LOGIC
800   AS=(0.)
      IF ((MS)-(MR)) 810,820,810
810   IF ((MS)-(ME)) 880,820,880
820   IF ((ICD(MS))-(5)) 830,1320,860
830   IF ((ICD(MS))-(2)) 840,840,850
840   AS=-(1.)
850   IF ((SWITCH(MS))) 880,1320,1320
860   IF ((ICD(MS))-(6)) 870,1320,870
870   AS=(1.)
880   IRBS=(IIRB(MS))
      IRES=(IIRE(MS))
      ICBS=(IICB(MS))
      ICES=(IICE(MS))
      INDEXS=(NM(MS-1))
C                                   PICK AN ELEMENT ON THE SHADOWER
      DO 1310 IS=IRBS,IRES
      DO 1300 JS=ICBS,ICES
      INDEXS=(INDEXS)+(1)
      IF ((INDEXS)-(INDEXR)) 890,1300,890
890   IF ((INDEXS)-(INDEXE)) 900,1300,900
900   IF ((AS)) 910,1190,940
C                                   CYLINDER AND CONE
910   IF ((MS)-(ME)) 930,920,930
920   IF ((IS)-(IE)) 1190,1310,1190
930   IF ((IS)-(IR)) 1190,1310,1190
C                                   TOROID AND POLYNOMIAL
940   IF ((MS)-(ME)) 960,950,960
950   INDEX=(INDEXE)
      GO TO 970
960   INDEX=(INDEXR)
970   IF ((JS)-(ICES)) 980,990,990
```

```
980   IF ((INDEXS)+(1)-(INDEX)) 1020,1150,1020
990   IF ((ICD(MS))-(8)) 1000,1020,1000
1000  IF ((ICES)-(ICBS)+(1)-(NA(MS))) 1020,1010,1020
1010  IF ((INDEXS)-(ICES)+(1)-(INDEX)) 1020,1150,1020
1020  IF ((JS)-(ICBS)) 1040,1040,1030
1030  IF ((INDEXS)-(1)-(INDEX)) 1070,1150,1070
1040  IF ((ICD(MS))-(8)) 1050,1070,1050
1050  IF ((ICES)-(ICBS)+(1)-(NA(MS))) 1070,1060,1070
1060  IF ((INDEXS)+(ICES)-(1)-(INDEX)) 1070,1150,1070
1070  IF ((IS)-(IRES)) 1080,1090,1090
1080  IF ((INDEXS)+(ICES)-(ICBS)+(1)-(INDEX)) 1110,1150,1110
1090  IF ((IRES)-(IRBS)+(1)-(MA(MS))) 1110,1100,1110
1100  IF ((INDEXS)+((1)-(IRES))*((ICES)-(ICBS)+(1))-(INDEX)) 1110,1150,1
     1110
1110  IF ((IS)-(IRBS)) 1130,1130,1120
1120  IF ((INDEXS)-(ICES)+(ICBS)-(1)-(INDEX)) 1190,1150,1190
1130  IF ((IRES)-(IRBS)+(1)-(MA(MS))) 1190,1140,1190
1140  IF ((INDEXS)+((IRES)-(1))*((ICES)-(ICBS)+(1))-(INDEX)) 1190,1150,1
     1190
1150  VLS1(1)=(ALAM1(INDEXS))
      VLS1(2)=(ALAM2(INDEXS))
      VLS1(3)=(ALAM3(INDEXS))
      IF ((MS)-(ME)) 1170,1160,1170
1160  VRS(1)=(XC(INDEXS))-(XC(INDEXR))
      VRS(2)=(YC(INDEXS))-(YC(INDEXR))
      VRS(3)=(ZC(INDEXS))-(ZC(INDEXR))
      VRS1(1)=0.
      VRS1(2)=0.
      VRS1(3)=0.
      AMVRS=SQRT(VRS(1)**2+VRS(2)**2+VRS(3)**2)
      IF (VRS(1).NE.0.) VRS1(1)=VRS(1)/AMVRS
      IF (VRS(2).NE.0.) VRS1(2)=VRS(2)/AMVRS
      IF (VRS(3).NE.0.) VRS1(3)=VRS(3)/AMVRS
      COSS=-VRS1(1)*VLS1(1)-VRS1(2)*VLS1(2)-VRS1(3)*VLS1(3)
      COSC=(COSE)
      GO TO 1180
1170  VES(1)=(XC(INDEXS))-(XC(INDEXE))
      VES(2)=(YC(INDEXS))-(YC(INDEXE))
      VES(3)=(ZC(INDEXS))-(ZC(INDEXE))
      VES1(1)=0.
      VES1(2)=0.
      VES1(3)=0.
      AMVES=SQRT(VES(1)**2+VES(2)**2+VES(3)**2)
      IF (VES(1).NE.0.) VES1(1)=VES(1)/AMVES
      IF (VES(2).NE.0.) VES1(2)=VES(2)/AMVES
      IF (VES(3).NE.0.) VES1(3)=VES(3)/AMVES
      COSS=-VES1(1)*VLS1(1)-VES1(2)*VLS1(2)-VES1(3)*VLS1(3)
      COSC=(COSR)
1180  IF ((COSC)*(COSS)) 1190,1190,1300
C
C                                END OF ADJACENT ELEMENT SHADOWING
C                                LOGIC
C
C                                DETERMINE THE POINT OF INTERSECTION
C                                BETWEEN THE RAY AND THE PLANE OF THE
C                                SHADOWING ELEMENT
1190  IF ((VER(1))) 1250,1200,1250
1200  IF (VER(2)) 1230,1210,1230
1210  IF (ALAM3(INDEXS)) 1220,1300,1220
1220  XP=XC(INDEXE)
```

```
      YP=YC(INDEXE)
      ZP=(ALAM1(INDEXS)*(XC(INDEXS)-XC(INDEXE))+ALAM2(INDEXS)*(YC(INDEXS
     1)-YC(INDEXE))+ALAM3(INDEXS)*ZC(INDEXS))/ALAM3(INDEXS)
      GO TO 1270
1230  COM1=VER(3)/VER(2)
      COM2=ALAM2(INDEXS)+ALAM3(INDEXS)*COM1
      IF (COM2) 1240,1300,1240
1240  XP=XC(INDEXE)
      YP=(ALAM1(INDEXS)*(XC(INDEXS)-XC(INDEXE))+ALAM2(INDEXS)*YC(INDEXS)
     1+ALAM3(INDEXS)*(COM1*YC(INDEXE)+ZC(INDEXS)-ZC(INDEXE)))/COM2
      ZP=ZC(INDEXE)+COM1*(YP-YC(INDEXE))
      GO TO 1270
1250  COM1=VER(2)/VER(1)
      COM2=VER(3)/VER(1)
      COM3=ALAM1(INDEXS)+COM1*ALAM2(INDEXS)+COM2*ALAM3(INDEXS)
      IF (COM3) 1260,1300,1260
1260  XP=(ALAM1(INDEXS)*XC(INDEXS)+ALAM2(INDEXS)*(COM1*XC(INDEXE)-YC(IND
     1EXE)+YC(INDEXS))+ALAM3(INDEXS)*(COM2*XC(INDEXE)-ZC(INDEXE)+ZC(INDE
     2XS)))/COM3
      YP=COM1*(XP-XC(INDEXE))+YC(INDEXE)
      ZP=COM2*(XP-XC(INDEXE))+ZC(INDEXE)
1270  COM4=(XP-XC(INDEXS))**2+(YP-YC(INDEXS))**2+(ZP-ZC(INDEXS))**2
      IF (COM4-TR2(INDEXS)) 1280,1280,1300
1280  VCOM(1)=XP-XC(INDEXE)
      VCOM(2)=YP-YC(INDEXE)
      VCOM(3)=ZP-ZC(INDEXE)
      VERCOM=VER(1)*VCOM(1)+VER(2)*VCOM(2)+VER(3)*VCOM(3)
      IF (VERCOM) 1300,1300,1290
1290  AMVCOM=SQRT(VCOM(1)**2+VCOM(2)**2+VCOM(3)**2)
      AMVER=SQRT(VER(1)**2+VER(2)**2+VER(3)**2)
      IF (AMVCOM-AMVER) 1340,1300,1300
1300  CONTINUE
1310  CONTINUE
1320  CONTINUE
1330  DSFX=COSE*COSR/(VER(1)*VER(1)+VER(2)*VER(2)+VER(3)*VER(3))*A(INDEX
     1E)*A(INDEXR)
      SFX=SFX+DSFX
1340  CONTINUE
1350  CONTINUE
1360  CONTINUE
1370  CONTINUE
1380  CONTINUE
1390  CONTINUE
      SFER=SFX/AREAE/PI
      AREAET=AREAE*FLOAT(NSYM)
      SS=SFER*AREAET
      SFRE=SS/AREAR
      IDG-1
      IF(NODE1.EQ.0) GO TO 1395
      NODEE=NODE(1)
      NODER=NODE(2)
      IF(KEM(1).GT.0) GO TO 1392
      NODEE=NODE(2)
      NODER=NODE(1)
1392  WRITE (7,1807) NODEE,NODER,SS
1395  WRITE (6,1750) (IS,SWITCH(IS),PIT(IS),YAW(IS),ROL(IS),XO(IS),
     1YO(IS),ZO(IS),IIRD(IS),IIBF(IS),IICB(IS),IICE(IS),IS=1,L)
      IF(NODE1.GT.0) GO TO 1396
      WRITE (6,1751) AREAET,SFER
      WRITE (5,1752) AREAR,SFRE
```

```
      GO TO 1397
 1396 WRITE (6,1753) AREAET,SFER,NODEE
      WRITE (6,1754) AREAR,SFRE,NODER
 1397 WRITE (6,1755) SS
 1400 CONTINUE
      KPNT=1
C
C     END NODE INCREMENTING DO LOOPS.  ADJUST LAST INCREMENT TO BE
C     CONSISTANT WITH LAST ROW OR COLUMN NUMBER.
C
      IF(NODE1.EQ.0) GO TO 1450
      IF(IC2.LT.IICE2) GO TO 1420
      IEND=ICESAV(2)-IICE(2)
      IF(IEND.EQ.0) GO TO 1420
      IICB(2)=IICE(2)+1
      IICE(2)=ICESAV(2)
      GO TO 38
 1420 CONTINUE
      IF(IR2.LT.IIRE2) GO TO 1422
      IEND=IRESAV(2)-IIRE(2)
      IF(IEND.EQ.0) GO TO 1421
      IIRB(2)=IIRE(2)+1
      IIRE(2)=IRESAV(2)
      GO TO 37
 1421 INOD2=-1
 1422 CONTINUE
      IF(IC1.LT.IICE1) GO TO 1424
      IEND=ICESAV(1)-IICE(1)
      IF(IEND.EQ.0) GO TO 1424
      IICB(1)=IICE(1)+1
      IICE(1)=ICESAV(1)
      GO TO 36
 1424 CONTINUE
      IF(;R1.LT.IIRE1) GO TO 1426
      IEND=IRESAV(1)-IIRE(1)
      IF(IEND.EQ.0) GO TO 1426
      IIRB(1)=IIRE(1)+1
      IIRE(1)=IRESAV(1)
      GO TO 35
 1426 CONTINUE
 1430 DO 1432 IS=1,2
      IIRB(IS)=IRBSAV(IS)
      IICB(IS)=ICBSAV(IS)
 1432 CONTINUE
 1450 IF (NMIX-NM1) 1480,1510,1510
C
C     INCREMENT TRANSFORMATIONS AND INITIALIZE CONFIGURATION DATA
C
 1480 DO 1490 IS=1,L
      IRB=IIRB(IS)
      IRE=IIRE(IS)
      ICB=IICB(IS)
      ICE=IICE(IS)
      DO 1490 I=IRB,IRE
      DO 1490 J=ICB,ICE
      INDEX=NM(IS-1)+(ICE-ICB+1)*(I-IRB)+J-ICB+1
      ALAM1(INDEX)=SWITCH(IS)*ALAM1(INDEX)
      ALAM2(INDEX)=SWITCH(IS)*ALAM2(INDEX)
      ALAM3(INDEX)=SWITCH(IS)*ALAM3(INDEX)
      XC(INDEX)=XC(INDEX)-XO(IS)
```

```
      YC(INDEX)=YC(INDEX)-YO(IS)
      ZC(INDEX)=ZC(INDEX)-ZO(IS)
 1490 CONTINUE
      NMIX=NMIX+1
      DO 1500 IS=1,L
      PIT(IS)=PIT(IS)+DPI(IS)
      YAW(IS)=YAW(IS)+DYA(IS)
      ROL(IS)=ROL(IS)+DRL(IS)
      XO(IS)=XO(IS)+DXO(IS)
      YO(IS)=YO(IS)+DYO(IS)
      ZO(IS)=ZO(IS)+DZO(IS)
 1500 CONTINUE
      GO TO 31
C
C     END PROBLEM AND RETURN FOR NEW PROBLEM
C
 1510 DO 1515 IS=1,L
      PIT(IS)=PIT(IS)-FNMI*DPI(IS)
      ROL(IS)=ROL(IS)-FNMI*DRL(IS)
      YAW(IS)=YAW(IS)-FNMI*DYA(IS)
      XO(IS)=XO(IS)-FNMI*DXO(IS)
      YO(IS)=YO(IS)-FNMI*DYO(IS)
      ZO(IS)=ZO(IS)-FNMI*DZO(IS)
 1515 CONTINUE
      WRITE (6,1760)
      IF(IFLAG.NE.0) GO TO 22
      WRITE (7,1807) NZERO,NZERO,ZERO
      CALL EXIT
C
 1520 FORMAT (1H1,40X,31HRADIATION CONFIGURATION FACTORS//1X)
 1530 FORMAT (//7H IFLAG=,I2,5X,2HL=,I2,5X,5HNSYM=,I5,5X,4HNMI=,I3,
     15X,6HNODE1=,I5)
 1531 FORMAT (7H NODE1=,I5,5X,6HNODE2=,I5,5X,8HIIRD(1)=,I5,5X,
     18HIICD(1)=,I5,5X,8HIIRD(2)=,I5,5X,8HIICD(2)=,I5)
 1580 FORMAT (/1X,7HSECTION,I2/17,5H ROWS,6X,12H    FIRST ROW,I6,3X,
     111H    LAST ROW,I6/17,8H COLUMNS,15H    FIRST COLUMN,I6,
     214H    LAST COLUMN,I6/5H KEM=I1,7H    KSH=I1,7H    KRE=I1)
 1590 FORMAT (45H THERE ARE TOO MANY ROWS SPECIFIED ON SECTION,I2)
 1600 FORMAT (48H THERE ARE TOO MANY COLUMNS SPECIFIED ON SECTION,I2)
 1610 FORMAT (24H CYLINDER            RADIUS=1PE11.4,14H        LENGTH=E11.4)
 1620 FORMAT (24H CONE                RADIUS=1PE11.4,14H        LENGTH=E11.4)
 1630 FORMAT (24H SPHERE              RADIUS=1PE11.4)
 1640 FORMAT (24H ELLIPSOID                A=1PE11.4,14H             B=E11.4)
 1650 FORMAT (24H FLAT PLATE          LENGTH=1PE11.4,14H         WIDTH=E11.4)
 1660 FORMAT (24H DISK                RADIUS=1PE11.4)
 1670 FORMAT (24H TOROID      SMALL RADIUS=1PE11.4,14H LARGE RADIUS=E11.4)
 1680 FORMAT (24H POLYNOMIAL          LENGTH=1PE11.4/4H A0=E11.4,5H  A1=E11.
     14,5H  A2=E11.4,5H  A3=E11.4,5H  A4=E11.4,5H  A5=E11.4)
 1685 FORMAT (6H IIRD(,I1,16H) EXCEEDS (IIRE(,I1,7H)-IIRB(,I1,4H)+1))
 1686 FORMAT (6H IICD(,I1,18H) EXCEEDS (IICE(,I1,7H)-IICB(,I1,4H)+1))
 1690 FORMAT (26H IRE EXCEEDS AM ON SECTION,I3)
 1700 FORMAT (26H ICE EXCEEDS AN ON SECTION,I3)
 1710 FORMAT (69H THERE ARE MORE THAN 2800 FLAT PLATES CONSIDERED ON ALL
     1 THE SECTIONS.,25H THIS OCCURRED ON SECTION,I5,9H WITH NM=I5)
 1720 FORMAT (/1X,7HSECTION,I2/5H DPI=F8.4,6H  DYA=F8.4,6H  DRL=F8.4,
     16H  DXO=F8.4,6H  DYO=F8.4,6H  DZO=F8.4)
 1730 FORMAT (/73H A CALCULATION WAS SKIPPED SINCE AN EMITTER AND A RECE
     2IVER WERE TOUCHING.)
 1750 FORMAT (/115H SECTION  SWITCH     PIT        YAW        ROL        XO
     1        YO         ZO      FIRST R.   LAST R.  FIRST C.   LAST C./
```

```
     2(I5,0PF9.0,2X,6F10.4,I7,3I10))
1751  FORMAT (15H EMITTER AREA =,E11.4,35H   EMITTER TO RECIEVER VIEW FA
     1CTOR=,E11.4)
1752  FORMAT (15H RECEIVER AREA=,E11.4,35H   RECEIVER TO EMITTER VIEW FA
     1CTOR=,E11.4)
1753  FORMAT (15H EMI-TER AREA =,E11.4,35H   EMITTER TO RECIEVER VIEW FA
     1CTOR=,E11.4,21H   EMITTER NODE NO. =,I5)
1754  FORMAT (15H RECEIVER AREA=,E11.4,35H   RECEIVER TO EMITTER VIEW FA
     1CTOR=,E11.4,21H   RECEIVER NODE NO.=,I5)
1755  FORMAT (18H INTERCHANGE AREA=,E11.4)
1760  FORMAT (1H1)
1800  FORMAT (A10)
1801  FORMAT (/21HTYPE INPUT FILE NAME./
     153HFIRST 3 CHARACTERS ARE APPENDED TO OUTPUT FILE NAMES.)
1802  FORMAT (/22HOUTPUT FILE NAMES ARE:/8HOUTPUT= ,A6/
     119HVIEW FACTOR CARDS= ,A7)
1803  FORMAT (/17HFLOE ERROR NUMBER,I5,30H FOR OPEN INSTRUCTION OF FILE
     1,A10)
1804  FORMAT (1X,8A10)
1806  FORMAT (3X,7HEMITTER,2X,8HRECEIVER,1X,9HINT. AREA)
1807  FORMAT (2I10,E10.3)
1820  FORMAT (8A10)
1821  FORMAT (16I5)
1822  FORMAT (8E10.3)
      END
      SUBROUTINE MVM (A,V,P)
C   THIS SUBROUTINE COMPUTES THE PRODUCT W OF A  MATRIX A AND A VECTOR V
      DIMENSION A(3,3), V(3), W(3), P(3)
      DO 20 J=1,3
      U=0.
      DO 10 K=1,3
10    U=U+A(J,K)*V(K)
20    W(J)=U
      DO 30 J=1,3
30    P(J)=W(J)
      RETURN
      END
      SUBROUTINE MTR (A,B,C)
C   THIS SUBROUTINE COMPUTES THE MATRIX PRODUCT C OF A  MATRIX A
C     AND THE TRANSPOSE OF B      A T(B)=C
      DIMENSION A(3,3), B(3,3), C(3,3)
      DO 20 J=1,3
      DO 20 K=1,3
      X=0.
      DO 10 L=1,3
10    X=X+A(J,L)*B(K,L)
20    C(J,K)=X
      RETURN
      END
*....................FILE OPEN SUBROUTINE..............1/17/75....
            SUBROUTINE OPENFN(FN,NT,LG,IE,MWX)
*
*         24 SEP 74 VERSION     D. LAI
*
*         INPUT  FN : NAME OF FILE TO BE OPENED OR CREATED
*                NT : TAPE NUMBER TO BE ASSIGNED TO FILE
*                     = 0 : NO TAPE NUMBER TO BE ASSIGNED
*                LG : LENGTH OF FILE IF CREATED
*                IE : OPTIONS AVAILABLE -
*                     =1 -1 : OPEN AND MAKE READ-WRITE
```

Technical Information Department
LAWRENCE LIVERMORE LABORATORY
University of California | Livermore, California | 94550