NASA Contractor Report 191044

NASCAP Programmer's Reference Manual

M.J. Mandell, P.R. Stannard, and I. Katz
S-Cubed
Division of Maxwell Laboratories, Inc.
La Jolla, California

May 1993

Prepared for
Lewis Research Center
Under Contract NAS3–22826

National Aeronautics and
Space Administration

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued).

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

NASCAP PROGRAMMER'S REFERENCE MANUAL*

M.J. Mandell, P.R. Stannard, and I. Katz
S-Cubed
Division of Maxwell Laboratories, Inc.
La Jolla, California 92038

SUMMARY

The NASA Charging Analyzer Program (NASCAP) is a computer program designed to model the electrostatic charging of complicated three-dimensional objects, both in a test tank and at geosynchronous altitudes.

This document is a programmer's reference manual and user's guide. It is designed as a reference to experienced users of the code, as well as an introduction to its use for beginners.

All of the many capabilities of NASCAP are covered in detail, together with examples of their use. These include the definition of objects, plasma environments, potential calculations, particle emission and detection simulations and charging analysis.

*Prepared for NASA Lewis Research Center under Contract NAS3-22826.

1. NASCAP OVERVIEW

1.1 WHAT IS NASCAP?

NASCAP, the NASA Charging Analyzer Program, is a computer program designed to simulate spacecraft charging. Spacecraft charging is the build-up of electrostatic potentials on the surfaces of spacecraft exposed to a plasma environment. This occurs when charged particles from the plasma collect on the exposed surface. Both the sign and the magnitude of the potential acquired from exposure to the same plasma may differ for different surface materials, or for different areas of the same material due to shadowing or electrostatic effects. Thus a complicated object composed of more than one material may charge non-uniformly leading to differential charging, i.e., potential differences between different parts of the object. Differential charging can cause electrical discharges that may be damaging to satellite systems.

For objects as structurally complicated as man-made satellites and other spacecraft, predicting their interaction with a surrounding plasma in a test tank or space environment becomes a very complex problem. The purpose of NASCAP is to solve this problem and calculate such observable quantities as electric potentials and currents to and from the spacecraft. NASCAP is an important tool for the analysis of spacecraft charging and the interplay between the various mechanisms responsible.

1.2 THE PHYSICS OF SPACECRAFT CHARGING

The atmosphere around the earth at geosynchronous altitude consists of a low density, energetic plasma. Both electron and ion components of the plasma have similar Maxwellian-like spectra, so that the flux of the much lighter electrons greatly exceeds that of the ions. If the collection of charge were due only to primary plasma currents, all materials would charge to negative potentials of a few

times the plasma temperature. However, the impact of both primary electrons and ions on the exposed surface causes the ejection of low energy (<10 eV) secondary electrons into space. Impacting electrons can also be reflected as backscatter. These mechanisms all act as additional sources of positive current. In sunlight, photoelectrons ejected from the surface also act as a source of positive current. Photoelectrons, like secondary electrons, have low energy. Finally, current may flow to and from a surface from other parts of the object via bulk and/or surface conduction. The net current (i) to any surface is the algebraic sum of these contributions:

$$i_{net} = i^{electrons}_{primary} + i^{ions}_{primary} + i^{electrons}_{secondary} + i^{ions}_{secondary}$$

$$+ i^{electrons}_{backscatter} + i_{conductivity} + i_{photoemission}$$

If i_{net} is initially negative, the exposed surface will begin to acquire a negative potential. As the magnitude of the potential increases the net current is attenuated, until it eventually approaches zero and the surface potential remains at a steady equilibrium value. Equilibrium potentials of up to -10 kV have been observed in geosynchronous earth orbit.

If i_{net} is initially positive, the exposed surface will begin to acquire a positive potential. However, large positive equilibrium potentials are not normally achieved. This is because low energy secondary and photoemissions provide the dominant contribution to a positive current. As soon as the surface reaches a potential greater than the energy of the emitted electrons (5 or 10 eV) they can no longer escape and charging stops. In this case equilibrium is determined by the suppression of low energy emission due to the surface's own electric field. A similar suppression effect may occur due to the electric fields of neighboring negatively charged surfaces. This adds to the complexity of the situation for charging

of complicated objects and makes spacecraft charging a truly three-dimensional problem.

1.3 NASCAP CAPABILITIES

NASCAP is a collection of the various models and algorithms needed to simulate the charging of a complex object. The various formulations are written to levels of accuracy and approximation appropriate to solving problems for geosynchronous-like conditions in a reasonable amount of computer time. The NASCAP user has a great deal of flexibility in applying these capabilities to his particular problem. Among NASCAP's capabilities are:

- To define complex objects from fairly simple input.
- To define properties of materials relevant to spacecraft charging.
- To calculate electrostatic potentials around complex objects.
- To calculate shadowing of one part of an object by another.
- To calculate primary currents incident on spacecraft surfaces from a plasma or from a point source.
- To calculate secondary and backscattered electron currents.
- To calculate conductivity, biasing, and grounding currents.
- To calculate charge accumulation and resulting surface potentials.
- To calculate trajectories of charged particles incident upon, or emitted from, specified surfaces.
- To meaningfully communicate results through printed output, graphical output, and interactive post-processors.

These capabilities satisfy the requirements for study of the processes and the consequences of spacecraft charging.

1.4 THE NASCAP PHYSICAL MODEL

NASCAP objects are defined within a three-dimensional cuboidal grid (rather like a shoe box). The grid is composed of many thousands of identical cubes or volume elements stacked together. Objects are defined by filling or partially filling the cubes. For example, a quasi-sphere is shown in Figure 1.1. The exterior surfaces of the filled volume elements form the exposed surface of the object. Thus, the object surface consists of rectangular or triangular patches called surface cells. In addition to the cubic elements, NASCAP allows arbitrarily narrow cylindrical booms and thin plates to be defined. The definition of NASCAP objects is discussed in detail in Chapter 3.

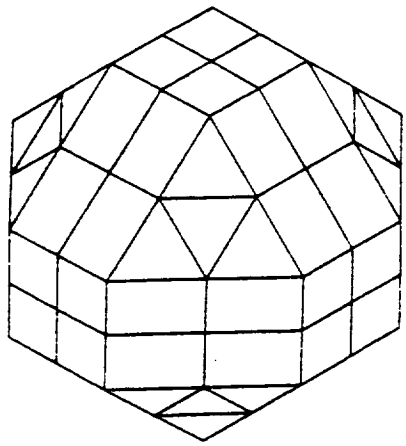


Figure 1.1. A quasi-sphere.

NASCAP calculates the potentials and currents for an object that has been exposed to a plasma environment for a chosen period of time or timestep. The initial conditions at the beginning of the timestep may be specified by the user or may be remembered from the previous timestep calculation. Similarly the results predicted for the end of the current timestep may be used as the initial condition for the next, and so on. By using a sequence of timesteps, a user may follow the dynamics of the approach to equilibrium as well as being able to examine the equilibrium state itself. The shorter the timesteps chosen, the more will be needed to reach equilibrium and the greater the detail of the dynamic charging behavior calculated.

For each timestep, or cycle, NASCAP calculates the total amount of charge that collects on each surface cell. This is determined from the net current at the beginning of the cycle, taking into account all of the contributions mentioned above. The variation of the net incident current as the surface potential changes during the cycle can also be taken into account. The charge collected is translated into a new set of surface potentials via a detailed resistive-capacitive electrical model of the satellite. Poisson's equation is then solved using the new (fixed) surface potentials to give new updated potentials in the space surrounding the object. The new potential and electric field values imply a new set of currents in the next cycle. Equilibrium is achieved when currents and potentials reach steady values for consecutive timesteps. The details of the many sophisticated physical models that are part of NASCAP are discussed in the later chapters. However, there are a number of assumptions built in that define the physical regime where NASCAP works best.

1.5 THE NASCAP PHYSICAL REGIME

NASCAP assumes orbit-limited spherical probe current collection. This is a good approximation for convex objects with radius of curvature smaller than the Debye length of the ambient plasma. Hence NASCAP works well for small objects (with dimensions of a few meters or less) in geosynchronous orbit (where Debye lengths are typically hundreds of meters). While NASCAP can simulate charging, taking into account a space charge sheath surrounding the object, it is primarily designed for the low density, high temperature plasmas found at geosynchronous altitudes where space charge can be ignored. The range of physical regimes where NASCAP can be most profitably used is discussed at length in Reference 1.

1.6 THE NASCAP FAMILY

In addition to the large NASCAP code described in this manual, there are three preprocessors and two postprocessors to aid in the use of NASCAP and the interpretation of NASCAP results. We provide very brief descriptions of these below.

1.6.1 MATCHG

MATCHG is an interactive code for the study of material-environment interactions in a zero-dimensional sense. It accepts the same material definition as NASCAP, and provides the same environment types. For simple cases, use of MATCHG can obviate the use of NASCAP, while for complex cases, it can aid the user to anticipate and understand NASCAP results.

1.6.2 FILES

FILES is a utility to aid in the maintenance (assign, copy, delete) of NASCAP restart files.

1.6.3 OBJCHECK

OBJCHECK is a semi-interactive version of the object definition portion of NASCAP.

1.6.4 CONTOURS

CONTOURS is an interactive contour plotting package. Because it makes use of available geometrical information, CONTOURS provides plots of electrostatic potential superior to those provided directly by NASCAP.

1.6.5 TERMTALK

TERMTALK is an interactive routine which extracts information from NASCAP restart files. It can provide flux breakdown for a chosen surface; time history of potential, flux, or field for chosen surfaces; ordering of surfaces by potential, flux, or field; and definition of surface cell subsets.

2. NASCAP COMMAND STRUCTURE

2.1 EXECUTING NASCAP (OR HOW DO I RUN NASCAP?)

NASCAP is delivered as one executable program element, or in the language of UNIVAC and CDC, as an 'absolute'. To run NASCAP one needs only to "execute" that element. For example, in the UNIVAC world if the NASCAP absolute resides as element 'NASCAP*NASCAP.ABS' then

@XQT NASCAP*NASCAP.ABS

will initiate a NASCAP run. Such a run can be carried out interactively, or in batch mode. Running NASCAP interactively can be fun for very simple objects, but involves many minutes (perhaps hours) staring at an inactive screen for more complex examples. Most NASCAP runs are carried out in batch mode.

Suppose you do start an interactive run and enter the line above (or its equivalent). What happens next? Nothing! NASCAP is waiting for you to tell it what to do.

2.2 KEYWORDS (OR HOW DO I TELL NASCAP WHAT TO DO?)

NASCAP has a very limited vocabulary. It understands only a small set of words. These are called keywords.

The keywords tell NASCAP exactly what you want it to do. There are a number of very basic steps the program must do to provide you, the user, with potentials and currents. These include:

1. Understand the object you wish to analyze.
2. Calculate its capacitances.
3. Understand the plasma environment you wish to study, and then go ahead and calculate the potentials on the object resulting from its interaction with the plasma.

Not all of these basic steps need be repeated with each execution of the program. For example, you may wish to study the interaction of the same sphere with different plasma environments. It is more

efficient to do this without defining the same object and then recalculating its capacitances each time. In other words, it would be convenient if NASCAP could do steps 1, 2 and 3 just once and then repeat step 3 with different environments. To enable it to do this, NASCAP is broken up internally into several modules, each of which is activated, or executed, by its primary keyword.

2.3 NASCAP MODULES

There are thirteen NASCAP modules. Each performs a specific task, may require additional input of its own, and may require output from other modules. (This is explained later for each module.) There is only one module that must be executed in every NASCAP run and it must always be executed first. This is the module RDOPT, which reads the many run options that the user may specify. (More about RDOPT and run options later in Chapter 6.)

The RDOPT module is executed, and options are read, by entering the keyword 'RDOPT' as NASCAP input. So if you are running NASCAP interactively and you type RDOPT, NASCAP will finally do something. It will read the options from file 26 (more about files later too!) and echo them back to you. Exactly the same thing happens in batch mode. The word 'RDOPT' should follow the statement beginning the execution of the NASCAP "absolute". 'RDOPT' is then followed by other primary keywords describing the sequence of operations appropriate to your problem. The primary keywords are summarized in Table 2.1.

The actual potential and current calculations are carried out by module TRILIN. Before TRILIN can be successfully executed however, it requires knowledge of the object at hand and its capacitances. This information is generated by the execution of modules OBJDEF (OBJect DEFinition) and CAPACI (CAPACItances) respectively, and is written out by them to their output files (output files are explained in Section 2.6). Unless these files are available to TRILIN it cannot be executed successfully.

The files needed by TRILIN can be generated by executing OBJDEF and CAPACI in the same NASCAP run, or by executing them in a previous run and saving their output files. Whether in the same run or in separate runs, the modules RDOPT, OBJDEF and CAPACI must be executed in that historical order for each new object defined before attempting to execute TRILIN. Once OBJDEF and CAPACI have been executed, and their files established, subsequent runs can skip straight from RDOPT to TRILIN.

2.4 THE NASCAP RUNSTREAM

The sequence of primary keywords that tell NASCAP what modules to execute form the NASCAP runstream. The simplest runstream consists of just two keywords:

```
RDOPT
END
```

RDOPT must always be the first keyword encountered in any run, and all runs must be terminated with the card 'END'.

The runstream above will not do any actual calculations. Module RDOPT will be executed, and read input from the run options file (2.6). NASCAP will then print out the resulting option values, will assign required scratch and restart files, and exit.

A more typical runstream has the form

```
COMMENT first run
RDOPT
OBJDEF
CAPACI
TRILIN
END
```

These four modules must be executed in this order to obtain currents and potentials. Note that the word

```
COMMENT
```

is also a primary keyword. It is read and has no effect. This allows

parts of the NASCAP runstream to be labeled with reminders. The same effect could be achieved with two separate runs, i.e.:

```
COMMENT  first run
RDOPT
OBJDEF
CAPACI
END
```

followed by

```
COMMENT  second run
RDOPT
TRILIN
END
```

(Note that RDOPT is executed in both runs.) Further potential calculations can be made with more runs of the form

```
RDOPT
TRILIN
END
```

Once OBJDEF and CAPACI have been executed once, and their output files saved, TRILIN can be executed by itself.

The remaining modules are all optional, in the sense that they are not necessary to calculate potentials. They too, however, must be executed according to their order of precedence.

2.5 ORDERS OF PRECEDENCE (OR WHAT COMES AFTER RDOPT?)

Table 2.2 summarizes the formal rules of precedence. The second column gives the module that must precede execution of the module at hand, and the third column the module that it logically precedes. For example HIDCEL, which calculates the shadowing of an object in sunlight prior to the calculation of its photoemission, must be preceded by OBJDEF. Otherwise there would be no object to shadow.

It logically precedes TRILIN, since TRILIN uses the shadowing information to calculate the photocurrent. If we were going to use HIDCEL in a full NASCAP run, it would come between OBJDEF and TRILIN.

```
.
.
OBJDEF
.
.
HIDCEL
.
.
TRILIN
.
.
```

However, OBJDEF must be preceded by RDOPT. Furthermore we must execute CAPACI for each new object. CAPACI and HIDCEL both have the same order of precedence, and so both of the following sequences of cards are acceptable:

```
RDOPT          RDOPT
OBJDEF         OBJDEF
HIDCEL         CAPACI
CAPACI         HIDCEL
TRILIN         TRILIN
END            END
```

Table 2.2 contains enough information to determine unambiguously an acceptable sequence of primary keywords in all cases.

It is possible to make multiple calls to the same module in the same runstream. For example, when using ROTATE this is required.

```
COMMENT  rotate run
RDOPT
OBJDEF
CAPACI
HIDCEL
TRILIN
ROTATE
TRILIN
ROTATE
TRILIN
END
```

This run calls TRILIN three times, with the sun at different angles to the object. The orientation of the sun is calculated by ROTATE to simulate a spinning satellite.

2.6 FILES

NASCAP generates large amounts of information in the form of lists and arrays as each of the modules are executed; too much information to be held in program memory. To overcome this problem NASCAP stores information by writing it out to a file, and reads it back into memory only when needed. Writing to files also allows modules to share information with each other, both in the same run and separate runs.

The UNIVAC version of NASCAP assigns all of its own (temporary) output (or scratch) files. Versions running under other operating systems require the user to pre-assign these files. A list of output files is shown in Table 2.3. There are a minimum of 14. Some options require additional output files. (This is explained in sections dealing with those options.)

Input files must be assigned (and written) by the user. There are three principle input files: The object definition file, the flux definition file and the run options file.

The object definition file contains sets of secondary keywords and parameters that define the structure of the object. This is read by module OBJDEF and is discussed in detail in Chapter 3.

The flux definition file also consists of secondary keywords and parameters. It defines the plasma spectrum and its angular distribution, in space or in a test tank. This is read by module TRILIN and is discussed in Chapter 5.

The run option file is read by RDOPT and lists the options chosen by the user, from the many available that control the way the program runs. Each option is specified with a secondary keyword. This is explained in Section 6.1.

The default input file numbers for each primary keyword are shown in Table 2.4. The input file numbers can be specified by the user simply by following the primary keyword by the file or unit number; e.g.,

RDOPT 24

will cause the RDOPT module to search for input in file 24 instead of the default file 26.

FILE 5 is the NASCAP runstream; i.e.,

RDOPT 5

will cause the cards following 'RDOPT 5' in the NASCAP runstream to be read by module RDOPT. In the same way

OBJDEF 5

will cause module OBJDEF to read cards from the keyword runstream, and so on. In this way all NASCAP input can be included in one self-contained runstream. For example:

```
@XQT  NASCAP*NASCAP.ABS  (UNIVAC)

RDOPT  5
rdopt options (Chapter 6)
END

OBJDEF  5
object definition cards (Chapter 3)
END

CAPACI

HIDCEL

TRILIN  5
plasma environment cards (Chapter 5)
END

END
```

NASCAP also assigns names to each file number. For example, file 22 read by TRILIN is called IFLUX. The default file (number 22) can be changed by setting IFLUX to a different value. IFLUX and the other files may be set by the user as run options. (This is discussed in Chapter 6 dealing with RDOPT and run options in detail.) Changing IFLUX from 22 to, say <n>, causes the default TRILIN file to be changed from 22 to <n> for that particular run only. So multiple calls to TRILIN will read from file <n> each time if no file number is included after the keyword; e.g.,

```
TRILIN
TRILIN
```

will read from the new default <n>. Including a file number after the keyword has the same effect as changing IFLUX.

The names of each file are included in Tables 2.3 and 2.4. Table 2.5 gives a list of spare file numbers available to the user up to 49. The following discussion assumes the user will use the default file numbers for NASCAP output files.

2.7 RESTART FILES

If NASCAP information is intended for use in subsequent runs some of the output files must be made permanent and saved. Only six need to be saved. These are called the restart files. They are files 10, 15, 16, 17, 21, 27 (and 19 for runs specifying TANK). These files store, among other things, the object definition and capacitance information that allow TRILIN to be executed in runs subsequent to OBJDEF and CAPACI. They also allow information from previous TRILIN cycles (or timesteps) to be used by new TRILIN executions, and to continue charging sequences from where previous runs left off. This is carried out using the RESTART option discussed in Section 6.2.9.

It is also often useful to save file 2. This allows graphical output to be replotted later (see Chapter 9).

2.8 TECHNICAL DISCUSSION

All NASCAP output files are sequential files accessed by Fast I/O routines, except file 21 (and 38). File 21 is a random access file. In the UNIVAC version of NASCAP the routines FASTRW, FASREW, FASPOS are used to access all files. In CDC versions, BUFFER IN and BUFFER OUT (MSIO for file 21) perform this function. The random access file 21 contains surface cell information and other run parameters in individual records. The record "housekeeping" is carried out by routine CELLIO. Access calls always occur via this routine. The information stored in each record is summarized in Table 2.6.

2.9 SUMMARY

NASCAP is divided into thirteen MODULES, each of which is activated by its primary keyword. NASCAP runstreams consist of a control card to execute the program "absolute", followed by a sequence of primary keywords. The execution of the NASCAP modules and hence the order of the keywords must follow certain rules of precedence. NASCAP reads and writes information to files. If six of these files (the restart files) are made permanent, separate runs may share information.

TABLE 2.1. NASCAP MODULES AND PRIMARY KEYWORDS

Module and Keyword	Task	Additional Input
CAPACI	Calculates object capacitances	No
DETECT	Enables DETECTOR run option	Yes. Default - assumes input follows keyword (Unit 5)
HIDCEL	Calculates the shadowing of an object illuminated by the sun	No
IPS	Sets up initial potentials other than zero on surface cells	Yes. Default - assumes input follows keyword (Unit 5)
NEWMAT	Defines new material properties	Yes. (No default - input file must be specified)
OBJDEF	Reads and processes object definition information	Yes. Default - read object definition from file 20
RDOPT	Reads run option and initializes program parameters	Yes. Default - read option from file 26
ROTATE	Causes NASCAP to model a rotating object	Yes. (No default - input file must be specified)
SATPLT	Produces plots and pictures of the object	No
SPIN	Causes NASCAP to model a rotating object by averaging the effect of the sun and magnetic field over one rotation	Yes. (No default - input file must be specified)
STRESS	Searches for insulating cells having the highest internal stress	Yes. (No default - input file must be specified)
TANK	Defines a test tank environment with multiple particle guns	Yes. Default - read gun definitions from file 22
TRILIN	Reads parameters describing the plasma environment and calculates potentials and currents	Yes. Default - read environment from file 22

TABLE 2.2. PRECEDENCE OF PRIMARY KEYWORDS

Keyword	Must Be Preceded By	Logically Precedes
CAPACI	OBJDEF	TRILIN or IPS
DETECT	TRILIN (or IPS)	(None)
HIDCEL	OBJDEF	TRILIN
IPS	CAPACI	TRILIN or DETECT
NEWMAT	OBJDEF	TRILIN
OBJDEF	RDOPT	CAPACI
RDOPT	(None)	(All)
ROTATE	TRILIN	TRILIN
SATPLT	OBJDEF	(None)
SPIN	OBJDEF	TRILIN
STRESS	TRILIN	(None)
TANK	RDOPT	TRILIN*
TRILIN	CAPACI	DETECT
COMMENT	(None)	(None)

* If shadowing options HIDCEL, SPIN or ROTATE are chosen, they must follow TANK before TRILIN.

TABLE 2.3. NASCAP OUTPUT FILES

Default File No.	File Name	Written By	Read By	Information Content
2	None	OBJDEF SATPLT HIDCEL *ROTATE SPIN DETECT TRILIN *when plot options are specified	NASCAP*PLOTREAD. (Chapter 9)	NASCAP graphics calls.
10 (RESTART)	IP	TRILIN CAPACI IPS	TRILIN CAPACI IPS	Conjugate gradient scratch file (Section 3.15). Contains potential array on completion of TRILIN, CAPACI or IPS.
11	IAUN	TRILIN CAPACI IPS	TRILIN CAPACI IPS	Conjugate gradient scratch file (Section 3.15).
		SPIN	SPIN	SPIN scratch file - used to store shadowing information.
12	IR	TRILIN CAPACI IPS	TRILIN CAPACI IPS	Conjugate gradient scratch file (Section 3.15).
13	IU	TRILIN CAPACI IPS	TRILIN CAPACI IPS	Conjugate gradient scratch file (Section 3.15).

TABLE 2.3. NASCAP OUTPUT FILES (CONTINUED)

Default File No.	File Name	Written By	Read By	Information Content
14	ISPARE	TRILIN CAPACI IPS	TRILIN CAPACI IPS	Conjugate gradient scratch file (Section 3.15).
		HIDCEL SPIN TANK SATPLT ROTATE	HIDCEL SPIN TANK SATPLT ROTATE	Scratch file for shadowing information.
15 (RESTART)	IROUS	TRILIN CAPACI IPS	TRILIN CAPACI IPS	Charge density array.
16 (RESTART)	IPQCND	TRILIN	Associated independent program 'TERMTALK'	TERMTALK information (Section
17 (RESTART)	ILTBL	OBJDEF	OBJDEF CAPACI TRILIN IPS DETECT	Object volume element table (LTBL).
18	IOBJ	None	None	Reserved for future use.
19 (RESTART when 'TANK' is specified)	IOBPLT	TANK	TRILIN	Beam shadowing information.

TABLE 2.3. NASCAP OUTPUT FILES (CONCLUDED)

Default File No.	File Name	Written By	Read By	Information Content
21 (RESTART)	ICNOW	All	All	Individual cell information (Section
25	IDIV	TRILIN, CAPACI, IPS	TRILIN, CAPACI, IPS	D^2 (Scaled conjugate gradient array).
27 (RESTART)	IAREA	OBJDEF	TRILIN, CAPACI, IPS	Boom conjugate gradient matrices.
28	IPART	TRILIN	DETECT	Particle plotting information.
38	None	DETECT	(User program)	Particle trajectory information (Chapter 7).
46	None	END	-	EXEC file to automatically execute PLOTREAD.

TABLE 2.4. USER INPUT FILES

NASCAP Name	Default File Number	Read By	Information Content
None	5	Main Program	NASCAP KEYWORDS and runstream (cannot be changed).
ISPECTR	9	TRILIN in 'UPDATE' or 'DIRECT' modes (Chapter 5)	Environment information (Chapter 5).
ISAT	20	OBJDEF	Object definition statements (Chapter 3).
IFLUX	22	TRILIN or TANK	Environment information (Chapter 5).
IKEYWD	26	RDOPT	User specified options (Chapter 6).
None	None	TRILIN - when EMITTER option is enabled	Emitter information (Chapter 7).
None	None	DETECT	Detector information (Chapter 7).
None	None	NEWMAT	Material properties (Chapter 4).
None	None	IPS	Initial potential specifications (Chapter 8).
None	None	ROTATE	ROTATE parameters (Chapter 8).
None	None	SPIN	SPIN parameters (Chapter 8).

TABLE 2.5. SPARE FILES AVAILABLE TO THE USER

1	30	37	47
3	31	39	48
4*	32	40**	49
8	33	42	
23	34	43	
24	35	44	
29	36	45	

* Files 6 and 7 are reserved for printed and punched (not used) output, respectively.

** File 41 is used by the 'DISSPLA' graphics package and is best avoided.

TABLE 2.6. FILE 21 RECORDS

Record No.	Record ID	Length	Content
1	VINS	1024	Potentials of insulating surface cells (V)
2	VPTS	1024	Not used
3	EINS	1024	Electric field external to insulating surface cells (V $mesh^{-1}$)
4	ATOT	1250	Areas of surface cells $(mesh)^2$
5	AREA	1250	Fraction of the area of surface cells sunlit
6	C-INF	1024	Capacitance of insulating cells to plasma ground or tank wall (code units)
7	DPTLST	500	List of double points (see 3.13)
8	C-COND	1024	Capacitance from the surface of an insulating cell to its underlying conductor (code units)
9	FLUX	1250	Explicit net particle flux to each surface cell (code units)
10	DQEMIT	1024	Change in charge due to low energy emitted electron for each insulating cell (code units)
11	DQ	1024	Change in charge for each insulating cell (code units)
12	PTLIST	1024	List of all points that are corners of insulating surface cells
13	APT	1024	Areas associated with above points (PTLIST) $(mesh)^2$

TABLE 2.6. FILE 21 RECORDS (CONTINUED)

Record No.	Record ID	Length	Content
14	LINS	1024	List of insulating surface cell numbers
15	VBOOM	100	Potentials of the boom cells (V)
16	SIGMA	1024	(Not used)
17	EBOOM	100	Electric fields external to boom surface cells (V mesh^{-1})
18	DFDV	1024	Flux derivatives for insulating surface cells
19	CSCOND	15	Capacitance of each conductor to plasma ground or test tank wall (code units)
20	CIJSMA	15	Stray capacitances of conductor to spacecraft ground (code units)
21	SCMAT	9537	Conductivity matrix (code units)
22	SCLIST	9537	Sparseness pattern of conductivity matrix (who connects to whom)
23	CPTLST	1024	List of surface points which are not corners of insulating cells
24	BINF	141	BINF common block - boom parameters
25	BSHAD	100	Shadowing factors for boom cells

TABLE 2.6. FILE 21 RECORDS (CONTINUED)

Record No.	Record ID	Length	Content
26	XFLUX	200	Explicit net flux for boom cells (code units)
27	PPEE	500	Potentials for bottom point of a double point (conjugate gradient)
28	PYOU	500	Vector U (conjugate gradient) for bottom points
29	PARR	500	Vector R (conjugate gradient) for bottom points
30	PAUN	500	Vector AU (conjugate gradient) for bottom points
31	PDIV	500	Vector D^2 (scaled conjugate gradient) for bottom points
32	PROUS	500	Charge densities for bottom points (code units)
33	VCELLS	1250	Potentials of surface cells (V)
34	ECELLS	1250	External electric fields of surface cells V ($mesh^{-1}$)
35	PZLIST	500	List of bottom points held at fixed potentials
36	ZLIST	1024	List of top points held at fixed potentials
37	RFLAGS	1	Type of shadowing performed
38	SURF3	1251	Common block - number of surface cells (1) and surface cell list (1250)
39	MATLS	316	Material properties (MATLS common block) (see Chapter 4)
40	VTXL	6200	Vertex surface cell list
41	BOOMS	111	Common block - boom information

TABLE 2.6. FILE 21 RECORDS (CONTINUED)

Record No.	Record ID	Length	Content
42	SILHOU	6289	Non-hidden line object plotting information
43	BLOCKS	597	Common block - volume cell information
44	TIMHIS	150	Elapsed time for each cycle performed so far (seconds)
45	QSUHIS	150	Total charge on the object at each cycle (code units)
46	RELSAV	35	Time and conductor potentials and charges for current cycle (volts and code units)
47	INTSAV	35	Cycle number, number of conductors, etc.
48	RDOTSV	100	Residuals for each conjugate gradient iteration
49	CAPRDO	100	Residuals from each conjugate gradient iteration called from CAPACI
50	PCONSV	2250	Conductor potential for each cycle completed (V)
51	PHCMAT	9537	Conductivity matrix including photoconductivity (code units)
52	CNDCUR	60	Currents to each conductor (A)
53	FIFLUX	1350	Average flux to each surface cell during the previous timestep (A m^{-2})
54	SCOPT	5	Common block - screening options
55	GUNS	181	Common block - multigun definition information
56	FIN	1250	Incident electron current to surface cells (A m^{-2})

TABLE 2.6. FILE 21 RECORDS (CONCLUDED)

Record No.	Record ID	Length	Content
57	FOU	1250	Secondary electron current from surface cells (A m^{-2})
58	FINP	1250	Incident ion current to surface cells (A m^{-2})
59	FOUP	1250	Secondary electron current due to ion impact from surface cells (A m^{-2})
60	FELB	1250	Backscatter from surface cells (A m^{-2})
61	PCURR	1250	Photocurrent from surface cells (A m^{-2})
62	BFIN	250	Incident electron current to boom cells (A m^{-2})
63	BFOU	250	Secondary electron current from boom cells (A m^{-2})
64	BFIP	250	Incident ion current to boom cells (A m^{-2})
65	BFOP	250	Secondary electron current due to ion impact on boom cells (A m^{-2})
66	BFEL	250	Backscatter from boom cells (A m^{-2})
67	BPCU	250	Photocurrent from boom cells (A m^{-2})
68	ANIP	4	Anisotropic flux parameters
69	TNKSZ	5	Grid truncation information
70	CLST	1024	Field-induced bulk conductivity of insulating cells (code units)
71	FINER	61	(Not used by NASCAP)
72	MCOND	286	Common block - capacitance between conductors and fixing information

3. DEFINING OBJECTS

3.1 COMPUTATIONAL SPACE

NASCAP calculates the electric potential in the space surrounding an object as well as the potential of the object itself. Before it can determine these potentials NASCAP must first recognize and understand both the object defined and the amount of surrounding space to be included in the calculations. The total amount of space (including that filled by the object) included in the potential calculation is called the computational space. The edges of the space form the outer boundary.

3.2 THE GRID

The computational space used by NASCAP is a three-dimensional Cartesian space. Any point may be determined by specifying its coordinates according to three mutually perpendicular axes X, Y and Z. If all three axes have the same scale we may imagine the space to be subdivided into many small identical cubic volumes (with the length of cube's side equal to one axis unit). These cubic volumes are called volume elements. This is shown in Figure 3.1. The corners of the volume elements are points in the coordinate system or nodal (or grid) points. Each grid point is described by its X, Y, Z coordinates. For example, the grid point labeled in Figure 3.1 is (5, 6, 8). The grid points and the volume elements filling the space between them form a computational grid (or just a grid).

The default NASCAP grid has dimensions 17 x 17 x 33. This means that there are 17 points (and hence 16 length units) in the X and Y directions and 33 points (32 length units) in the Z direction (a "shoe box-like" space). The number of points in the Z direction can also be specified by the user to be a number less than 33 (6.4.8). The length unit, or distance along the axes between points, is called the grid spacing or 'XMESH'. XMESH is determined by the user as a run

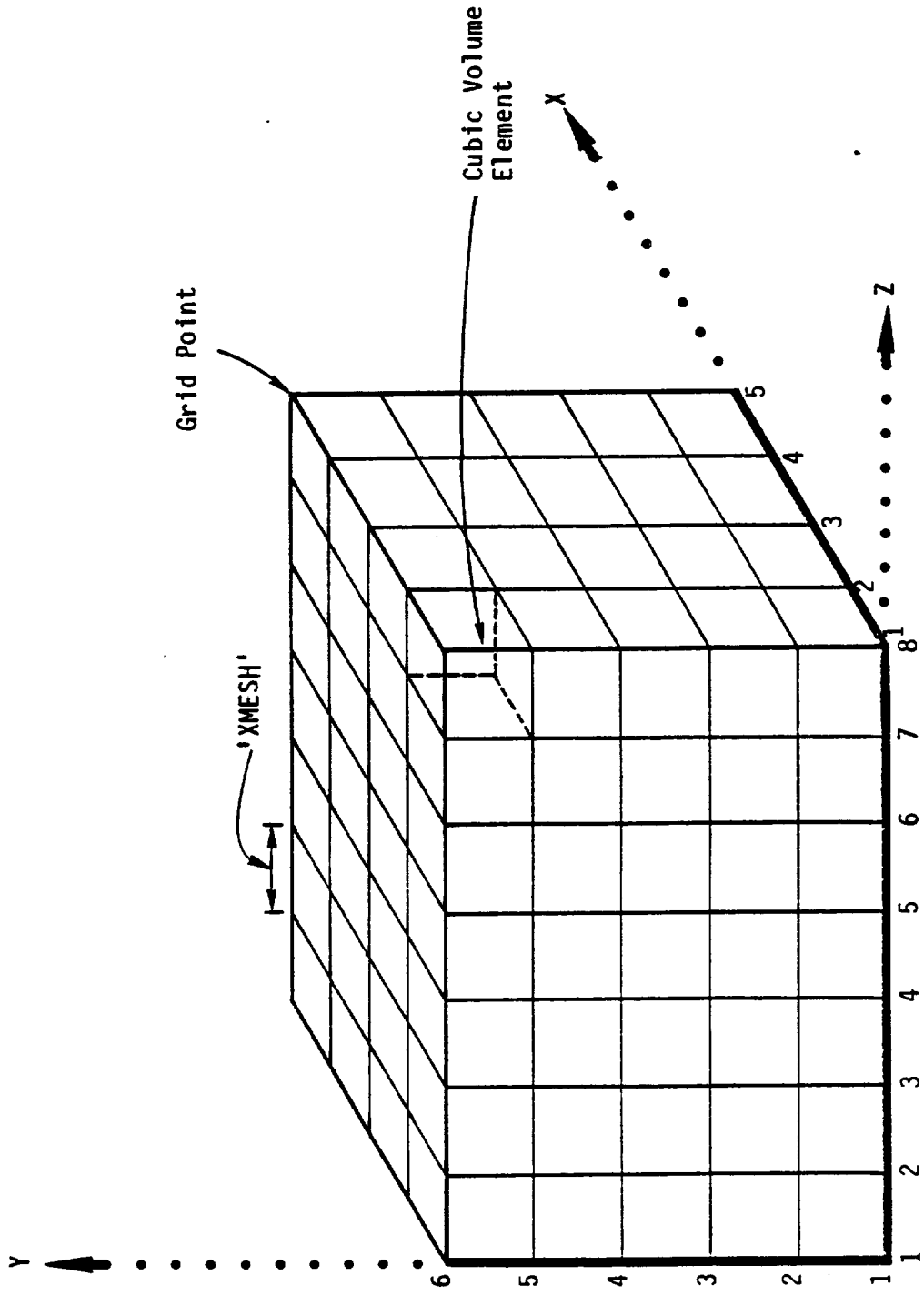


Figure 3.1. Three-dimensional computational grid.

option (6.4.15). It may be any positive value, and so the computational space may be any physical size. However, as the absolute size of XMESH is increased the smallest amount of volume that can be recognized by NASCAP (the volume of a volume element) is also increased. This means that any interesting and/or important physical phenomena that occur on length scales much smaller than XMESH become too detailed for NASCAP to model - or resolve. Increasing XMESH decreases the resolution of the NASCAP calculations.

To overcome this problem and allow NASCAP to include large amounts of computational space without sacrificing resolution everywhere, nested grids are allowed. Two grids are said to be nested when one exists inside the other. NASCAP allows up to five nested grids. Each shares a common origin at the center of the innermost grid. The grid spacing is successively doubled from grid to grid. For example, consider grid 2 to extend from -8 to +8 in the X and Y directions and -16 to +16 in the Z direction in its own (doubled) coordinates, and the inner grid (grid 1) to extend to and from the same values in grid 1 coordinates. In grid 2 coordinates grid 1 extends from -4 to +4 in X and Y and -8 to +8 in Z only, while in grid 1 coordinates grid 2 extends from -16 to +16 and -32 to +32. The same relationships then apply to grid 2 and 3, 3 and 4, and so on. A two-dimensional illustration of nested grids is shown in Figure 3.2.

Nested grids allow a small XMESH and hence high resolution for the innermost grid while allowing NASCAP to incorporate large amounts of space (with coarser resolution) far from the origin. This arrangement is particularly well suited to the calculation of potentials of satellite-sized objects exposed to the long (many meters) Debye length plasmas found at geosynchronous altitudes.

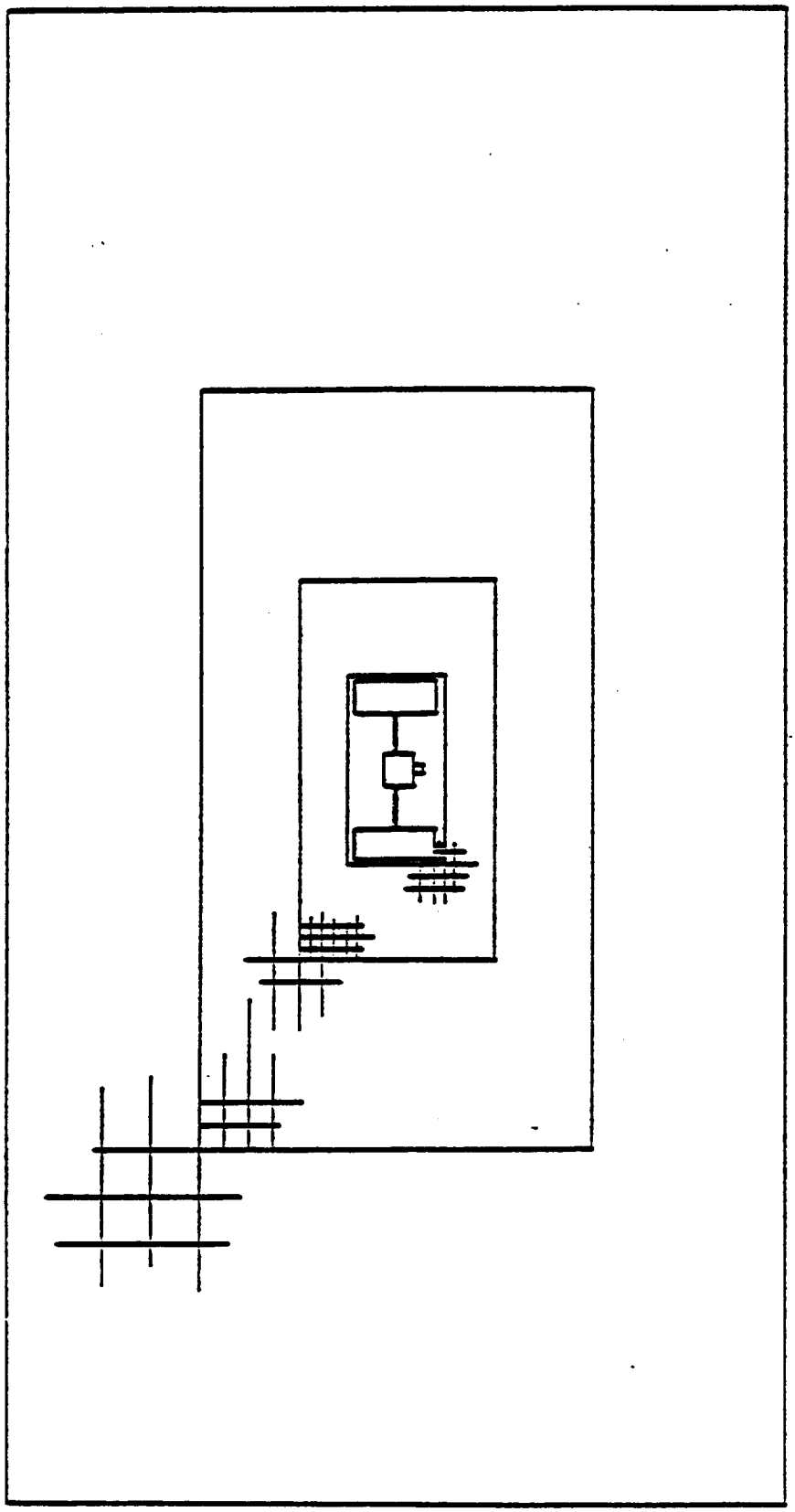


Figure 3.2. Cross-section of grid, showing first four embedded meshes.

3.3 OBJECTS

All NASCAP objects are confined to the space inside the innermost 17 x 17 x 33 grid. Only BOOMS (see Section 3.6) are allowed to extend into outer grids. If "empty space" and "object" both coexist in the same computational space what makes objects distinguishable? The answer is that NASCAP can distinguish between volume elements that are filled (with object) and those that are empty (except for ambient plasma of course). Once we have this distinction it is easy to see how objects can be constructed by filling in collections of volume elements. For example, a simple cuboid may be constructed by filling in 2 x 3 x 4 = 24 elements as shown in Figure 3.3.

While arrangements of completely filled and completely empty cubes can be quite versatile in representing objects of many different shapes, more sophisticated representations are possible if we allow cubes to be partially filled (or as a pessimist might say, partially empty). Only three partially filled cubes are allowed. These are shown in Figure 3.4.

While it is easy to see how objects might be constructed by filling or partially filling individual volume elements, a command structure that required the user to specify every element comprising an object would be very cumbersome to use.

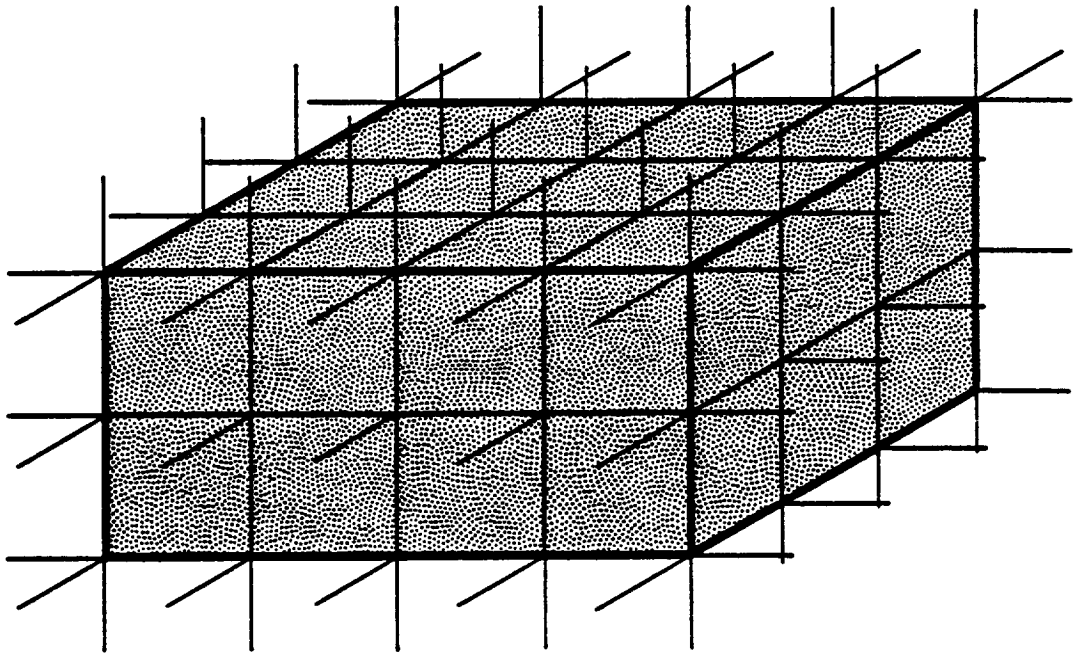


Figure 3.3. Cuboid made by filling in twenty-four volume elements.

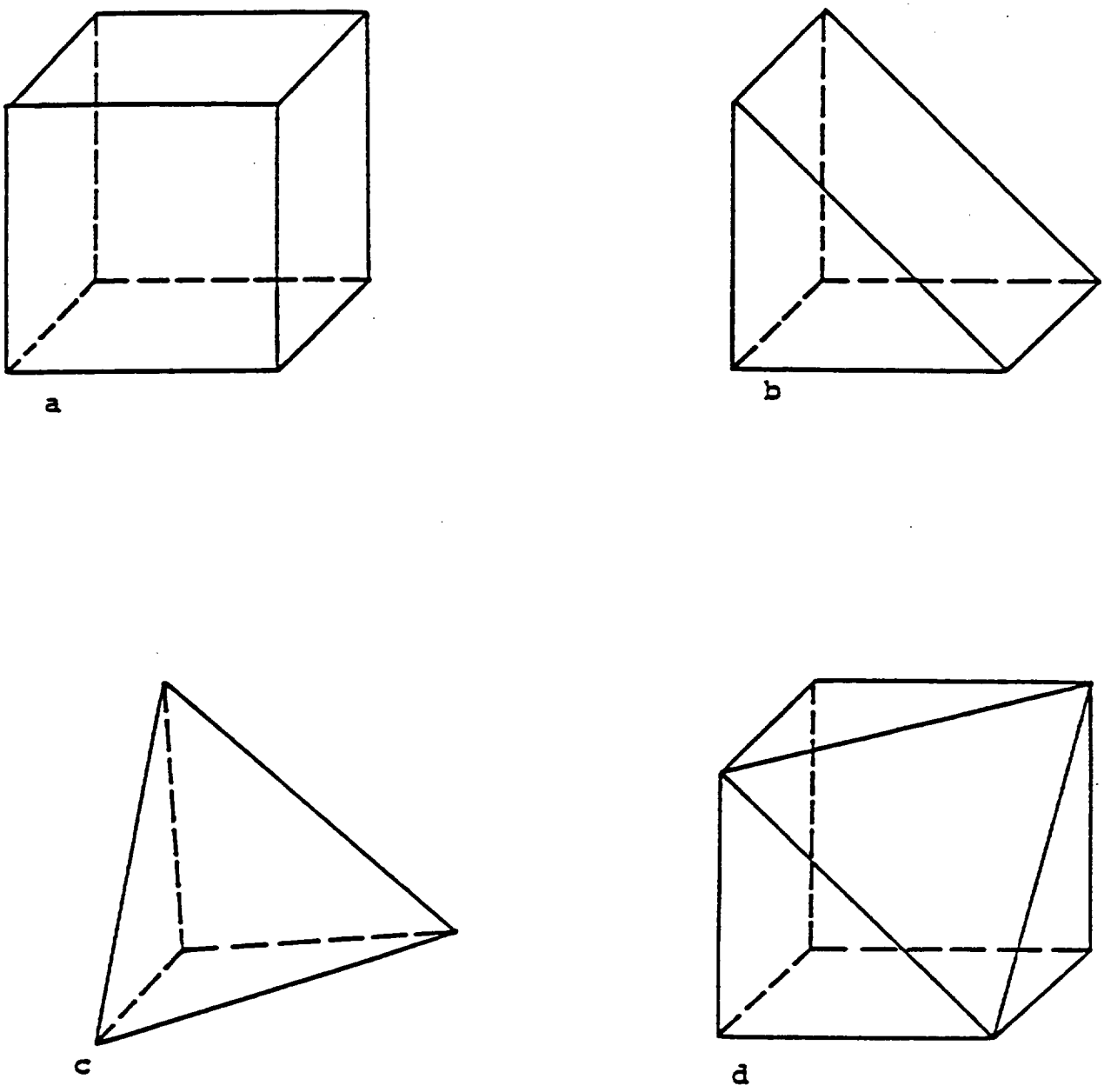


Figure 3.4. Four shapes of volume cells considered by the NASCAP code: (a) empty cube; (b) wedge-shaped cell with 110 surface; (c) tetrahedron with 111 surface; (d) truncated cube with 111 surface.

3.4 BUILDING BLOCKS

To greatly simplify the user definition of objects NASCAP pre-defines commonly used shapes built up from individual elements. These shapes are called NASCAP BUILDING BLOCKS. There are six.

Cuboid
Octagon
Quasisphere
Tetrahedron
Wedge
FIL111

These are shown in Figure 3.5. These basic shapes can be defined to be any size (within the inner grid). NASCAP automatically includes the correct number of individual elements for the size of building block chosen by the user.

3.5 COMMANDS (OR HOW DO I ACTUALLY DEFINE AN OBJECT?)

The NASCAP module OBJDEF is responsible for recognizing and understanding the OBJect DEFined by the user. Just as the primary keyword (Chapter 2), 'OBJDEF' in the main runstream causes OBJDEF to be executed, so secondary keywords are used to give instructions to the OBJDEF module. As explained in Chapter 2, OBJDEF reads information from a file whose default number is 20. This is called the object definition file and consists of a collection of secondary keywords and associated parameters.

Each building block has its own keyword. For example, the quasi-sphere is associated with the word QSPHERE, and the cuboid (rectangular parallelepiped) with the word RECTAN. The building blocks and their keywords are summarized in Table 3.1.

Once OBJDEF has read a building block keyword from the object definition file, it then expects to find several more lines (or cards) setting the block parameters. These might include the dimensions of

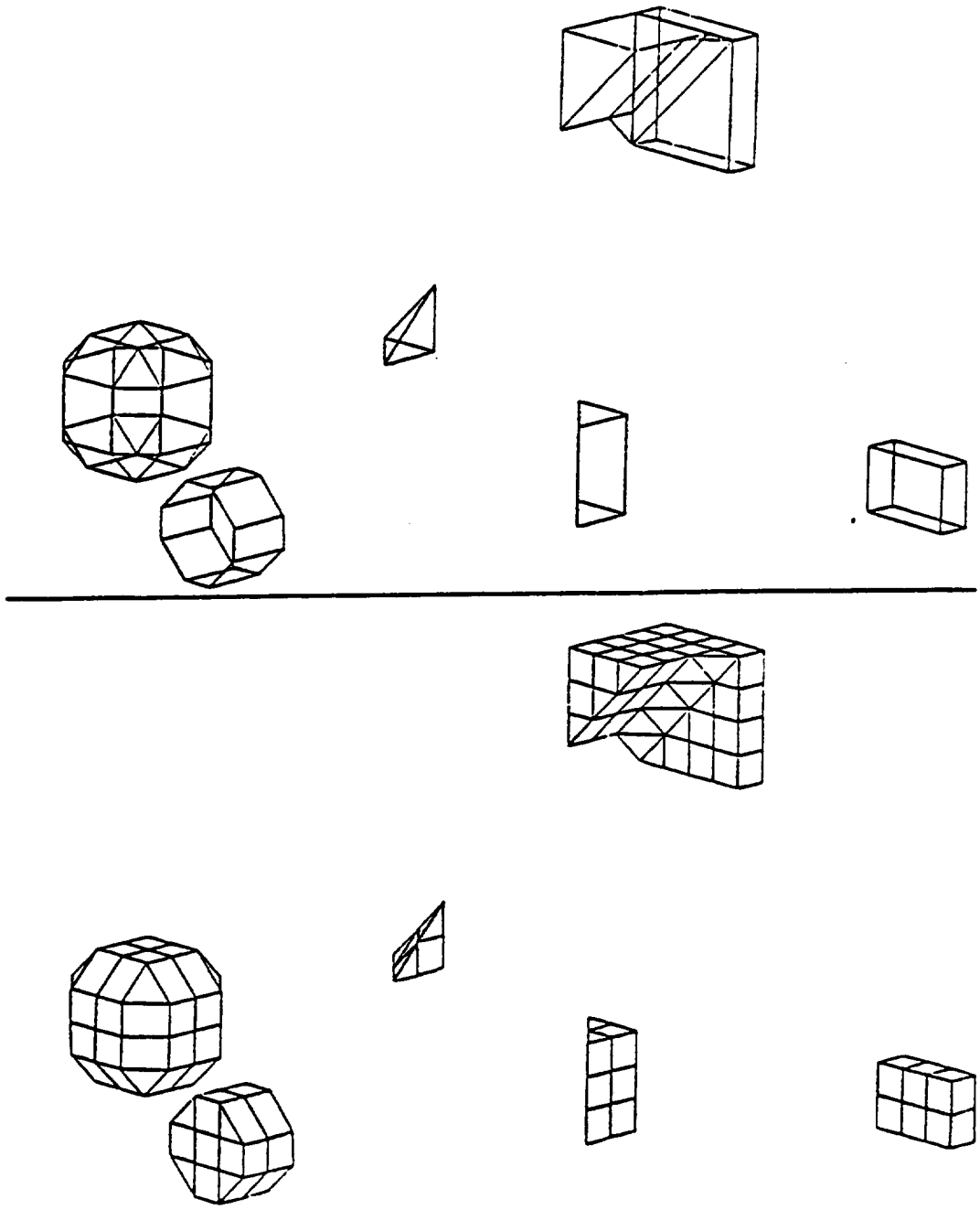


Figure 3.5. The six building block types are shown here. The uppermost object shows a FIL111 smoothing a corner. Below, from left to right are quasi-sphere, octagon right cylinder, tetrahedron, wedge, and rectangular parallelepiped.

TABLE 3.1. NASCAP BUILDING BLOCKS AND THEIR KEYWORDS

Keyword	Building Block Description
BOOM	Long thin BOOM
FIL111	Smooth inside of a diagonal corner
OCTAGON	Right octagonal cylinder
PATCHR	Surface of a rectangle
PATCHW	Diagonal face of a wedge
PLATE	Arbitrarily thin plate or cuboid
QSPHERE	Quasisphere
RECTAN	Cuboid or rectangular parallelepiped
TETRAH	Tetrahedron
WEDGE	Wedge derived from half a cube

the building block, its orientation and the materials that cover its surface. (Surface materials are discussed in Chapter 4.) Finally, OBJDEF expects to find a line 'ENDOBJ' telling it that no more information referring to the present block is coming and to expect the next building block keyword. The information to be entered in the object definition file for each building block is summarized in Table 3.2. Note that numbers and words may be separated by one or more spaces on the same line. (Input is free-format.)

3.6 BOOMS, PLATES AND PATCHES

A careful inspection of Table 3.1 will show that there are some building blocks that are not derived from cubic volume elements. These are the BOOM, PLATE, PATCHR and PATCHW.

BOOMs are long cylindrical projections that may have an arbitrary radius. They may only lie along the X, Y, or Z directions. Unlike any of the other building blocks they may extend beyond the innermost grid.

PLATEs are arbitrarily thin cuboids (RECTANS). They are assumed to have only a top and a bottom, the sides being of negligible height. They always lie in one of the axis planes (XY, XZ, YZ).

PATCHR and PATCHW are the surfaces only of a cuboid and wedge, respectively. They are used to change the surface material patterns of existing building blocks and should never be defined in spaces not already occupied by solid objects. (Objects defined to occupy the same space are explained in Section 4.7.)

TABLE 3.2. OBJECT DEFINITION — FILE 20

OBJECT DEFINITION—FILE 20

All integer input—except for "radius" and "materialname." See NASCAP Users Manual for information on material parameters.

OBJECT DEFINITION SYNTAX	OBJECT DEFINITION EXAMPLES
RECTAN CORNER x y z DELTAS Δx Δy Δz (UP TO 6 SURFACE CARDS) ENDOBJ	RECTAN CORNER 3 −2 8 DELTAS 1 2 4 SURFACE +X ALUMINUM SURFACE −X ALUMINUM SURFACE +Y ALUMINUM SURFACE −Y ALUMINUM SURFACE +Z ALUMINUM SURFACE −Z ALUMINUM ENDOBJ
WEDGE CORNER x y z FACE materialname normal (type 110) LENGTH Δx Δy Δz (UP TO 4 SURFACE CARDS) ENDOBJ	WEDGE CORNER −3 2 1 FACE SIO2 −1 −1 0 LENGTH 1 1 3 SURFACE +X SIO2 SURFACE +Y SIO2 SURFACE +Z GOLD SURFACE −Z SIO2 ENDOBJ
TETRAH CORNER x y z. FACE materialname normal (type 111) LENGTH Δx (UP TO 3 SURFACE CARDS) ENDOBJ	TETRAH CORNER −3 −2 8 FACE KAPTON 1 1 −1 LENGTH 2 SURFACE −X TEFLON SURFACE −Y KAPTON SURFACE +Z TEFLON ENDOBJ
OCTAGON AXIS x y z x′ y′ z′ WIDTH w SIDE s (UP TO 3 SPECIAL SURFACE CARDS "+", "−", or "C") ENDOBJ	OCTAGON AXIS 3. 2. −6 3. 2. −9 WIDTH 3 SIDE 1 SURFACE + SILVER SURFACE − SILVER SURFACE C MAGNES ENDOBJ
BOOM AXIS x y z x′ y′ z′ RADIUS radius (floating point) SURFACE materialname ENDOBJ	BOOM AXIS 0. 6. 0 0. 12. 0 RADIUS .25 SURFACE ALUMINUM ENDOBJ
QSPHERE CENTER x y z DIAMETER d SIDE s MATERIAL materialname ENDOBJ	QSPHERE CENTER 0. 0. 0 DIAMETER 4 SIDE 2 MATERIAL NPAINT ENDOBJ

OBJECT DEFINITION SYNTAX	OBJECT DEFINITION EXAMPLES
FIL111 CORNERLINE x y z x′ y′ z′ FACE materialname normal (type 111) ENDOBJ	FIL111 CORNER 3. 2. 6. −5. 4. 6 FACE SOLAR −1. −1. −1 ENDOBJ
PLATE CORNER x y z DELTAS Δx Δy Δz TOP $\pm\begin{pmatrix}x\\y\\z\end{pmatrix}$ materialname BOTTOM $\pm\begin{pmatrix}x\\y\\z\end{pmatrix}$ materialname ENDOBJ	PLATE CORNER −1 −1 −10 DELTAS 2 2 0 TOP +Z CPAINT BOTTOM −Z CPAINT ENDOBJ
PATCHR CORNER x y z DELTAS Δx Δy Δz (UP TO 6 SURFACE CARDS) ENDOBJ	PATCHR CORNER 3 −2 8 DELTAS 1 0 1 SURFACE −Y SCREEN ENDOBJ
PATCHW CORNER x y z FACE materialname normal (type 110) LENGTH Δx Δy Δz (UP TO 4 SURFACE CARDS) ENDOBJ	PATCHW CORNER −3 2 7 FACE AQUADG −1 −1 0 LENGTH 1 1 1 ENDOBJ

NOTES: "normal" is three values, each either +1. 0. or −1.

SURFACE CARD has the following format:

SURFACE $\pm\begin{pmatrix}x\\y\\z\end{pmatrix}$ materialname

SPECIAL SURFACE CARD is:

SURFACE $\begin{pmatrix}\pm\\C\end{pmatrix}$ materialname

OTHER OBJECT DEFINITION COMMANDS

ENDSAT	Must be last card in file.
COMMENT	No effect.
OFFSET i j k	Moves coordinate origin.
CONDUCTOR n	Sets number of underlying conductor ($1 \leq n \leq 15$).
DELETE i j k	Deletes surfaces, leaving empty cell.
unrecognized word	Assumed to be name of new surface material. Next card scanned for parameters.

3.7 FIL111 AND TRANSPARENT ANTENNA SURFACES

3.7.1 FIL111

FIL111 is a special shape designed to fill in "steps" whose corner line runs at 45° to the grid lines in any axis plane (i.e., XY, ZY, XZ) (Figure 3.6a). There are two kind of "steps" that can occur between NASCAP building blocks. For example, a small cuboid on top of another creates four "steps" that lie along grid lines (Figure 3.6b). These may be "filled in" or smoothed by defining a WEDGE to lie along the corner line of the step. A second type of step is possible however when, for example, a tetrahedron or octagon is defined to sit on top of another building block. These steps have corner lines that run at 45° between grid lines. This is shown in Figure 3.6c. Such steps can be smoothed or filled in by a combination of tetrahedra and truncated cubes. This combination is supplied as the building block FIL111.

3.7.2 TRANSPARENT ANTENNA SURFACES

Antenna surface cells may be square (defined by the PLATE subroutine), rectangular (defined by the ASLANT subroutine), or equilateral triangle (defined by the ATET subroutine). No provision is made for right triangle antenna cells. Antenna surface cells are automatically treated as two-sided by NASCAP; only one side of the surface should be defined. Antenna surfaces should not be used to supersede solid surfaces, although solid surfaces may supersede antenna surfaces. Mesh surfaces are marked by bit 4 of the surface cell word (equivalent to adding 16 to the material number). HIDCEL draws the cell outlines of antenna cells, except, of course, where they are shadowed by solid objects. For line-plot devices such drawings can be a bit messy; plots are far better on color-fill devices. For material plots, mesh surfaces are treated as non-transparent.

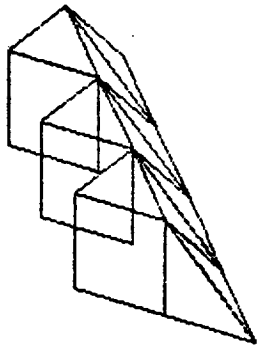


Figure 3.6a. A FIL111 building block all by itself.

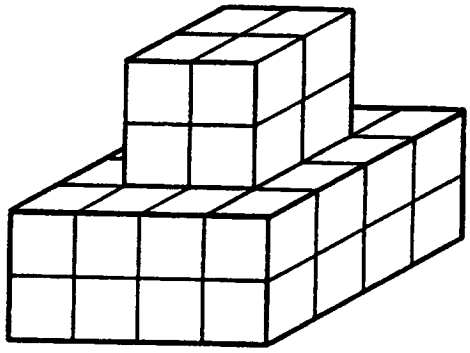


Figure 3.6b. "Steps" along grid lines.

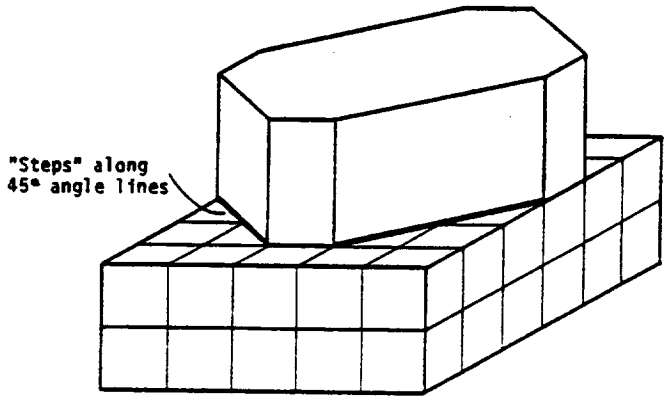


Figure 3.6c. "Steps" along 45° angle lines.

3.8 BUILDING BLOCK PARAMETERS (OR WHO'S ON NEXT?)

The very center of the 17 x 17 x 33 inner grid is assumed to be the origin of the coordinate system 0, 0, 0. Hence the grid itself extends from -8 to +8 in the X and Y directions and from -16 to +16 in the Z direction. This coordinate system is used to specify the position and size of the building blocks in the parameter "cards" or lines following the building block keyword. Let us examine the definition of each building block in detail to see how this works.

3.8.1 RECTAN

The following cards define a cuboid or rectangular parallelepiped:

```
RECTAN
CORNER   x y z
DELTAS   Δx, Δy, Δz
SURFACE  +X GOLD
SURFACE  -Y KAPTON
(Four more SURFACE cards for -X, +Y, +Z, -Z)
ENDOBJ
```

Notes:

1. RECTAN: is the building block keyword.

2. CORNER x y z: defines the coordinate of the lowest indexed corner of the cuboid (the one so that if you added up x + y + z it would give the lowest (least positive) number).

3. DELTAS Δx, Δy, Δz: gives the length of sides of the cuboid along the X, Y and Z axes. (Note that the edges of the cuboid must lie in the direction of the three axes.)

4. SURFACE +X GOLD: assigns the material GOLD (see Chapter 4) to the surface of the cuboid whose normal points in the +X direction. There are up to six surfaces that may be assigned materials (+X, -X, +Y, -Y, +Z, -Z). All surfaces that will eventually become a surface of the finished object (rather than become a connection to another building block) must be assigned a material. (For surfaces that are shared with other building blocks the material assigned is ignored.)

As an example, the following cards:

```
RECTAN
CORNER   -4  2  -1
DELTAS    3  2   5
SURFACE  +X  GOLD
SURFACE  +Y  GOLD
SURFACE  +Z  GOLD
SURFACE  -X  GOLD
SURFACE  -Y  GOLD
SURFACE  -Z  GOLD
ENDOBJ
```

define a gold bar extending from -4 to -1 in the X direction, 2 to 4 in the Y direction and -1 to +4 in the Z direction (Figure 3.7).

3.8.2 PATCHR

PATCHR is defined in exactly the same way as RECTAN.

```
PATCHR
CORNER  x y z
DELTAS  Δx  Δy  Δz
<SURFACE card(s) (usually just one)>
{e.g., SURFACE  +X  GOLD
{ENDOBJ
```

PATCHR should only be defined <u>within</u> an existing object (see 4.7).

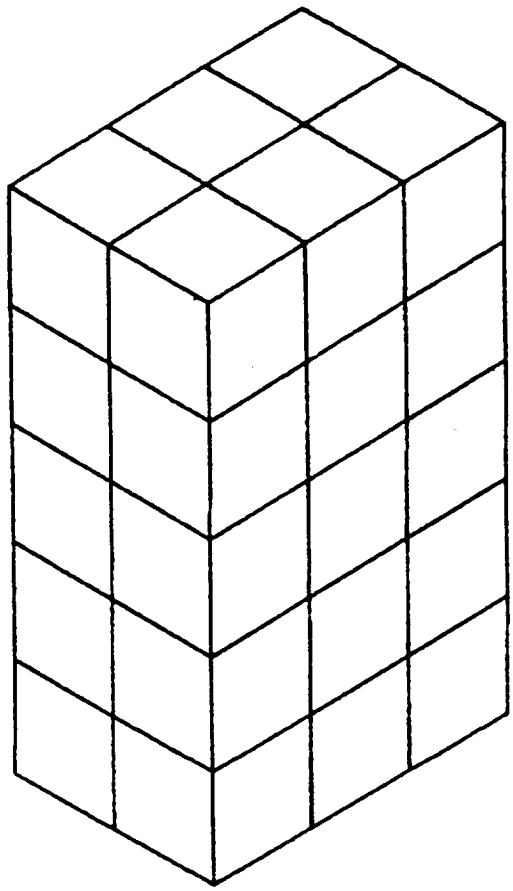


Figure 3.7. RECTAN.

3.8.3 WEDGE

The following cards define a right angled wedge:

```
WEDGE
CORNER   x  y  z
FACE     KAPTON  1 1 0
LENGTH   Δx  Δy  Δz
SURFACE  +X  TEFLON
<Up to four SURFACE cards>
ENDOBJ
```

Notes:

1. WEDGE: is the building block keyword.

2. CORNER x y z: defines the lowest indexed vertex of the right angled corner of the wedge (see note 2, 3.8.1).

3. FACE KAPTON 110: contains two pieces of information:

   a. 'KAPTON' assigns the material KAPTON to the surface of the face of the wedge. (The face is the sloping surface of the wedge.)

   b. '1 1 0' defines the direction of the normal to the face and hence the orientation of the wedge itself. The normal may point in any of the following directions only:

   $\pm 1, \pm 1, 0$

   $\pm 1, 0, \pm 1$

   $0, \pm 1, \pm 1$

   (For those of you not familiar with the '1 1 0' notation a '1 1 0' normal is a vector pointing to the coordinates X = 1, Y = 1 and Z = 0 from the origin.)

4. LENGTH Δx, Δy, Δz: gives the lengths of the sides of the wedge parallel to the X, Y and Z axes. To maintain symmetry two of these must be equal (i.e., the two right triangle sides).

5. SURFACE +X TEFLON: assigns the material 'TEFLON' (Chapter 4) to the surface whose normal points in the positive X direction. There are up to four remaining surfaces that may be assigned materials (see 3.8.1, note 4). These all have normals pointing along one of the axis directions. Along which axis direction they point depends on the orientation of the wedge or the choice of normal for the face (note 2). The possible combinations of face directions and remaining surface directions are summarized in Table 3.3. Cards defining materials for non-existent faces are ignored.

As an example, the following cards:

```
WEDGE
CORNER   0 0 0
FACE     GOLD  1 1 0
LENGTH   2 2 2
SURFACE  -X  GOLD
SURFACE  -Y  GOLD
SURFACE  +Z  GOLD
SURFACE  -Z  GOLD
ENDOBJ
```

define a wedge covered in gold with the origin as one of its corners and a face whose normal points between the X and Y axes in the XY plane. This is shown in Figure 3.8.

3.8.4 PATCHW

PATCHW is defined in exactly the same way as a wedge.

```
PATCHW
CORNER  x y z
FACE  GOLD  1  -1  0
LENGTH  Δx  Δy  Δz
<Up to four SURFACE cards (usually just one)>
ENDOBJ
```

Like PATCHR (3.8.2) it may only be used to define a wedge inside another building block. This is explained further in Section 4.7.

TABLE 3.3. DIRECTIONS OF SURFACE NORMALS ASSOCIATED WITH ALLOWED WEDGE ORIENTATION

Normal of WEDGE Face	Normals of Four Remaining Surfaces
1 1 0	-X, -Y, Z, -Z
-1 1 0	X, -Y, Z, -Z
1 -1 0	-X, Y, Z, -Z
-1 -1 0	X, Y, Z, -Z
1 0 1	-X, Y, -Y, -Z
-1 0 1	X, Y, -Y, -Z
1 0 -1	-X, Y, -Y, Z
-1 0 -1	X, Y, -Y, Z
0 1 1	X, -X, -Y, -Z
0 -1 1	X, -X, Y, -Z
0 1 -1	X, -X, -Y, Z
0 -1 -1	X, -X, -Y, -Z

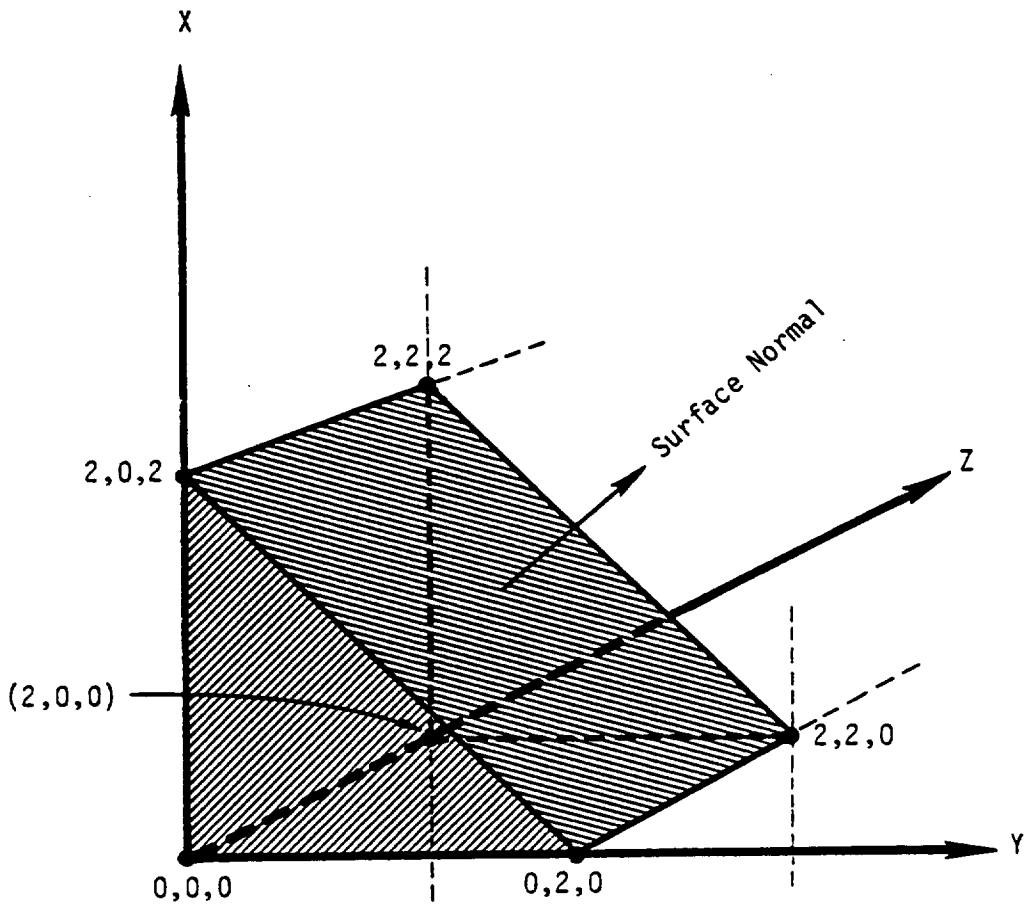


Figure 3.8. Wedge defined with surface normal 1,1,0 and corner 0,0,0.

3.8.5 TETRAH

The following cards define a tetrahedron:

```
TETRAH
CORNER   x  y  z
FACE  ALUMINUM  1  1  -1
LENGTH   Δx
SURFACE  -X  TEFLON
SURFACE  -Y  TEFLON
SURFACE  +Z  TEFLON
ENDOBJ
```

Notes:

1. TETRAH is the building block keyword.

2. CORNER x y z: defines the coordinates of the right angled corner of the tetrahedron. There is only one of these. (It corresponds to the corner of the partially filled cubic volume element that is actually filled.)

3. FACE 1 1 -1: assigns the material ALUMINUM to the unique face of the tetrahedron opposite the right angled corner. '1 1 -1' gives the direction of this face's surface normal and hence the orientation of the tetrahedron. The following directions only are allowed:

   $\pm 1, \pm 1, \pm 1$

   (This notation is the same as explained in 3.8.3, note 3.)

4. LENGTH Δx: gives the length of the sides along the X, Y and Z axis directions. (These must all be equal to preserve symmetry.)

5. SURFACE -X TEFLON: assigns the material teflon to the remaining surface with surface normal pointing along the negative X axis direction. Up to three surfaces remain to be assigned materials (see 3.8.1, note 2). The surface normals of these surfaces depend on the orientation of the tetrahedron and hence the normal of the "face". Table 3.4 summarizes these relationships. Definitions of non-existent surfaces are ignored.

TABLE 3.4. DIRECTIONS OF SURFACE NORMALS ASSOCIATED WITH ALLOWED TETRAHEDRON ORIENTATIONS

Normal of TETRAHedron Face	Normals of Three Remaining Surfaces
1 1 1	-X, -Y, -Z
-1 1 1	X, -Y, -Z
1 -1 1	-X, Y, -Z
1 1 -1	-X, -Y, Z
-1 -1 1	X, Y, -Z
-1 1 -1	X, -Y, Z
1 -1 -1	-X, Y, Z
-1 -1 -1	X, Y, Z

As an example, the following cards:

```
TETRAH
CORNER  0  0  0
FACE  KAPTON  1  1  1
LENGTH  2
SURFACE  KAPTON  -X
SURFACE  KAPTON  -Y
SURFACE  KAPTON  -Z
ENDOBJ
```

define a tetrahedron with its right angle corner at the origin and the normal of the opposite face pointing between the positive X, Y and Z axes. This is shown in Figure 3.9.

3.8.6 OCTAGON

The following cards define a right octagonal cylinder:

```
OCTAGON
AXIS  x y z   x' y' z'
WIDTH  w
SIDE  s
SURFACE  + GOLD
SURFACE  - GOLD
SURFACE  C GOLD
ENDOBJ
```

Notes:

1. OCTAGON: is the building block keyword.

2. AXIS x y z x' y' z': defines both the direction of the symmetry axis and the height of the cylinder. The symmetry axis must be parallel to one of the axis directions. Thus two of the coordinate pairs (x, x'), (y, y') and (z, z') must be identical. For example,

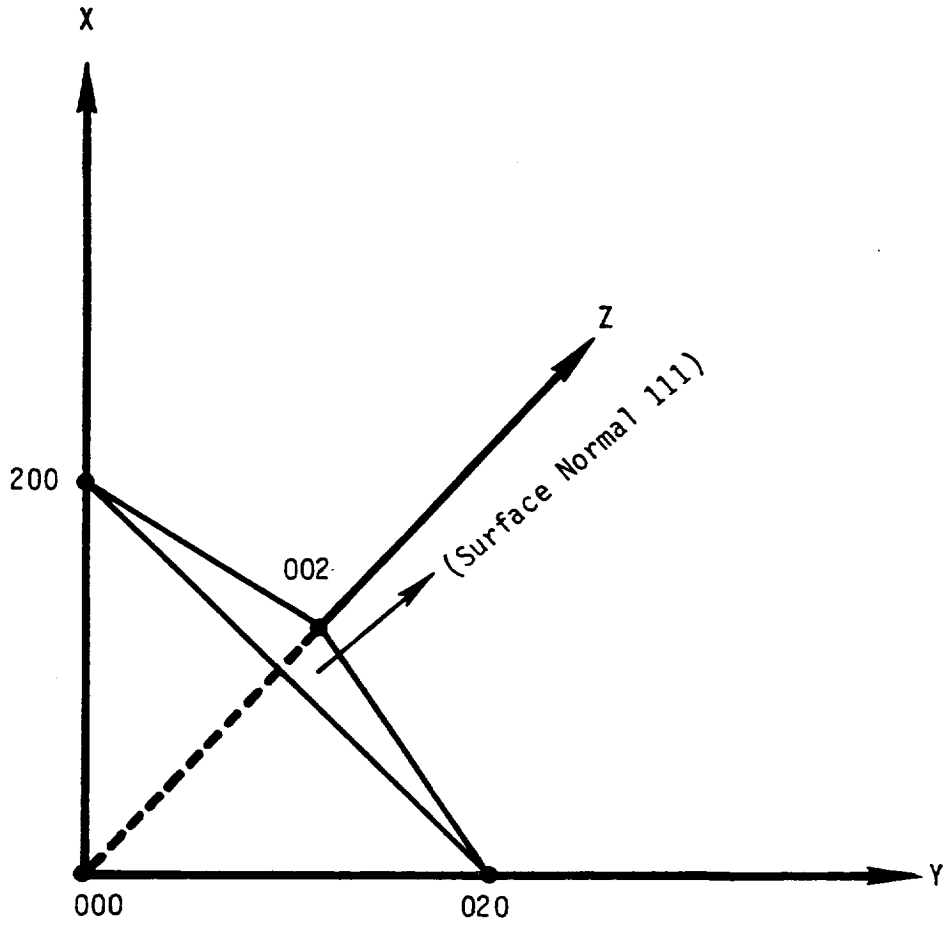


Figure 3.9. Tetrahedron defined with its "corner" at 000 and a surface normal 111.

'AXIS 6 3 -2 7 4 -2'

would define an axis that was not parallel to the X, Y or Z directions. However,

'AXIS 6 3 -2 7 3 -2'

defines an axis parallel to the X direction and is acceptable.

The height of the cylinder is given by the difference in coordinates along the axis direction. (For example, in the case above, the axis is one mesh unit long.)

3. WIDTH w: gives the width of the octagonal cross-section of the cylinder as w. If WIDTH is chosen to be odd, the axis must be moved or the sides of the cylinder will lie halfway across a volume element. NASCAP automatically moves the axis +1/2 a mesh unit in each direction in the plane perpendicular to it.

4. SIDE s: gives the length of one of the sides of the octagonal cross-section that lies in an axis direction. The symmetry relationship between the width and the sides of the cross-section is shown in Figure 3.10. To maintain this relationship the side must always be an even number of mesh units less than the width. This means that they both either must be odd or both even numbers of mesh units.

5. SURFACE + GOLD: assigns the material GOLD to the top surface of the cylinder. '-' and 'C' replacing the '+' assign surface materials to the bottom or side cylindrical surface, respectively. Only those surfaces that will eventually become surfaces of the completed object need be assigned a material.

As an example, the following cards:

```
OCTAGON
AXIS  2  -4  6    2  -4  10
WIDTH  5
SIDE  3
SURFACE + TEFLON
SURFACE - TEFLON
SURFACE C TEFLON
ENDOBJ
```

defines a right octagonal cylinder covered in teflon. The symmetry axis lies along the Z direction and the height of the cylinder is four mesh units. Because the WIDTH is odd the axis is imagined to pass through the point 2 1/2, -3 1/2 in the X Y plane. Hence the top and

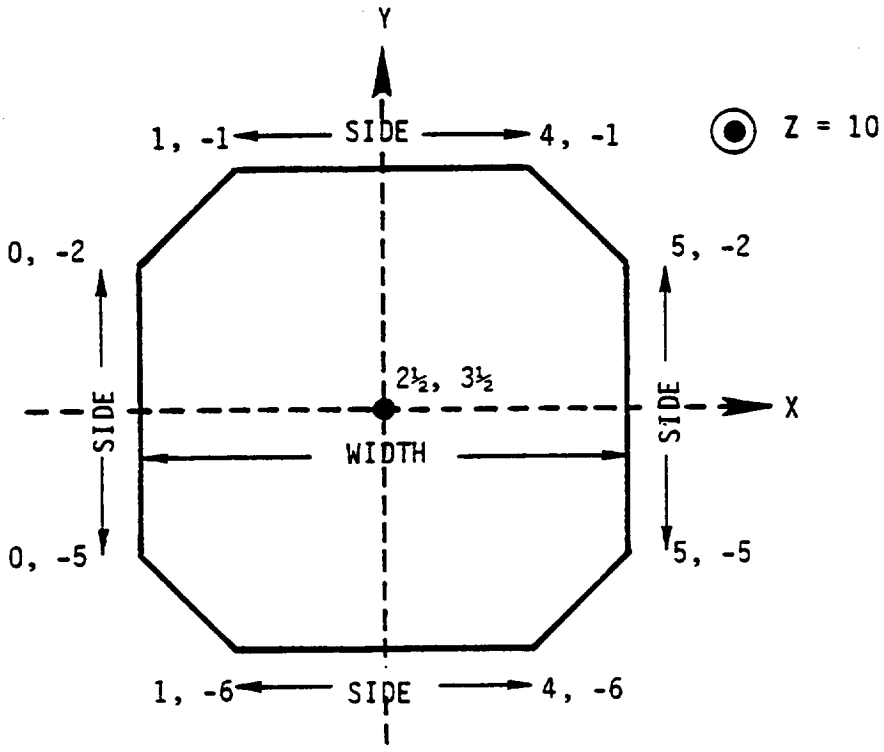


Figure 3.10. Top of an OCTAGON.

bottom faces run from X = 0 to X = 5 and from Y = -6 to Y = -1. The coordinates of the top of the cylinder are shown in Figure 3.10. A three-dimensional view is shown in Figure 3.11.

3.8.7 QSPHERE

The following cards define a quasisphere:

```
QSPHERE
CENTER  x  y  z
DIAMETER  d
SIDE  s
MATERIAL  SiO2
ENDOBJ
```

Notes:

1. QSPHERE: is the building block keyword.

2. CENTER x y z: defines the center of the sphere to be at coordinates X, Y, Z.

3. DIAMETER d: defines the diameter of the sphere to be d mesh units. The quasisphere can be thought of as an octagonal cross-section (like the top of an OCTAGON (see 3.8.6)) rotated about an axis in the cross-section plane. The diameter then corresponds to the WIDTH for a two-dimensional octagonal section. The same restrictions then apply: An odd value for the DIAMETER causes NASCAP to automatically move the CENTER by +1/2 a mesh unit in the X, Y and Z directions.

4. SIDE s: sets the length of a side lying in one of the axis planes (e.g., X Y plane). Like the OCTAGON, the SIDE and DIAMETER must differ by an even number of mesh units.

5. MATERIAL SIO2: assigns the material SIO2 to the whole sphere surface.

As an example, the following cards:

```
QSPHERE
CENTER  1  -3  5
DIAMETER  7
SIDE  3
MATERIAL  SILVER
ENDOBJ
```

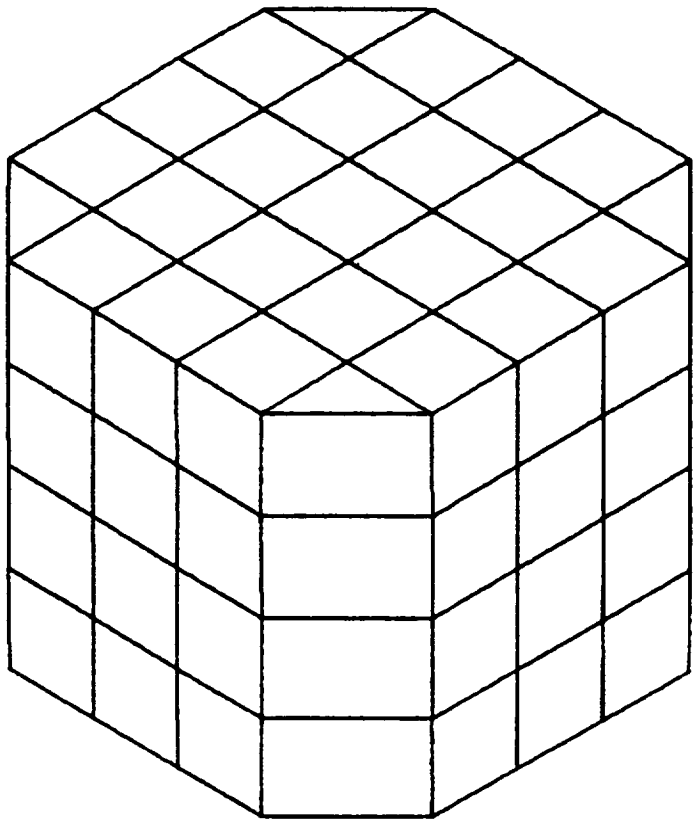


Figure 3.11. OCTAGON.

define a silver sphere centered at 1 1/2, -2 1/2 and 5 1/2. The sphere extends along the axis direction as follows:

x from -2 to 5

y from -6 to 1

z from 2 to 9

(See Figure 3.12.)

3.8.8 FIL111

The following cards define a FIL111:

```
FIL111
CORNERLINE  x  y  z   x'  y'  z'
FACE  KAPTON  1  -1  -1
ENDOBJ
```

Notes:

1. FIL111: is the building block keyword.

2. CORNERLINE x y z x' y' z': defines both the length and the direction of the "step" FIL111 is to fill. The line must lie in one of the axis planes (XY, XZ, YZ) and must have a direction lying 45° to two of the axes. This means that one pair of the coordinates (x', x), (y, y') (z, z') must be identical and the other two pairs must differ by the same magnitude. For example,

   'CORNERLINE 1 2 3 4 5 6'

   is unacceptable since all three coordinate pairs change. The following correct example

   'CORNERLINE 1 2 3 -1 4 3'

   defines a line in the XY plane (Z is constant) with $\Delta x = -2$, and $\Delta y = +2$. Hence the line is $2\sqrt{2}$ units in length and runs at 45° between the positive Y axis and the negative X axis.

3. FACE KAPTON 1 -1 -1: assigns the material KAPTON to the exposed surfaces of the FIL111 and defines its orientation via the surface normal of its exposed face: 1 -1 -1. The surface normal can only be combinations of

   $\pm 1 \quad \pm 1 \quad \pm 1$

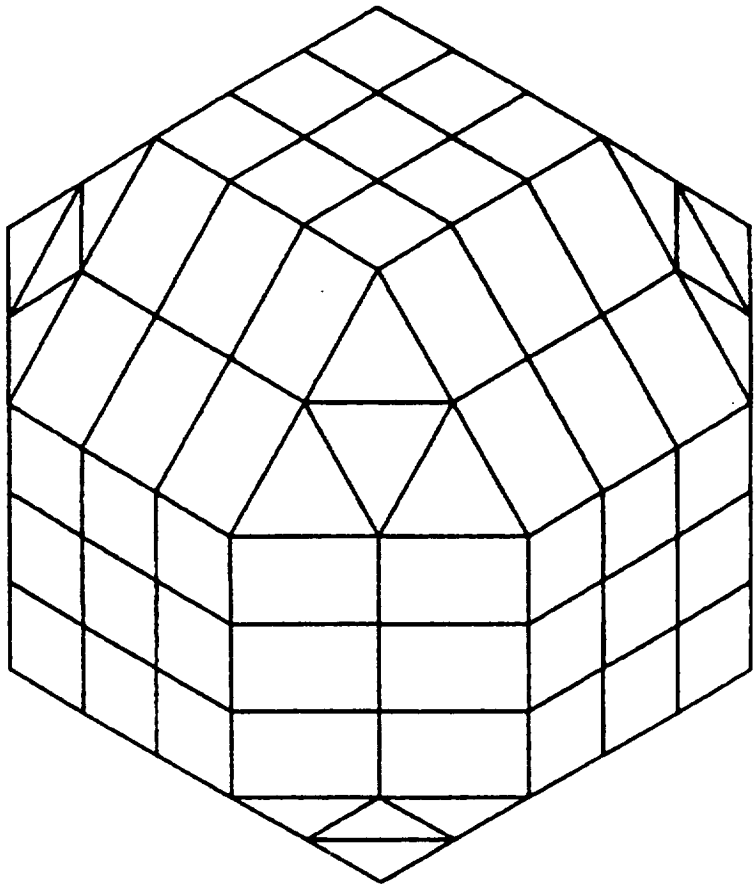


Figure 3.12. QSPHERE.

Only certain choices of corner line direction are consistent with each choice of FACE normal. If we subtract the x y z, x' y' z' coordinates defined in corner line

$$\Delta x = x' - x$$
$$\Delta y = y' - y$$
$$\Delta z = z' - z$$

then the surface normal n_1 n_2 n_3 (e.g., 1 1 1) must be orthogonal to Δx, Δy, Δz, i.e.,

$$\Delta x \cdot n_1 + \Delta y \cdot n_2 + \Delta z \cdot n_3 = 0.$$

With the choice 1 2 3 -1 4 3 for the corner line coordinates only 1 1 ± 1 or -1 -1 ± 1 faces are permissible, e.g.,

$$-2.\ -1 + 2.\ -1 + 0.\ +1 = 0.$$

However, with -1 +1 ± 1

$$-2.\ -1 + 2.1 + 0.\ +1 = 4$$

the vectors are not orthogonal and so are not allowed.

As an example, the following cards:

```
FIL111
CORNERLINE  1  4  -6   1  7  -3
FACE  GOLD  -1  1  -1
ENDOBJ
```

defines a FIL111 covered with gold smoothing a step with a corner line running from 1 4 -6 in the YZ plane, between the positive Y and Z axis to 1 7 -3. The face of the FIL111 points in the negative X and Z directions and positive Y direction. (See Figure 3.13.)

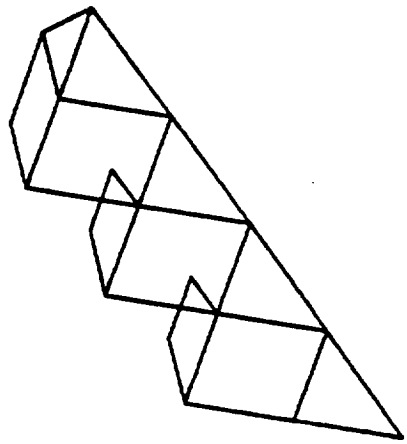


Figure 3.13. FIL111.

3.8.9 PLATE

The following cards define a PLATE:

PLATE

CORNER x y z

DELTAS Δx Δy Δz

TOP $\pm\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$ ALUMIN

BOTTOM $\pm\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$ KAPTON

ENDOBJ

Notes:

1. PLATE: is the building block keyword.

2. CORNER x y z: defines the vertex of the thin plate with the lowest indices (see 3.8.1, note 2).

3. DELTAS Δx Δy Δz: defines the length of the plate along the three axis directions. A PLATE may be thought of as a cuboid (or RECTAN) (see 3.8.1) with zero thickness in one direction. Hence one of Δx, Δy and Δz must be zero. For example, if Δy is chosen to be zero the PLATE will lie in the xz plane.

4. TOP $\pm\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$ ALUMIN:
assigns the material ALUMIN to the TOP surface of the plate. The "TOP" surface may be either in a + or - axis direction. This choice is arbitrary unless a "double point" conflict is possible. Double point conflicts are explained in Section 3.10.

5. BOTTOM $\pm\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$ KAPTON:
assigns the material KAPTON to the other side of the plate. If "top" were chosen as +X then bottom must be -X, and so on. Note that the choice of x, y or z must coincide with the Δx, Δy or Δz chosen to be zero.

As an example, the cards

```
PLATE
CORNER  0  0  0
DELTAS  0  2  2
TOP  -X  TEFLON
BOTTOM  +X  GOLD
ENDOBJ
```

defines a 2 x 2 thin plate with gold on the +X side and teflon on the -X side lying in the YZ plane. (See Figure 3.14.)

3.8.10 BOOM

The following cards define a thin BOOM:

```
BOOM
AXIS  x  y  z   x'  y'  z'
RADIUS  0.25
SURFACE  SIO2
ENDOBJ
```

Notes:

1. BOOM: is the building block keyword.

   AXIS x y z x' y' z': defines the length and orientation of the boom. x y z and x' y' z' are the coordinates of the beginning and end. They must be chosen so that the boom direction coincides with one of the axes.

   BOOMS are the only building blocks that can extend into outer grids. This may be done in two ways.

   a. The AXIS coordinates may be specified in inner grid units. For example

   ```
   'AXIS  0  0  0   0  0  20'
   ```

   defines a BOOM that ends at the +10 grid point of the second grid in the Z direction. (Recall that the second grid has twice the inner grid spacing.) Care must be taken, however, not to define the end of the boom between outer grid points. For example

   ```
   'AXIS  0  0  0   0  0  21'
   ```

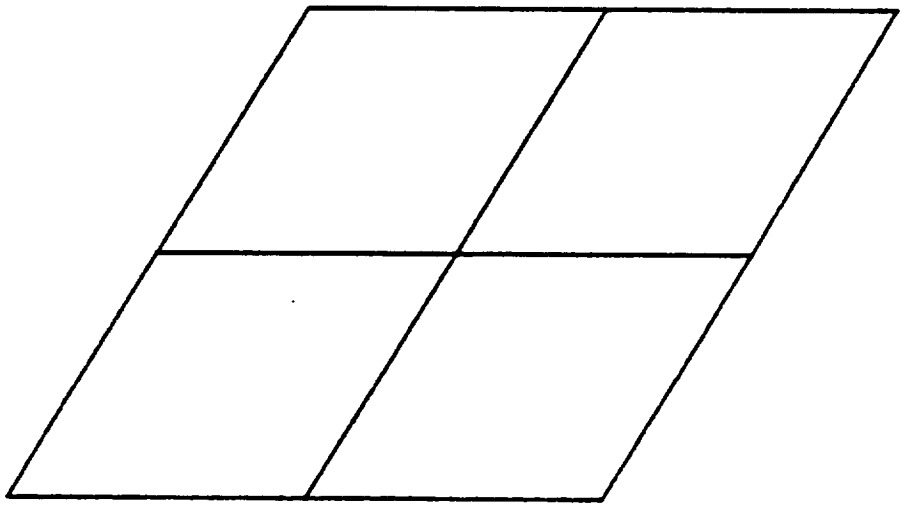


Figure 3.14. PLATE.

defines a boom that ends halfway between two second grid points and is illegal.

b. A second method avoids this problem. The same boom may be defined using two additional parameters or "grid numbers".

```
'AXIS  0  0  0  1   0  0  10  2'
```

This has the format

```
'AXIS  x  y  z  ng  x'  y'  z'  ng'
```

where ng is the starting grid number and ng' is the ending grid number. x y z are now in ng coordinates and x' y' z' are in ng' coordinates. Booms are not allowed to pass from outer grids to inner grids.

3. RADIUS 0.25: defines the radius of the thin cylindrical boom to be 0.25 mesh units. The radius may be any floating point number.

4. SURFACE SIO2: assigns the material SIO2 to the BOOM surface.

As an example, the following cards

```
BOOM
AXIS  -6  0  2   -6  0  32
RADIUS  0.1
SURFACE  KAPTON
ENDOBJ
```

define a boom along the X axis with radius 0.1 inner mesh units, covered with kapton. It runs from X = -6 in the inner mesh to X = -10 in the third mesh. (See Figure 3.15).

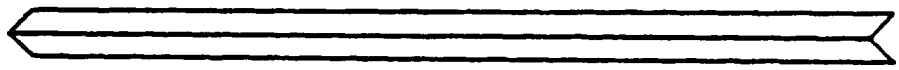


Figure 3.15. BOOM.

3.8.11 SQUARE ANTENNA MESH

Square (type [100]) mesh surfaces are defined using the PLATE module by replacing the TOP/BOTTOM specification by an ANTENNA card:

Syntax	Example
PLATE	PLATE
CORNER x_1 x_2 x_3	CORNER -4 -5 -6
DELTAS d_1 d_2 d_3	DELTAS 0 3 5
ANTENNA matl	ANTENNA GOLD
ENDOBJ	ENDOBJ

Note that one of (d_1, d_2, d_3) must be zero, and the surface normal direction is not specified.

3.8.12 RECTANGULAR ANTENNA MESH

Rectangular (type [110]) mesh surfaces are defined using the ASLANT subroutine, which is syntactically similar to the WEDGE subroutine. It must be particularly noted that the CORNER is not located on (or even near) the mesh surface, but is the corner of the WEDGE of which the antenna surface would be the slanted face:

Syntax	Example
ASLANT	ASLANT
CORNER x_1 x_2 x_3	CORNER 5 -3 -3
FACE matl n_1 n_2 n_3	FACE KAPTON -1 0 1
LENGTH d_1 d_2 d_3	LENGTH 4 6 4
ENDOBJ	ENDOBJ

Note that the two d_i's corresponding to nonzero n_i's must be equal. ASLANT will not accept additional surface cards.

3.8.13 TRIANGULAR ANTENNA MESH

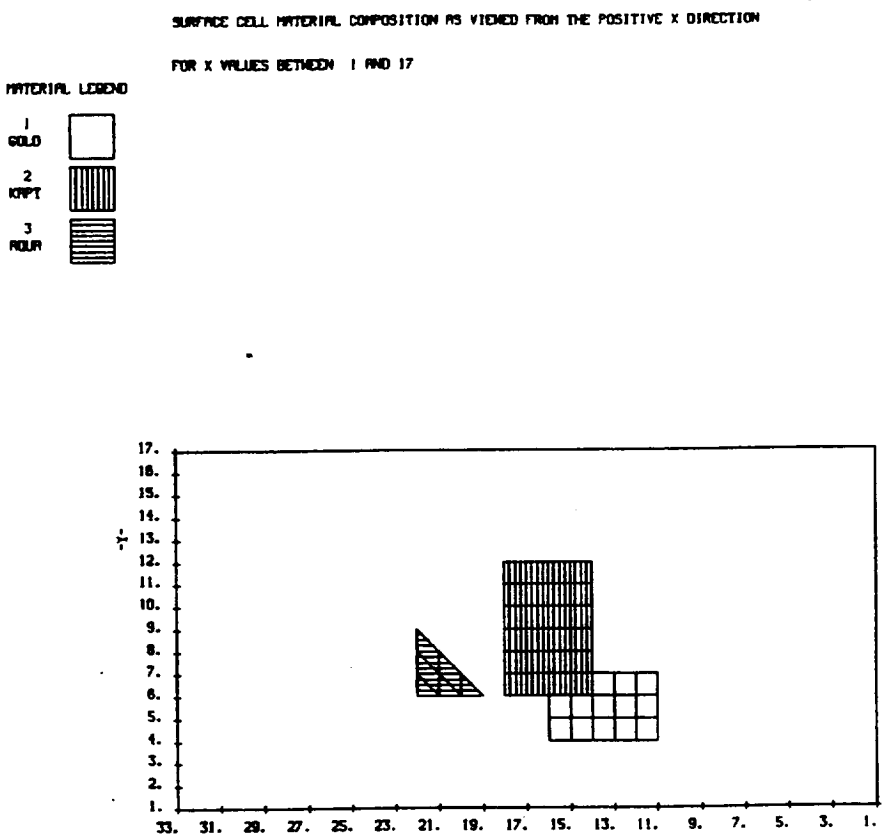
Equilateral triangle (type [111]) mesh surfaces are defined using the ATET subroutine, which is syntactically similar to the TETRAH subroutine. It must be particularly noted that the CORNER is not located on (or even near) the mesh surface, but is the corner of the TETRAH of which the antenna surface would be the slanted face:

Syntax	Example
ATET	ATET
CORNER x_1 x_2 x_3	CORNER 5 -3 5
FACE matl n_1 n_2 n_3	FACE AQUADG -1 1 -1
LENGTH d	LENGTH 3
ENDOBJ	ENDOBJ

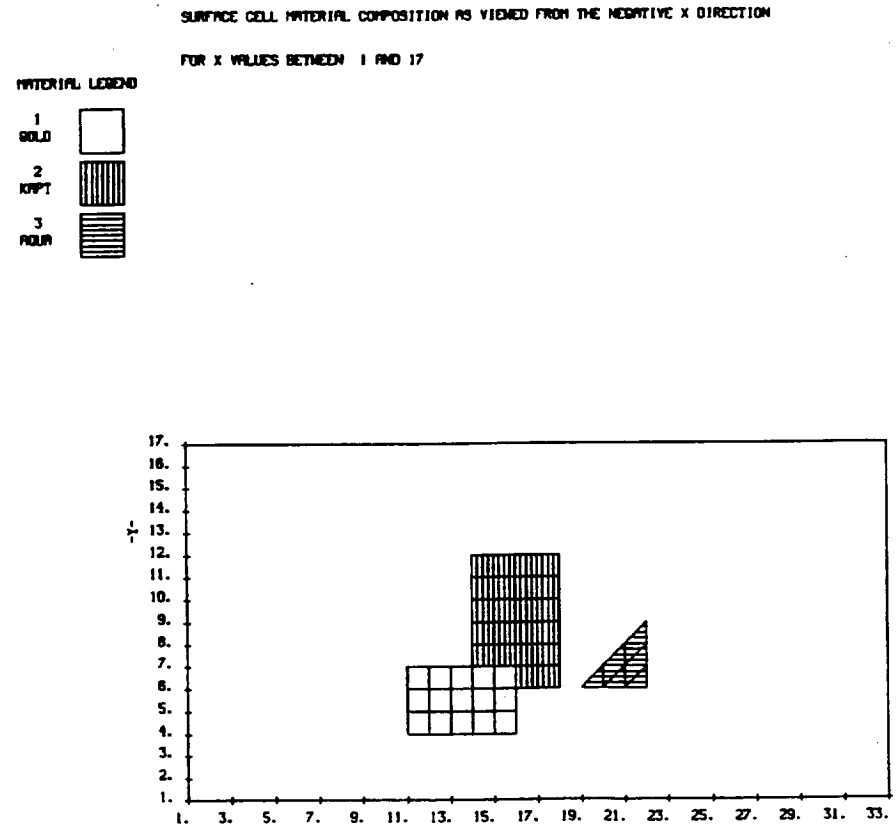
ATET will not accept any additiinal surface cards.

3.8.14 EXAMPLES OF TRANSPARENT ANTENNA BLOCKS

Figures 3.16a-h show MATPLT and HIDCEL views of the examples given in subsections 3.8.11, 3.8.12, and 3.8.13.

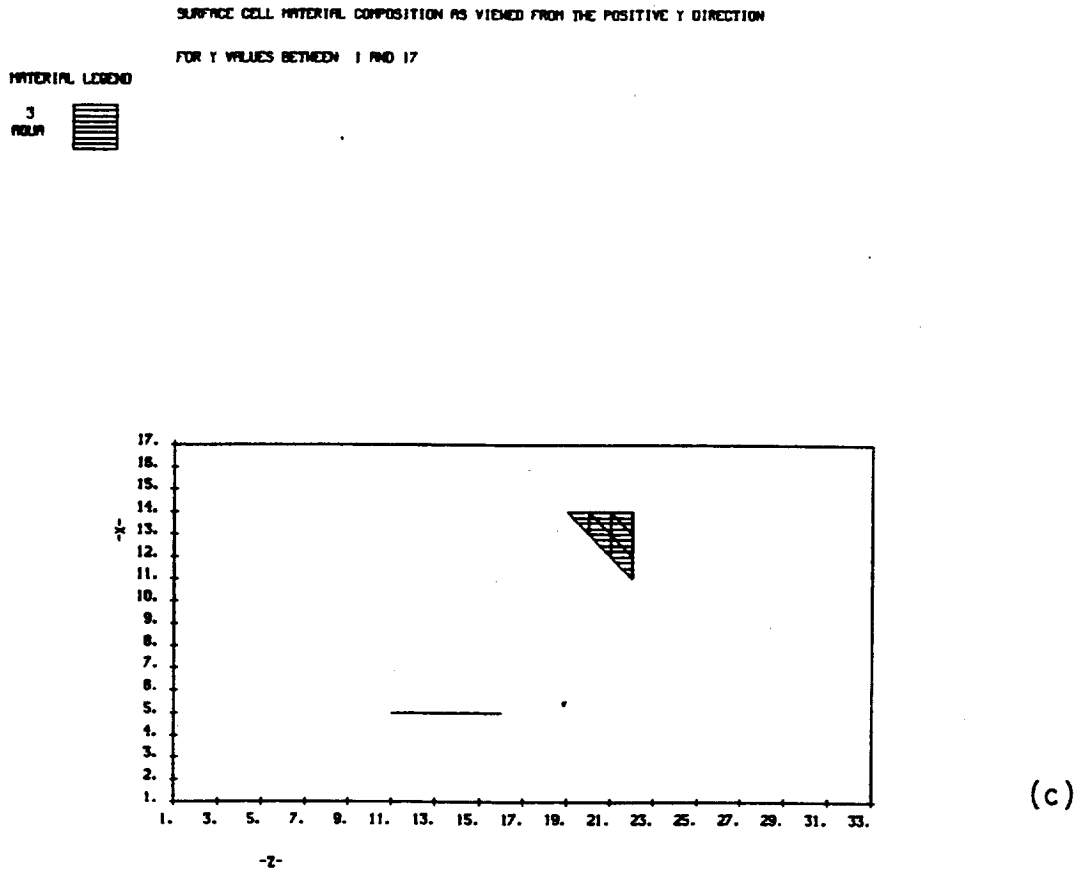


(a)

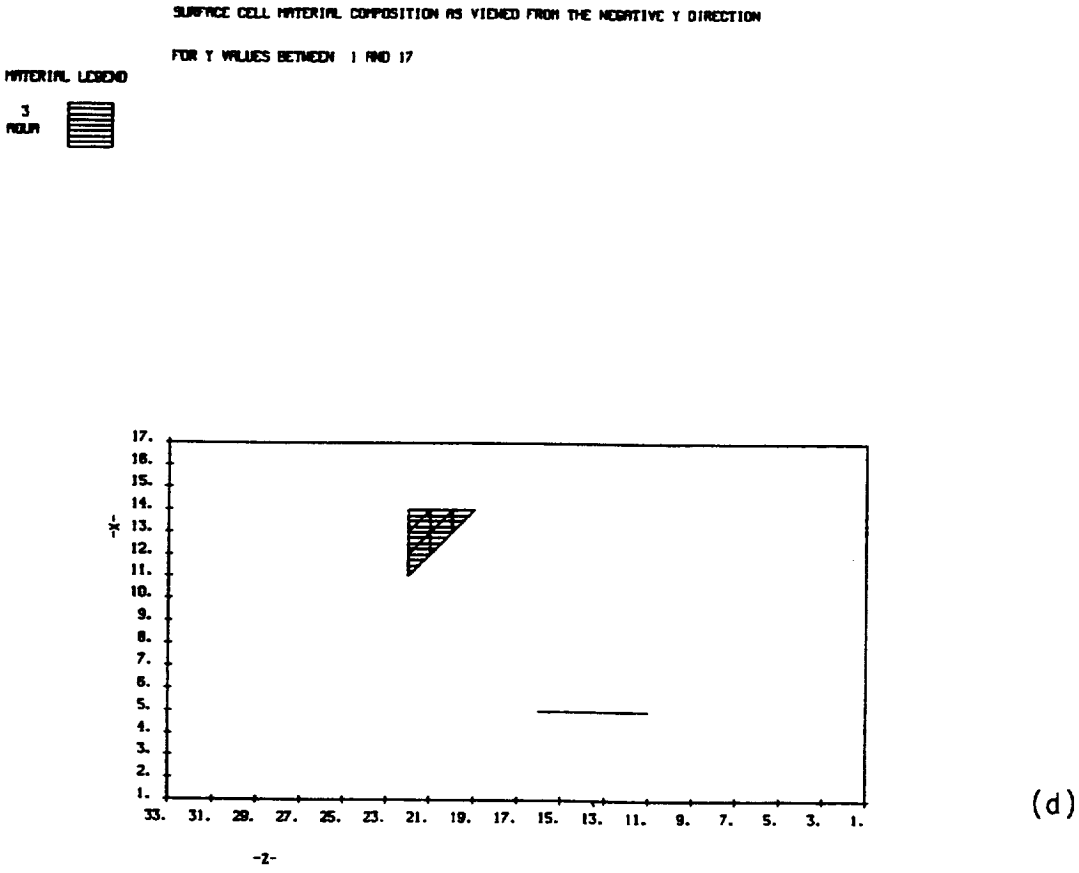


(b)

Figure 3.16a-h. MATPLT and HIDCEL views of the mesh objects defined in Sections 3.8.11, 3.8.12, and 3.8.13.

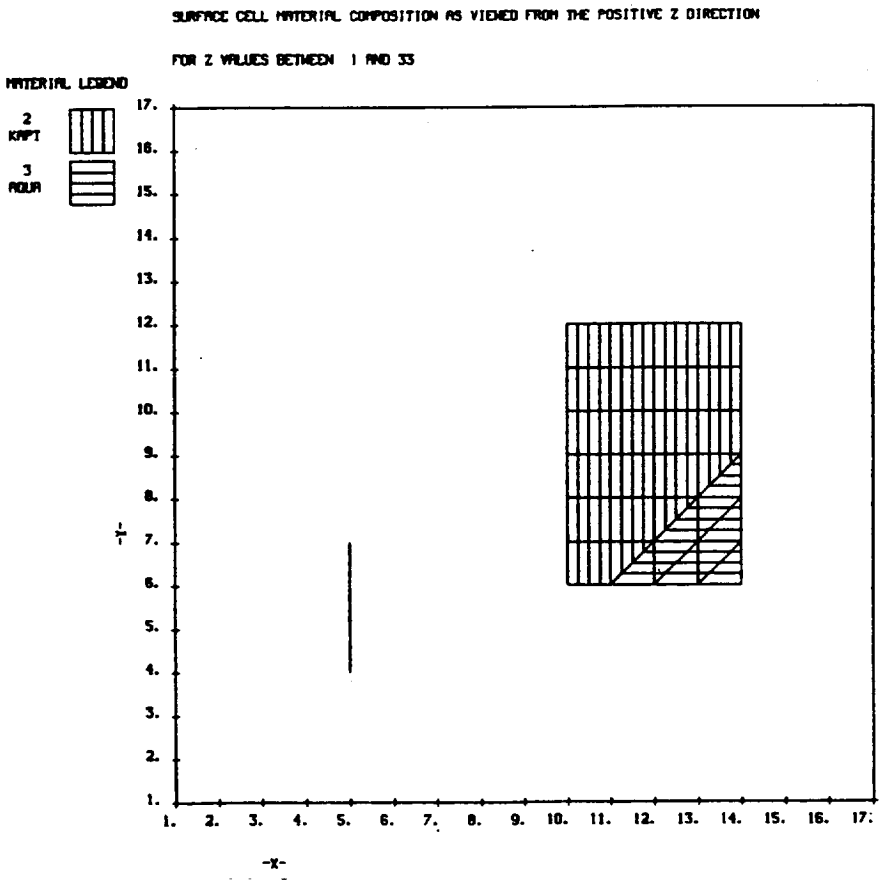


(c)

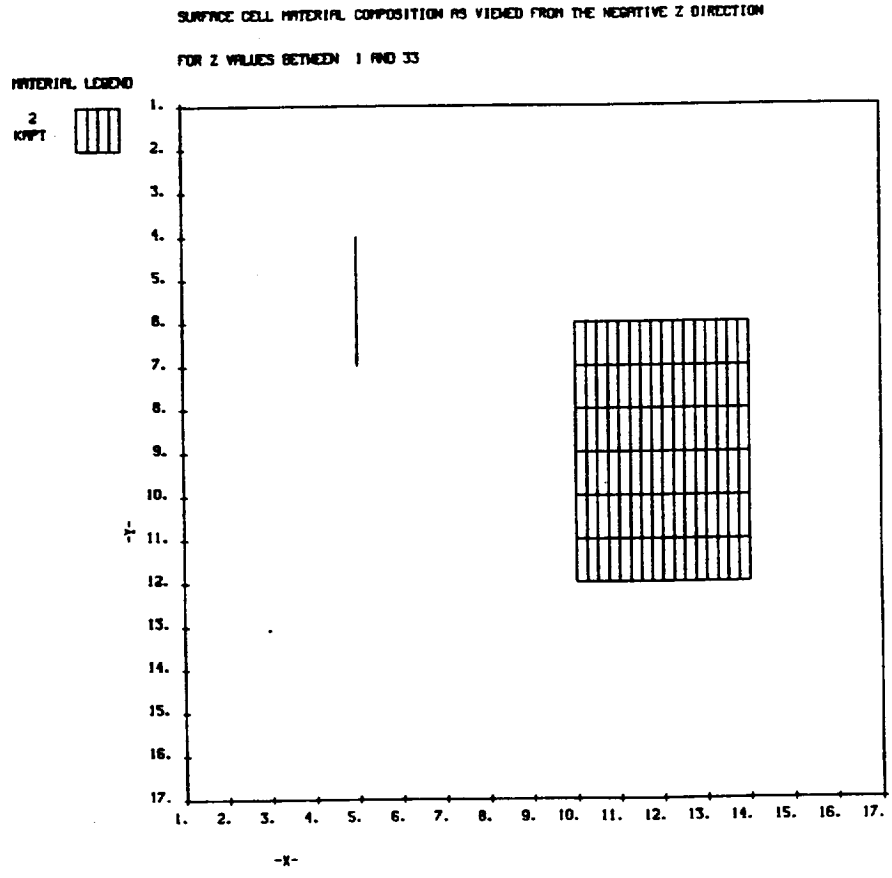


(d)

Figure 3.16. (Continued)

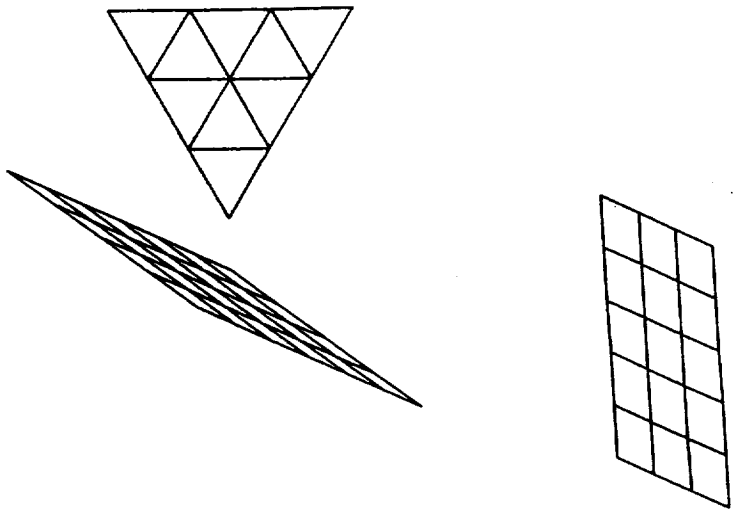


(e)

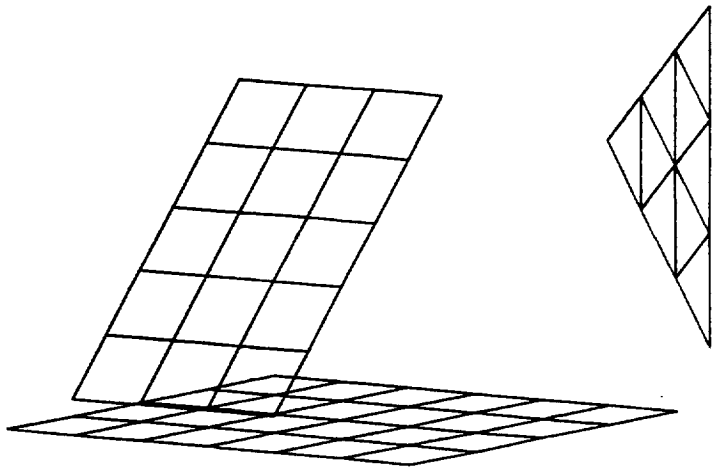


(f)

Figure 3.16. (Continued)



(g)



(h)

Figure 3.16. (Concluded)

3.9 MORE OBJECT DEFINITION KEYWORDS

In addition to the building block keywords and the parameter cards that follow OBJDEF also recognizes a few other keywords. With these and the building blocks a complete object definition file can finally be constructed. This is discussed in Section 3.9. Let us examine the remaining keywords and their effect one by one. All of the OBJDEF keywords are summarized in Table 3.1.

3.9.1 ENDSAT

Just as ENDOBJ terminates a set of building block parameter cards, so the keyword 'ENDSAT' terminates the whole object definition file. After reading an 'ENDSAT' card OBJDEF stops trying to read any more keywords from the object definition file and begins to process the information it has. Note that ALL object definition files must end with an 'ENDSAT' card.

3.9.2 COMMENT

OBJDEF ignores anything written on the same 80 character line (or card) that begins with the keyword 'COMMENT'. This allows the user to include notes or reminders in long and complicated object definition files, e.g.,

```
.
.
.
COMMENT  DEFINE AXIAL BOOM
BOOM
AXIS  -6  0  2    -8  0  2
.
.
.
```

3.9.3 OFFSET

The card

OFFSET x y z

relabels the grid center to be 9-x, 9-y, 17-z for a standard 17 x 17 x 35 inner grid. This result may seem rather startling until you realize that the so-called "absolute" NASCAP coordinate system labels the axes from 1 to 17 in the X and Y direction and 1 to 33 in the Z direction. In this "absolute system" the center of the grid, which we had previously labeled (0, 0, 0,) becomes (9, 9, 17). So we may move from the more intuitive 0, 0, 0 centered system to the "absolute" system with the command

OFFSET 0 0 0

To illustrate the difference the following two sets of cards define a sphere centered at the center of the grid.

Default coordinate system	Absolute coordinate system
QSPHERE	OFFSET 0 0 0
CENTER 0 0 0	QSPHERE
DIAMETER 7	CENTER 9 9 17
SIDE 3	DIAMETER 7
MATERIAL KAPTON	SIDE 3
ENDOBJ	MATERIAL KAPTON
	ENDOBJ

The coordinate system may be adjusted with the OFFSET command anytime at any point between building blocks. The active system is always the default or the coordinate system defined by the most recent OFFSET. Not all inner grids need be 33 points long in the Z direction. The number of points may be chosen to be any integer of the form (4n+1), $4 \leq n \leq 8$, by the user as a run option (6.4.8). If the Z axis is chosen to be NZ points long then the default coordinate system runs from -(NZ-1)/2 (rounded down) to +(NZ-1)/2.

3.9.4 CONDUCTOR

NASCAP allows for both insulating and conducting materials (Chapter 4). It assumes that all surface materials cover an underlying conductor. Up to 15 separate conductors are allowed. Each building block is associated with a particular conductor. This association is made by preceding all building block definitions associated with the first conductor with the card:

CONDUCTOR 1

Similarly, blocks associated with a second conductor are preceded by the card

CONDUCTOR 2

and so on. If no CONDUCTOR card is included in the object definition file all building blocks will be associated with CONDUCTOR 1. In the same way any building blocks defined before OBJDEF encounters a card

CONDUCTOR n (n > 1)

will be associated with conductor 1. All subsequent blocks will be associated with conductor n, until another conductor card is encountered.

It is conventional to choose conductor 1 as the satellite ground conductor. Skipping conductor numbers is not recommended.

3.9.5 DELETE

DELETE allows the user to modify building blocks already defined by selectively "deleting" filled or partially filled cells (i.e., "deleting" them by making them empty).

DELETE x y z

empties the filled cell with the indices of its lowest index vertex given by x y z. (The lowest index vertex is the one with the sum of its X, Y and Z coordinates equal to the least positive number.) The coordinates x, y, z refer to the coordinate system presently active (i.e., the default system or that associated with the most recent OFFSET command). The DELETE command requires great care in its use.

It does not assign materials to surfaces that are newly exposed by the removal of a filled element. The user must do this by defining a new object or objects with surfaces that coincide with those newly exposed. This is most easily done by overlaying objects (4.8).

3.9.6 OTHER WORDS

Any other words that OBJDEF reads in the object definition file are assumed to be the names of new materials and OBJDEF then expects four more cards defining the material properties (4.4) to follow immediately.

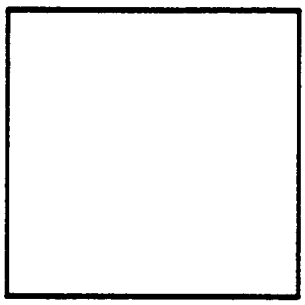
3.10 SURFACE CELLS

The exposed faces of the filled volume elements (or of the partially filled portions of the partially filled elements) that make up an object are called the surface cells. Surface cells combine to form the surface area of the object. Each surface is characterized by the following information:

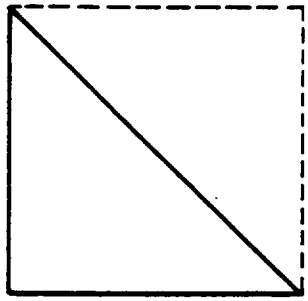
1. Index (number) of underlying conductor.
2. X, Y, and Z coordinates of the volume cell with which it is associated.
3. The direction of its surface normal (in n_1, n_2, n_3 notation, e.g, 1 -1 0).
4. Material number (assigned to each material in order of their definition).

This information uniquely determines each surface cell. NASCAP assigns a number to each cell based on these properties. The cells are numbered sequentially from the lowest indexes to the highest, with property 4 changing most rapidly and property 1 least rapidly. This surface cell list is printed out by NASCAP.

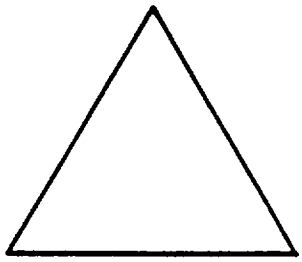
Only four types of individual surface cells are possible. They are the faces of the four possible filled, or partially filled, volume elements. They are illustrated in Figure 3.17.



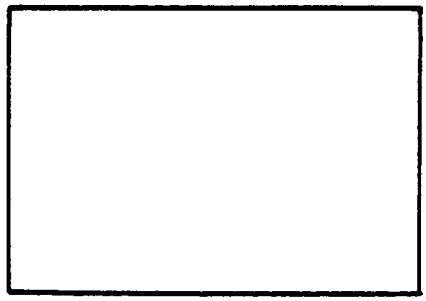
1. Square



2. Half Square



3. Equilateral Triangle (face of a tetrahedron)



4. Rectangle (face of wedge)

Figure 3.17. Four types of surface cell

3.11 DEFINING AN OBJECT

3.11.1 EXAMPLE: SOLID OBJECT

The input file of Figure 3.18 defines an object consisting of an ALUMINUM slab, trimmed with four KAPTON wedges and four TEFLON tetrahedra, and topped with a GOLD sphere. Three views of the resulting object are shown in Figure 3.19.

3.11.2 EXAMPLE: TRANSPARENT ANTENNA

Figure 3.20 is an object definition input showing how the three types of mesh cells may be joined together to make a dish-like antenna. HIDCEL plots of this object are shown in Figure 3.21. Figure 3.22 shows the same antenna mounted on a spacecraft.

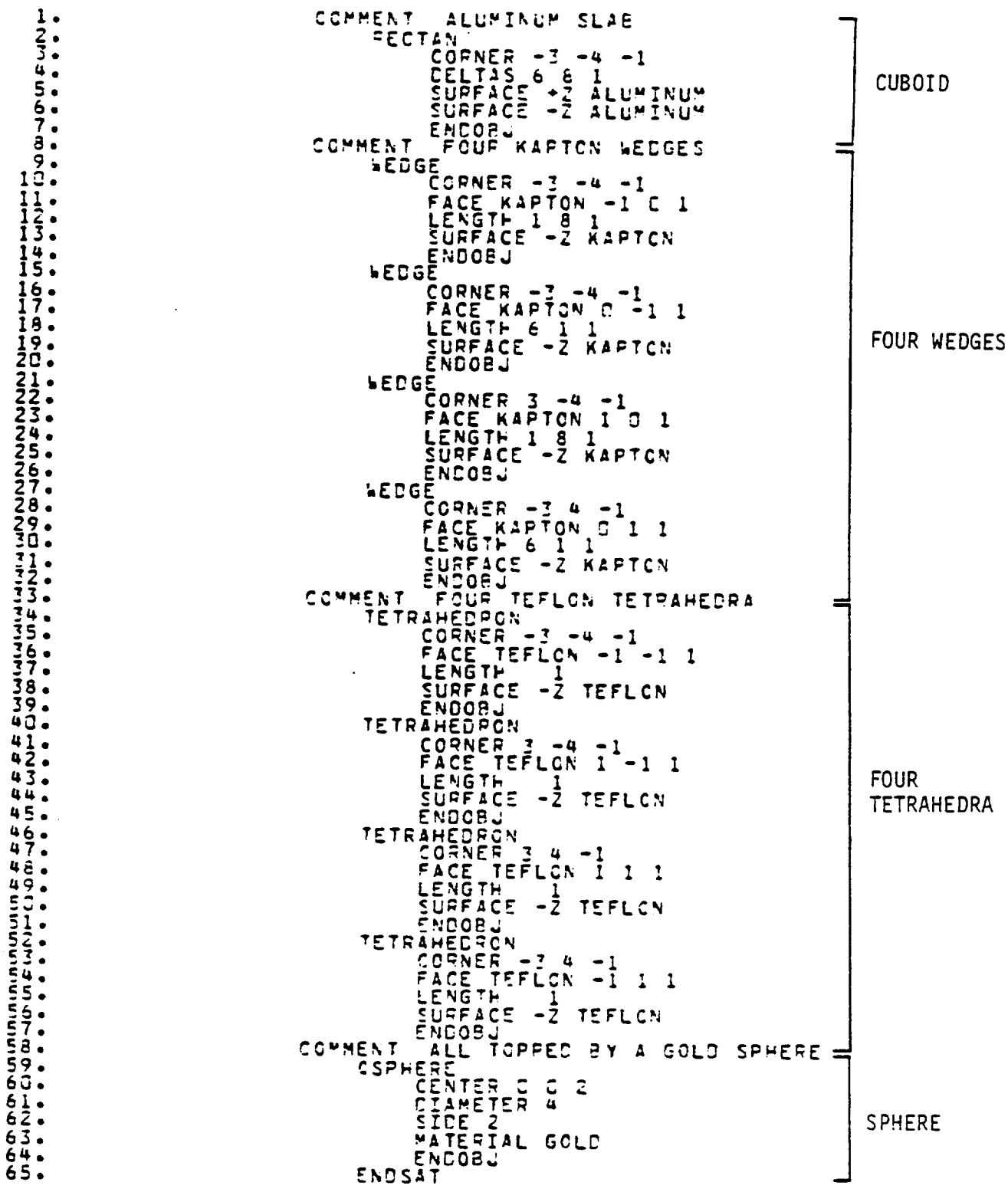


Figure 3.18. Object definition example.

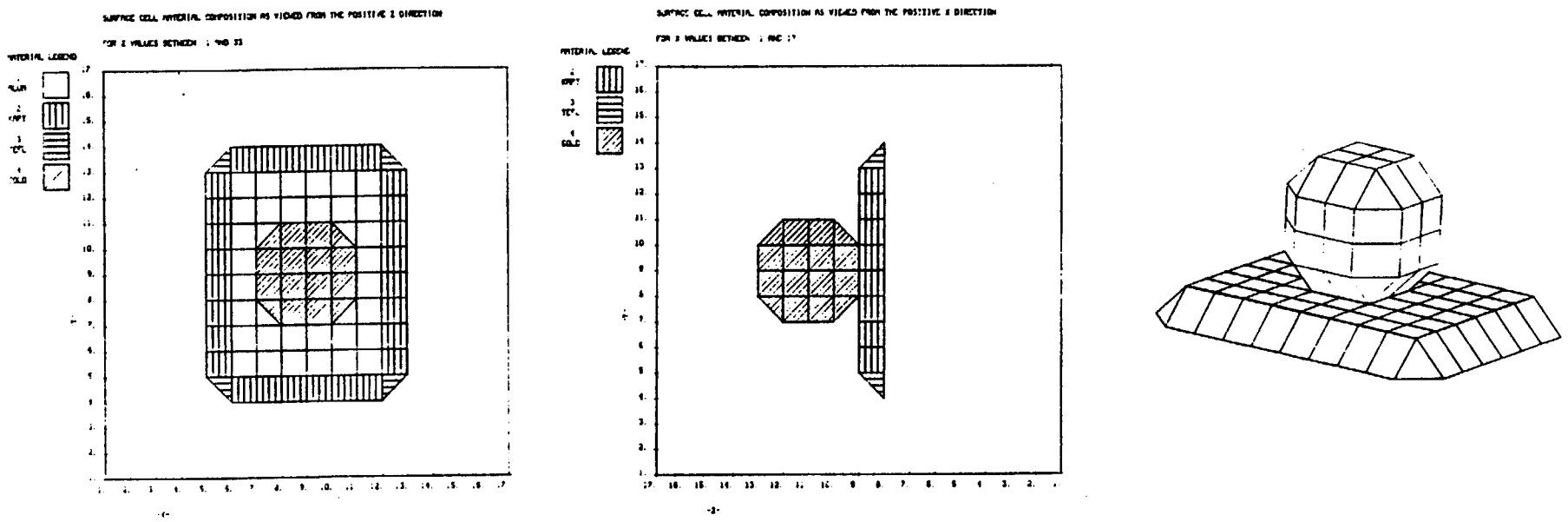


Figure 3.19. Three views of object defined by input of Figure 3.18.

```
COMMENT     DISH ANTENNA
OFFSET    9 9 12
PLATE
              CORNER -2 -2 0
              DELTAS 4 4 0
              ANTENNA GOLD
              ENDOBJ
ASLANT
              CORNER 2 -2 3
              FACE GOLD 1 0 -1
              LENGTH 3 4 3
              ENDOBJ
ASLANT
              CORNER -2 -2 3
              FACE GOLD -1 0 -1
              LENGTH 3 4 3
              ENDOBJ
ASLANT
              CORNER -2 -2 3
              FACE GOLD 0 -1 -1
              LENGTH 4 3 3
              ENDOBJ
ASLANT
              CORNER -2 2 3
              FACE GOLD 0 1 -1
              LENGTH 4 3 3
              ENDOBJ
ATET
              CORNER 2 2 3
              FACE GOLD  1 1 -1
              LENGTH 3
              ENDOBJ
ATET
              CORNER -2 2 3
              FACE GOLD  -1 1 -1
              LENGTH 3
              ENDOBJ
ATET
              CORNER -2 -2 3
              FACE GOLD  -1 -1 -1
              LENGTH 3
              ENDOBJ
ATET
              CORNER 2 -2 3
              FACE GOLD  1 -1 -1
              LENGTH 3
              ENDOBJ
ENDSAT
```

Figure 3.20. Object definition input for a dish-like antenna.

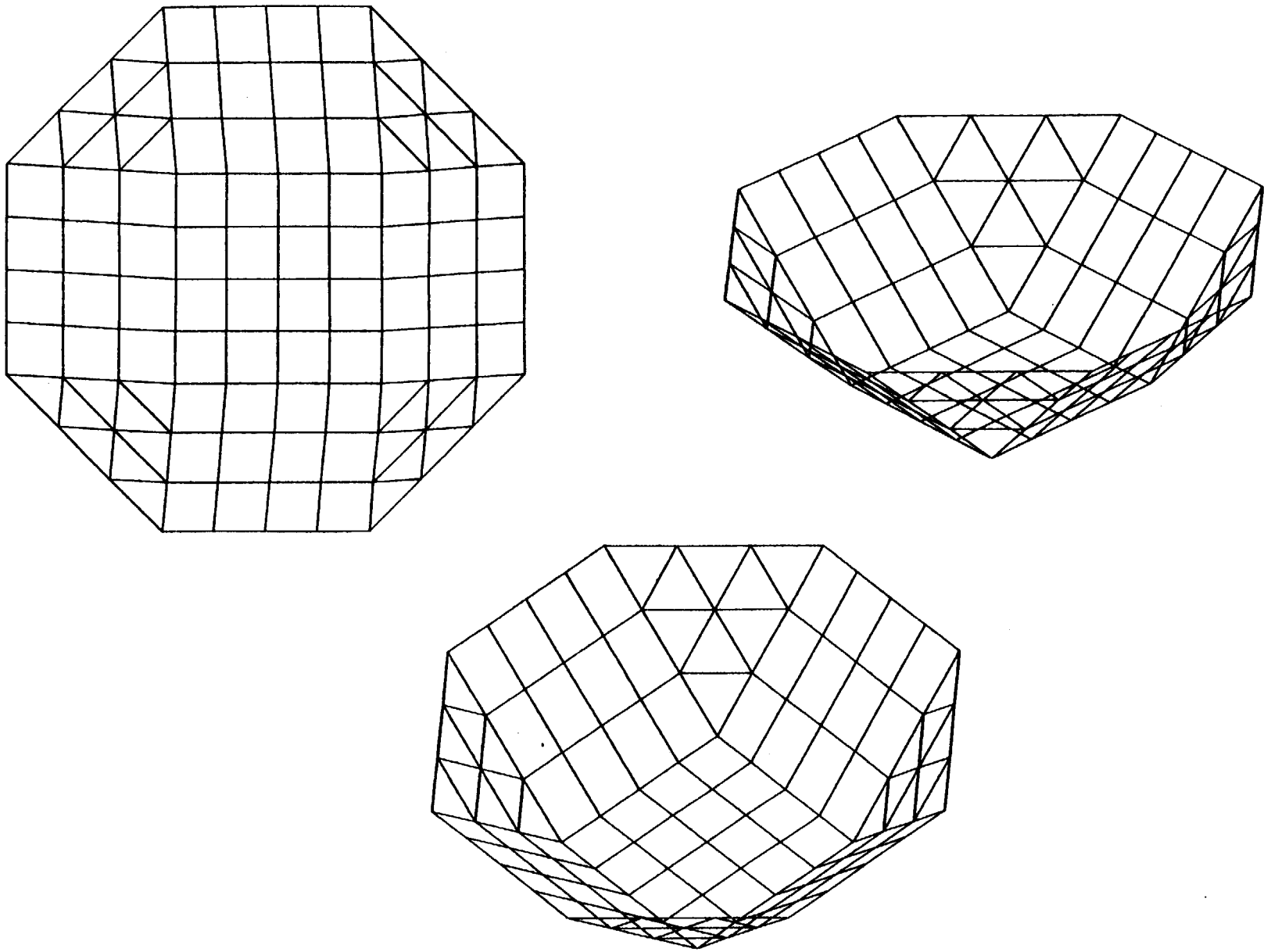


Figure 3.21. Three views of the dish-like antenna defined by Figure 3.20.

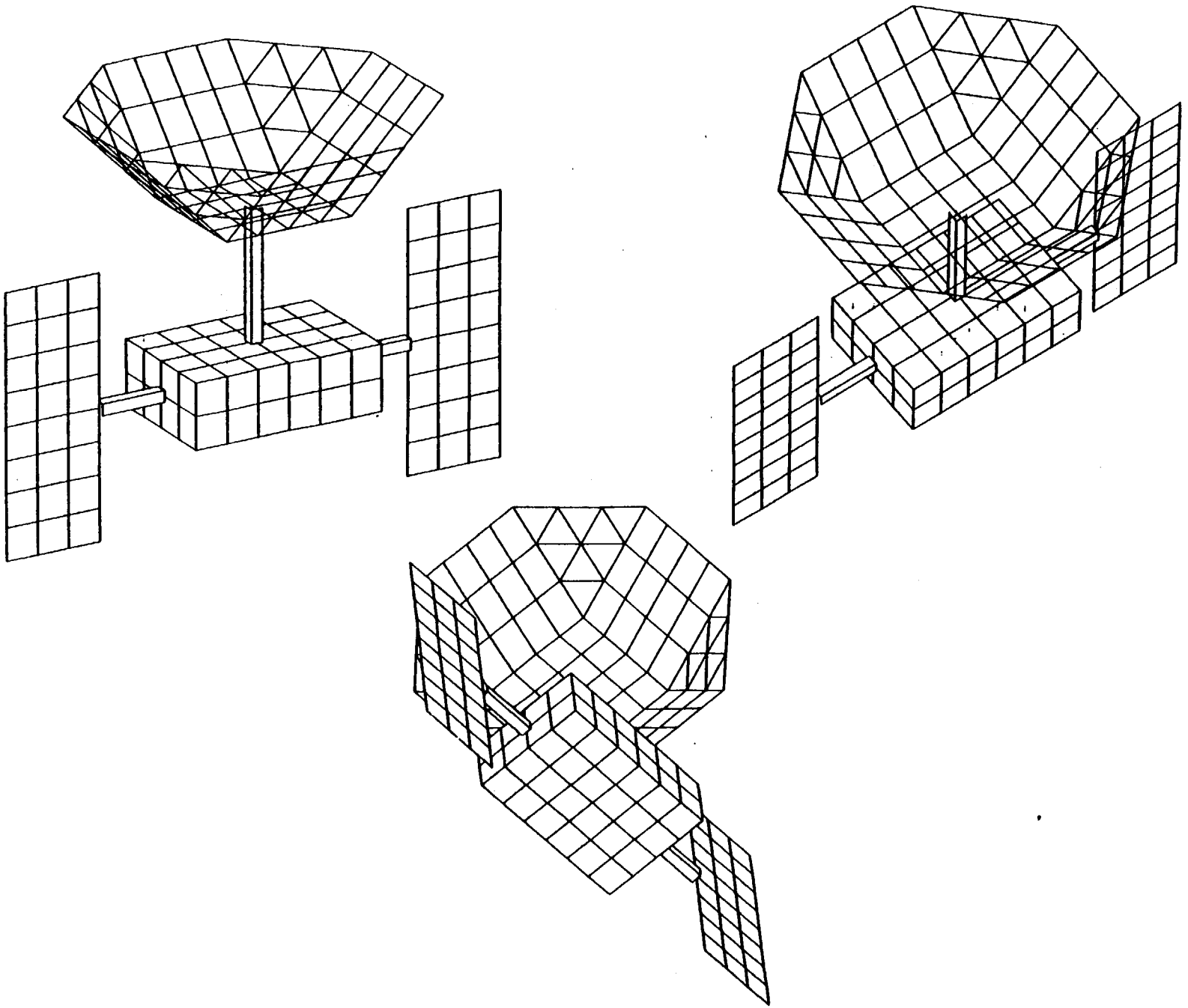


Figure 3.22. Three views of the dish-like antenna (previous two figures) mounted on a spacecraft.

3.12 LIMITATIONS IN OBJECT DEFINITION

It is probably fair to say that you can link building blocks together and nine times out of ten there will not be a problem. This section deals with the other one time out of ten, when what appears to be a perfectly reasonable combination of building blocks is rejected by OBJDEF. We itemize here a rather formidable list of object definition "don'ts". However, you should remember that it takes hard work to break more than one or two of these rules defining any one object if you use a little common sense.

1. All exposed surfaces must be assigned materials.

2. The parameter cards for each building block, discussed in Section 3.8, must appear in the order shown, and no other.

3. No surface may lie in the planes that form the boundary of the inner mesh. Surfaces may touch the boundary planes at a point or line.

4. Booms may not lie in the boundary planes. Booms may cross a boundary plane but only from an inner to an outer grid and not vice versa.

5. Booms may not lie along the edges of filled or partially filled volume elements or pass through objects.

6. Two booms may not share the same volume element; i.e., two parallel booms must be at least two grid units apart, and two perpendicular booms may not intersect.

7. Thin plates sharing the same volume element can do so only if the TOP face of one shares volume with the TOP of the other, or the BOTTOM face of one shares volume with the BOTTOM face of the other. TOP faces may not share volume elements with BOTTOM faces.

8. Thin plates may only intersect each other at the edges or corners.

9. Double points must be assigned TOP and BOTTOM sets (see Section 3.13).

10. A boom cannot share a volume element with the BOTTOM of a thin plate.

(Rules 7 through 10 are all manifestations of conflicts involving double and triple points.)

3.13 DOUBLE POINTS

Thin plates may have different potentials on their two surfaces, yet they occupy only one plane of grid points. These grid points must therefore be associated with two distinct sets of potentials. For this reason they are called double points. The two sets of potentials associated with each half of the double points are distinguished by calling one set 'TOP' and one set 'BOTTOM'. Recall (3.8.9) that the surfaces of a thin plate may be defined as 'TOP' or 'BOTTOM' regardless of whether their surface normal points along a positive or negative axis direction: The TOP and BOTTOM definition refers to the (arbitrary) choice of which set of potentials (TOP or BOTTOM) to associate with each surface. When double points share a volume element they must all be of the same type; i.e., all TOP or all BOTTOM. This is the basis for rule 7 in Section 3.12.

Double points also occur when other building blocks touch in such a way that their single points come together to form a common vertex of two "disjoint" volume elements. By "disjoint" volume elements we mean elements physically separated from each other by solid surfaces. This is shown for two cuboids touching along one edge only in Figure 3.23. The row of points along the touching edges are double points and one set must be defined as BOTTOM. This may be done by defining a thin plate touching the common edge. If the exterior surface of the plate pointing into one of the disjoint volumes is 'BOTTOM' then the half of the double point associated with the other disjoint volume becomes 'TOP'.

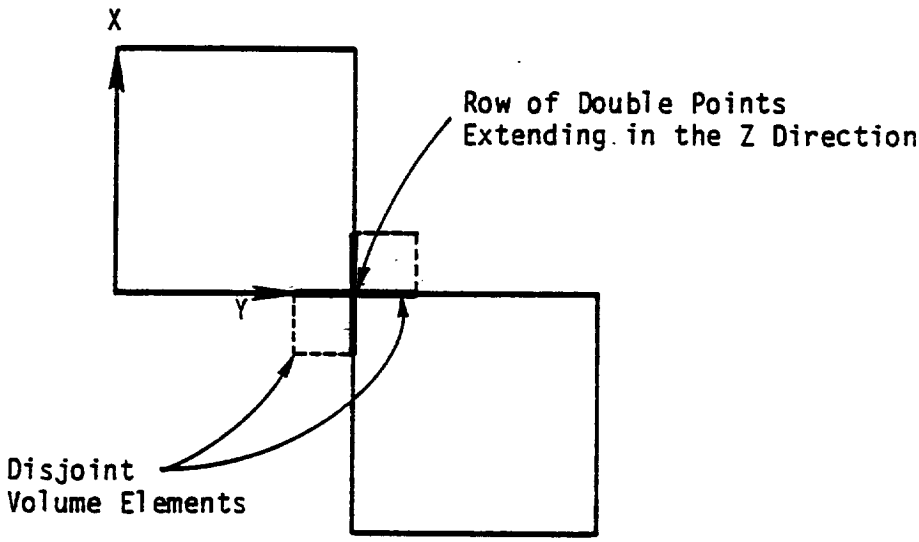


Figure 3.23. Profile of two cuboids sharing a common edge and resultant double points. Heavy lines show possible orientations for the definition of a thin plate to resolve the conflict.

Because of the way surface cell potentials are assigned to the grid points the edges of thin plates are only single points. However, a thin plate touching another building block (not BOOMs!) with its edge creates a row of double points similar to that caused by two cuboids touching at an edge (Figure 3.24). These double points are automatically assigned TOP and BOTTOM sets.

3.14 TRIPLE POINTS

A triple point is said to occur when a vertex is common to three or more disjoint volume elements. Triple points are illegal! The easiest way to get a triple point is to define one thin plate passing through another. This is not allowed (rule 8, Section 3.12).

3.15 TECHNICAL DISCUSSION

Here we examine some of the technical details of how NASCAP actually calculates potentials, and treats volumes and surfaces. The casual user may wish to omit this section.

3.15.1 CONJUGATE GRADIENT POTENTIAL SOLVER

Consider a charged object isolated in space. The potential ϕ everywhere is given by the solution to Poisson's equation

$$\nabla^2\phi = -\rho/\varepsilon \tag{3.1}$$

The variational principle[2] associated with this equation is given by:

$$\frac{\delta}{\delta\phi}\left[\left(\int dV\ \frac{1}{2}\,(\nabla\phi)^2 + \frac{\rho\phi}{\varepsilon}\right) + \int_{C_S} \frac{\sigma\phi}{\varepsilon}\,ds + \int_{C_B} \phi \cdot \phi \cdot dS'\right] = 0$$

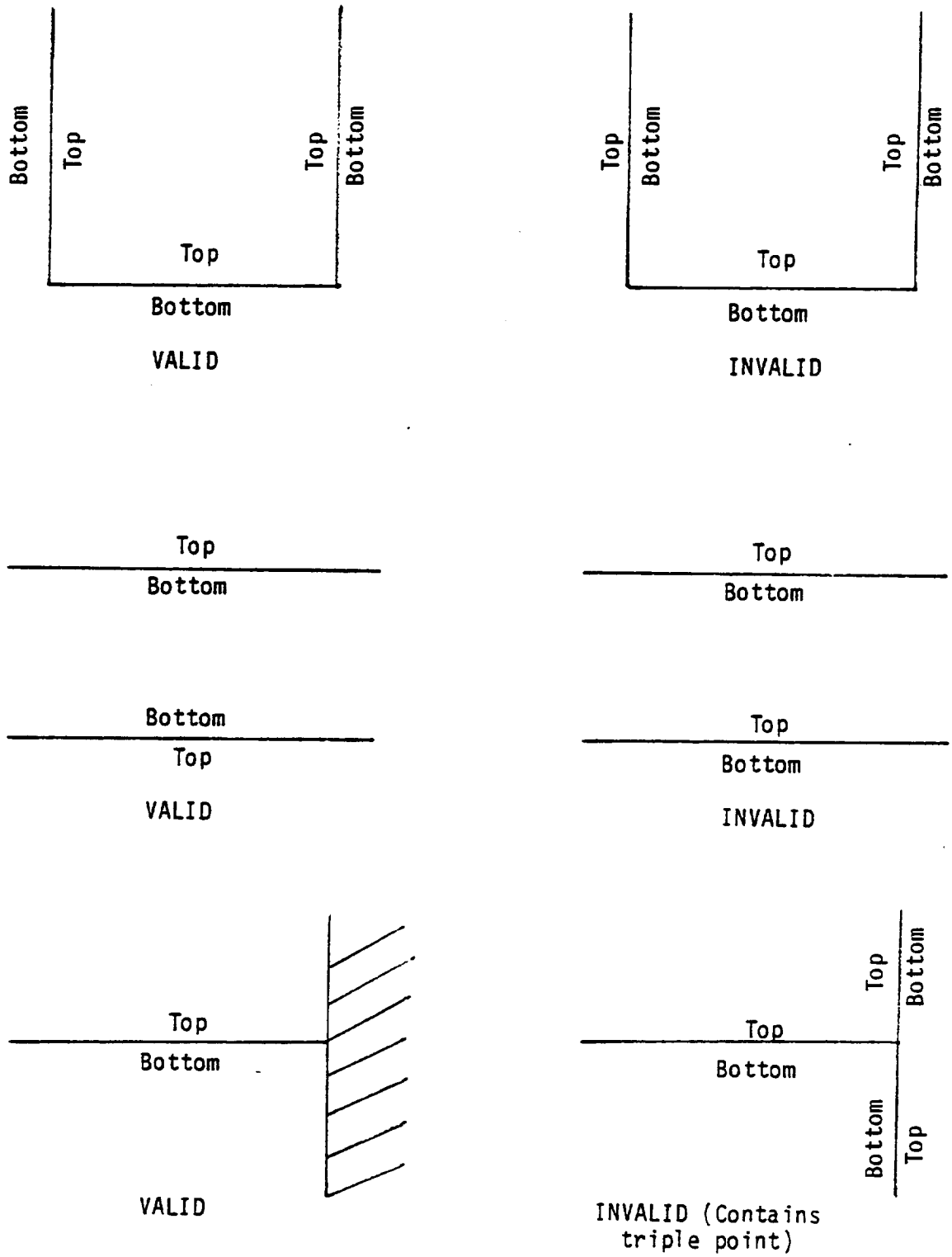


Figure 3.24. Examples of plates intersecting objects.

where we integrate over both the object and boundary surfaces (c_S, c_B).

To simplify things for the purpose of illustration, let us fix the potentials on these surfaces and assume zero charge density. The equation then simplifies to

$$\frac{\delta}{\delta\phi} \int dV \, \frac{1}{2} (\nabla\phi)^2 = 0 \qquad (3.2)$$

Equation (3.2) involves an integral over the volume of the computational space. One way to treat this integral is to divide the space up into finite cubic volume elements.

$$\int dV \, \frac{1}{2} (\nabla\phi)^2 = \sum_e \int_{V_e} dV_e \, \frac{1}{2} (\nabla\phi)^2$$

In this approach the potential ϕ is defined at each grid point, or node, defining the vertices of the elements. The potential inside each element is then trilinearly interpolated from the values of each of its eight vertices.

$$\phi^e (x,y,z) = \sum_{i \in e} N_i^{xyz} \, \phi_i$$

where "i" are the nodes of element "e"

$$\nabla\phi^e (x,y,z) = \sum_i \nabla N_i^{xyz} \, \phi_i$$

and

$$\int dV \, \frac{1}{2} (\nabla\phi)^2 = \sum_e \int dV_e \left| \sum_i \nabla N_i^e (x,y,z) \phi_i \right|^2$$

The quantity

$$W_{ij}^{e} = \int_{e} dV_e \nabla N_i^{xyz} \cdot \nabla N_j^{xyz} \tag{3.3}$$

is completely defined just by knowledge of the shape of the element "e" (i.e., whether the cube is empty or partially filled). The variational principle therefore becomes:

$$\frac{\delta}{\delta \phi} \left[\sum_{j} \sum_{i} \sum_{e} W_{ij}^{e} \phi_i \phi_j = 0 \right] \tag{3.4}$$

Let $\sum_{e} W_{ij}^{e} = M_{ij}$. Equation (3.4) becomes

$$\frac{\delta}{\delta \phi} \left[\sum_{ij} \phi_i M_{ij} \phi_j \right] = 0 = \underset{\approx}{M}\, \underset{\sim}{\phi}$$

Thus the set of ϕ values at each node (ϕ) that satisfy $\underset{\approx}{M}\, \underset{\sim}{\phi}$ is the solution to the Poisson equation (3.1) under conditions of fixed object and boundary potentials and zero charge density.

We may solve Eq. (3.4) iteratively. Our initial choice of $\underset{\sim}{\phi}$ will yield a residual $\underset{\sim}{r}$

$$\underset{\approx}{M}\, \underset{\sim}{\phi} = -\underset{\sim}{r}$$

The iterative scheme used is the Scaled Conjugate Gradient technique. It is based on the following equations:[3]

$$\underset{\sim}{r}_o = -\underset{\approx}{M}\ \underset{\sim}{p}_o$$

$$D_{ij} = |M_{ij}|^{-1/2}\ \delta_{ij}$$

$$\underset{\sim}{r}^o_s = \underset{\approx}{D}\ \underset{\sim}{r}_o$$

$$\underset{\sim}{u}^o_s = \underset{\sim}{r}^o_s$$

$$\underset{\approx}{M}_s = \underset{\approx}{D}\ \underset{\approx}{M}\ \underset{\approx}{D}$$

Then solve iteratively:

$$a^i_s = (r^i_s, r^i)/(u^i_s, M_s\ u^i_s)$$

$$(D^{-1}p)^{i+1} = (D^{-1}p)^i + a^i_s\ p^i_s$$

$$r^{i+1}_s = r^i_x - a^i_s\ M_s\ u^i_s$$

$$b^i_s = (r^{i+1}_s, r^{i+1}_s)/(r^i_s, r^i_s)$$

$$u^{i+1}_s = r^{i+1}_s + b^i_s\ u^i_s$$

until $|r|$ reaches a small value and the resultant p vector:

$$p^n = D\ (D^{-1}\ p)^n$$

becomes the solution to Poisson's equation.

The major computational operation in the iterative set of equations is the evaluation of the matrix-vector product $\underset{\approx}{M}\ \underset{\sim}{u}$. The

vectors $\underset{\sim}{p}$, $\underset{\sim}{u}$, and $\underset{\sim}{r}$ all have the same number of elements as the number of grid points. $\underset{\approx}{M}$ contains the square of this number. Such a huge array is impractical to store all at once and so $\underset{\approx}{M}\,\underset{\sim}{u}$ is evaluated using the following implicit algorithm

$$\underset{\sim}{r} = \sum_e \underset{\sim}{r}_e = \sum_e \underset{\approx}{w}_e \underset{\sim}{u}$$

The residual $\underset{\sim}{r}$ is constructed element by element (where the $\underset{\approx}{w}_e$ matrix is only 8 x 8) and then summed. The 8 x 8 "weight" matrices $\underset{\approx}{w}_e$ may be calculated analytically for each type of empty or partially filled volume element, allowed by NASCAP. There are five of these. Filled cells are not included in the potential calculation. This is how NASCAP treats filled, partially filled and empty elements, differently.

3.15.2 STANDARD VOLUME CELLS

The five standard cells are summarized below.

(Format)
Description
Standard Orientation

Potential Function = $\sum_i N^i \phi_i$

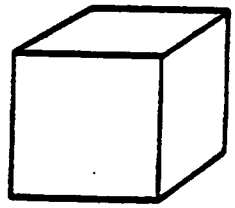
Weight Matrix, W_{ij}: $\int d\Omega |\nabla \phi|^2 = \sum_{ij} W_{ij} \phi_i \phi_j$

Point Index	Cube Corner
1	0 0 0
2	1 0 0
3	0 1 0
4	1 1 0
5	0 0 1
6	1 0 1
7	0 1 1
8	1 1 1

Standard Cell 0

Empty trilinear cube

Orientation: Arbitrary



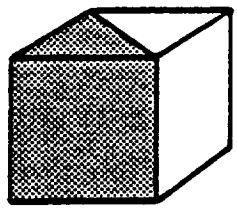
Potential Function:

i	N^i
1	(1-x)(1-y)(1-z)
2	(1-z)(1-y)x
3	(1-x)y(1-z)
4	(1-z)yx
5	z(1-y)(1-x)
6	x(1-y)(z)
7	zy(1-x)
8	xyz

W_{ij}

1/3							
0	1/3						
0	-1/12	1/3					
-1/12	0	0	1/3				
0	-1/12	-1/12	-1/12	1/3			
-1/12	0	-1/12	-1/12	0	1/3		
-1/12	-1/12	0	-1/12	0	-1/12	1/3	
-1/12	-1/12	-1/12	0	-1/12	0	0	1/3

Standard Cell 1



Half-Empty Wedge

$1 < x + y < 2$

$0 < z < 1$

Orientation: Right angle along line 4-8

Potential Function:

i	N^i
1	0
2	(1-y)(1-z)
3	(1-x)(1-z)
4	(x+y-1)(1-z)
5	0
6	(1-y)z
7	(1-x)z
8	(x+y-1)z

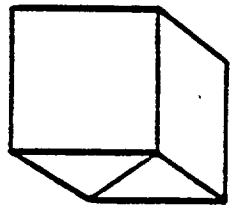
W_{ij}

0						
0	1/4					
0	1/24	1/4				
0	-1/8	-1/8	5/12			
0	0	0	0	0		
0	0	-1/24	-1/8	0	1/4	
0	-1/24	0	-1/8	0	1/24	1/4
0	-1/8	-1/8	-1/12	0	-1/8	5/12

Standard Cell 2

Cube with diagonal line on one face

Orientation: Line from 2 to 3

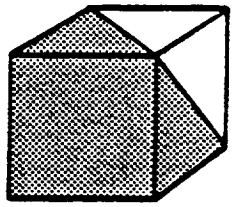


Potential Function:

i	N^i
1	(1-x-y)(1-z)θ(1-x-y)
2	[x (1-x-y)+(1-y)θ(x+y-1)](1-z)
3	[y (1-x-y)+(1-x)θ(x+y-1)](1-z)
4	(x+y-1)(1-z)θ(x+y-1)
5	(1-x)(1-y)z
6	x(1-y)z
7	(1-x)yz
8	xyz

W_{ij}:

5/12							
-1/8	1/2						
-1/8	1/12	1/2					
0	-1/8	-1/8	5/12				
7/360	-37/360	-37/360	-23/360	1/3			
-11/180	-1/45	-19/180	-11/180	0	1/3		
-11/180	-19/180	-1/45	-11/180	0	-1/12	1/3	
-23/360	-37/360	-37/360	7/360	-1/12	0	0	1/3



Standard Cell 3

Tetrahedron

$2 < x + y + z < 3$

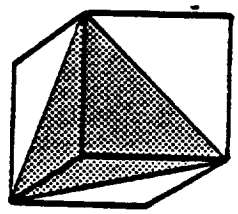
Orientation: Empty corner at point 8

Potential Function:

i	N^i
1	0
2	0
3	0
4	1-z
5	0
6	1-y
7	1-x
8	x+y+z-2

W_{ij}:

0							
0	0						
0	0	0					
0	0	0	1/6				
0	0	0	0	0			
0	0	0	0	0	1/6		
0	0	0	0	0	0	1/6	
0	0	0	-1/6	0	-1/6	-1/6	1/2



Standard Cell 4

Truncated Cube

Orientation: 000 corner (point 1) missing

Potential Function:

i	N^i
1	0
2	
3	
4	exercise for reader
5	
6	
7	
8	

W_{ij}:

0							
0	5/12						
0	1/72	5/12					
0	-11/120	-37/360	13/36				
0	1/72	1/72	-1/9	5/12			
0	-37/360	-1/9	-7/180	-11/120	13/36		
0	-1/9	-11/120	-7/180	-37/360	-7/180	13/36	
0	-5/36	-5/36	1/45	-5/36	1/45	1/45	7/20

Additional Standard Cells:

Standard cell 5 (not treated by NASCAP/GEO) is a cube divided into two wedges by a slanted thin plate. In standard orientation, the "top" half corresponds to the empty portion of standard cell 1.

Standard cell 6 is a cube divided into two wedges by a slanted rectangular transparent antenna cell. It is treated by the potential solver as two complementary type 1 cells.

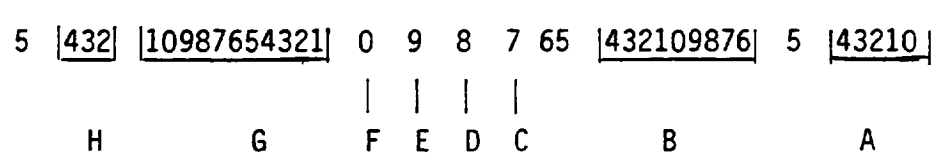
Cells containing equilateral triangle antenna surfaces are treated by the potential solver as empty (type 0) cells.

THIS PAGE INTENTIONALLY LEFT BLANK

3.15.3 VOLUME ELEMENT TABLE

Information concerning each volume element is stored in file ILTBL (Chapter 2). Each entry is bit coded as follows:

CODE FOR ELEMENT TABLE [LTBL(NX,NY,NZ)]



Field	Bits	
A	4–0	Elt-type code
	5	(Not used)
B	14–6	Orientation code
	16–15	(Not used)
C	17	Set for cells bordering the "TOP" surface of a "PLATE"
D	18	Set if elt is completely filled (interior)
E	19	Set for an empty special (type 2) elt
F	20	Set for cells bordering the "BOTTOM" surface of a "PLATE"
G	31–21	Index used to reference BEAMJ array to determine emitter currents
H	34–32	Number of surfaces pointing into volume cell

ORIENTATION CODE

The orientation code is a nine-bit (three octal digit) code describing how a non-symmetric element may be transformed into its "standard" orientation. The transformation (consisting of rotations, inversions, and translations) to the "standard" orientation is that transformation which takes vector $\underset{\sim}{r}$ into vector $\underset{\sim}{s}$, where

$$\underset{\sim}{r} = (x,y,z)$$
$$\underset{\sim}{s} = (q(i_1), q(i_2), q(i_3))$$

i_1 is the octal digit in bits 14-12
i_2 is the octal digit in bits 11-9
i_3 is the octal digit in bits 8-6

q(1) = x	q(5) = 1-x
q(2) = y	q(6) = 1-y
q(3) = z	q(7) = 1-z

For example, the octal code 365 implies the transformation

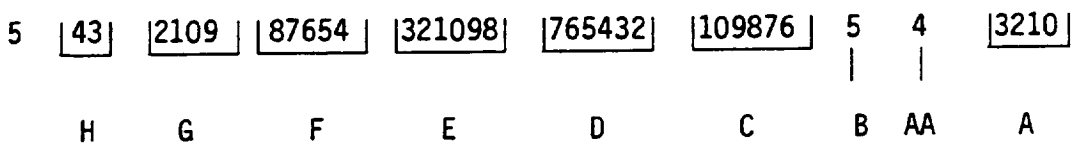
$$\underset{\sim}{s} = \begin{pmatrix} 0 & 0 & 1 \\ 0 & -1 & 0 \\ -1 & 0 & 0 \end{pmatrix} \underset{\sim}{r} + \begin{pmatrix} 0 \\ 1 \\ 1 \end{pmatrix}$$

3.15.4 SURFACE CELL POTENTIALS

The potentials, charge densities, etc. are stored in 17 x 17 x 33 arrays for each grid, with an entry for each grid point in free space. In addition, a separate list of potentials for each surface cell is kept (Table 2.6). The entries in the potential array for the grid points lying on the surface of the object are calculated determined by the potentials in the surface potential list. Each grid point belonging to a surface cell is assigned an "area weighted" proportion of that cell's potential. The final potential of the grid point is then the sum of contribution from all the surface cells touching it. The area weights are given by the area of the cell divided by the number of points defining the area; e.g., a point at the corner of a square cell has a weight of 0.25.

3.15.5 SURFACE CELL LIST

In addition to an element table list, bit-coded information concerning each surface cell is stored in array JSURF, the surface cell test. (This resides in random access file ICNOW, see Chapter 2.) The bit coding convention is shown in Figure 3.25.



Field	Bits	
A	3–0	Material index
AA	4	Set for transparent antenna surface
B	5	Set for right-triangular 100 surfaces and for 111 surfaces whose enclosing volume cell is mostly empty
C	11–6	Direction of surface normal (in crystallographic notation)
D	17–12	Z-coordinate
E	23–18	Y-coordinate
F	28–24	X-coordinate
G	32–29	Conductor index
H	34–33	Orientation code for right-triangular 100 surfaces

Figure 3.25. Surface cell list (JSURF) entry format.

Notes:

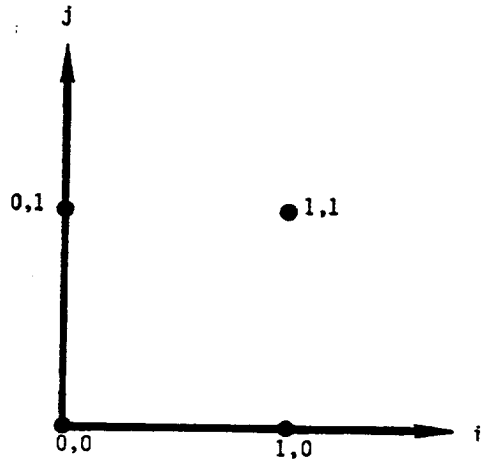
A – Gives the material number. Materials are numbered sequentially as encountered in the object definition file. Up to 15 materials are actually allowed (leaving one bit spare).

C - Two bits are taken for each crystallographic index. The rightmost of the pair for 1, 0, the leftmost for $\pm$ (set for minus).

D,E,F - The X, Y, Z coordinates refer to the lowest index or vertex of the associated volume cell (the one whose sum of X, Y, Z coordinates would be least positive). The associated volume cell is the cell containing a slanted surface, or out of which the surface points.

G - Conductor number - from 1 to 15.

H - The two bits define the location of the right angled corner in the plane of the triangle, i, j.



The rightmost bit refers to j. If i and j are related to the direction of the surface normal as follows

Normal	i	j
Z	X	Y
X	Y	Z
Y	Z	X

3.15.6 GEOMETRICAL ANALYSIS OF OBJECTS

Following completion of an object definition, NASCAP automatically invokes the routine GENMTL to perform a detailed geometrical analysis of the defined object. Among the functions performed are:

1. Verifying that every edge (of a surface cell) has a surface on either side.
2. Determining multiple-defined points. (Consider a path connecting surface cells of which the point is a vertex and circumnavigating the point. If there is only one such path, the point is a "single" point. If two paths, it is a "double" point. More than two paths make the point illegal.) When double points are found, it is verified that there is no ambiguity between "top" and "bottom".

When object definition errors are found, a message is printed indicating the approximate location (in absolute coordinates) of the error. Some errors are fatal, and others merely warnings. These warnings should be taken very seriously. The object definition graphics (obtainable through the module SATPLT) are often helpful in identifying the error.

In the process of performing this analysis GENMTL forms and outputs (to file ICNOW) several lists for later use in NASCAP. These are:

PTLIST - List of points which are vertices of insulating surface or boom cells; in format

```
C + 64*((D+2*(B+2*(V+2*E)))
  + 64*(Z+64*(Y+64*(X+64*G)))).
```

C = conductor number of all neighboring cells have same underlying conductor; otherwise C = 0.

D = 1 for double point; 0 otherwise.

B = 1 for bottom point; 0 otherwise.

V = 0.

E = 1 if point is vertex of a conducting surface cell;
E = 0 otherwise.

X, Y, Z are "absolute" [1-17, 1-17, 1-33] coordinates of point.

G = grid number (boom nodes only).

CPTLST - List of vertices of surface cells which do not appear in PTLIST. Same format as PTLIST, except V = 1.

DPTLST - List of double points in format Z + 64*(Y+64*X).

LINS - List of insulating surface and boom cells, in format

C + 4096*CELLNO.

C = underlying conductor number.

CELLNO = surface cell number or NSURF + boom cell number.

VTXL - Vertex-surface cell list to be used by subroutine REFIX. Format is

2^{18}*[PTLIST index] + [LINS index].

Each entry in the PTLIST produces an entry in VTXL for each surface or boom cell of which it is a vertex. For conducting cells, [LINS index] is replaced by NINS + [conductor number], where NINS is the length of LINS.

SCLIST - Surface connectivity map. Contains a negative number for each LINS entry and each conductor. Each negative number is followed by positive numbers indicating LINS entries or conductors to which the negative index is linked by bulk or surface conductivity.

SCMAT - Intrinsic surface and bulk conductivity matrix, ordered as SCLIST, with diagonal elements in positions corresponding to negative SCLIST entries.

Some of the highlights of those lists (such as their length) will be printed as GENMTL is executed. Additionally, if 'PRINT OBJDEF' is specified, the full PTLIST, CPTLST, and DPTLST will be printed.

4. MATERIAL PROPERTIES

4.1 SURFACES, CURRENTS AND CHARGING

An object exposed to a neutral plasma may charge electrostatically as charged particles (electrons and ions) collide with, and collect on, the surface. At geosynchronous altitudes the ambient plasma consists of electrons and ions with similar distributions of energy. Since electrons are almost 2000 times less massive than the lightest ions, this means that the particle velocity distributions are not similar, and the electron flux (or current) incident on an exposed surface greatly exceeds (by a factor of $\sqrt{1836} = 43$) the incident ion flux. If incident electron and ion currents were the only source of charge, all surfaces exposed to such plasmas would rapidly acquire a negative potential. However, there are several other contributions to the overall net current to the surface. These include:

1. Secondary emission due to primary electron impact, i_e^s.
2. Secondary emission due to ion impact, i_p^s.
3. Backscattered primary electrons, i^b.
4. Photoemission due to UV illumination (sunlight), i^p.
5. Conductivity (bulk and surface), i^c.

NASCAP takes all of these sources of current into account, as well as the incident primary currents, in calculating the net current to each surface cell. The mechanism for each source is discussed in detail in Section 4.8. If i_e and i_p are the incident primary electron and ion currents, respectively, the net current i_{net} to a particular surface cell is given by the equation:

$$i_{net} = i_e + i_p + i_e^s + i_p^s + i^b + i^p + i^c$$

In most cases the incident electron current i_e is the only negative contribution. Secondary emission, backscatter and photoemission are sources of positive current since they involve the ejection of electrons from the surface back to the plasma. The incident ion flux (i_p) is also a source of positive current but the secondary emission (plus photoemission in sunlight) forms the dominant contribution. Thus the sign of the net current i_{net} depends mainly on the balance between the secondary emission current (plus photoemission) and the incident electron current.

When i_e exceeds i_e^s ($+i^p$) the net current is negative and the surface will begin to acquire a negative potential. As the surface becomes negatively charged both the secondary emission and the incident electron current are modified. The effect is to attenuate the net negative current and the rate of charging declines. This continues until $i_{net} = 0$ and an equilibrium surface potential is reached. Equilibrium potentials of up to -10 kV have been observed in geosynchronous orbit.

When i_e is exceeded by i_e^s ($+i_p$) so that the net current is positive, then the surface begins to acquire a positive potential. However, large equilibrium positive potentials are not observed. This is because the secondary emission and photoemission, which form the dominant contribution to the positive current, have low energy (<10 eV). As soon as the surface potential approaches a few eV positive the low energy emission can no longer escape and is suppressed. This causes rapid attenuation of i_{net} and equilibrium is achieved. Since an equilibrium of just a few volts positive is negligible compared with potentials of kilovolts that are typical of negative charging, surfaces with net positive currents are often said to "not charge" or "remain neutral".

4.2 SURFACE CURRENTS AND MATERIAL PROPERTIES

Clearly it is important for NASCAP to include contributions from all of the important surface current sources mentioned in 4.1. Currents due to secondary emission, photoemission, backscatter, etc. all depend strongly on the nature of the material covering the surface. (The mechanisms for all of these current sources are explained in Section 4.8.)

For NASCAP to include realistic estimates of these currents in its calculations it must allow surface cells to be assigned different materials. In Chapter 3 we saw how object definition required a material name to be assigned to each exposed surface. NASCAP makes the connection between each material name and their different surface currents via a list of material properties.

4.3 MATERIAL PROPERTIES

Each material name (e.g., KAPTON, GOLD, FRED (the name is arbitrary)) has associated with it a list of material properties. The name of each material and the values for each material property are supplied by the user in the object definition file. (This is explained in Section 4.4.) The nineteen material properties are summarized in Table 4.1. Here we examine each one in more detail.

4.3.1 DIELECTRIC CONSTANT (PROPERTY 1)

Property 1 contains the relative dielectric constant for an insulating material ε_r

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$$

where ε is the absolute dielectric constant and ε_0 is the dielectric constant of free space. ε_r is dimensionless.

TABLE 4.1. MATERIAL PROPERTIES
(see Section 4.3 for notes)

Property No.	User Input Units	Description
1	None	Relative dielectric constant
2	m	Dielectric material thickness
3	$ohms^{-1}\ m^{-1}$	Bulk conductivity (= -1 for a metallic conductor)
4	None	Atomic number
5	None	Maximum secondary electron yield for electron impact
6	keV	Primary electron energy that produces maximum secondary yield
7	angstroms	Range parameters (4.3)
8	None	
9	angstroms	$R = P_7 E^{P_8} + P_9 E^{P_{10}}$
10	None	
11	None	Secondary electron yield due to impact of 1 keV protons
12	keV	Incident proton energy that produces maximum secondary electron yield
13	$A\ m^{-2}$	Photoelectron yield for normally incident sunlight
14	$ohms\ square^{-1}$	Surface resistivity (= -1 for non-conducting surface)
15	Volts	Maximum (absolute) potential attainable before a discharge must occur
16	Volts	Maximum potential difference between surface and underlying conductor before a discharge must occur
17	$ohms^{-1}\ m^{-1}$ $(m^2\ s^{-3})^{-1}$	Radiation-induced conductivity coefficient (k)
18	None	Radiation-induced conductivity power (Δ)
19	kg m-3	Material density

4.3.2 THICKNESS (PROPERTY 2)

Property 2 gives the thickness d of a dielectric film covering an underlying conductor in meters. d is arbitrary and may be chosen to be more or less than a mesh unit. However, note that NASCAP uses thin-film approximations in many of its calculations involving surfaces (Section 4.8).

4.3.3 BULK CONDUCTIVITY (PROPERTY 3)

Property 3 gives the bulk conductivity σ_0 of the surface material in ohms^{-1} m^{-1}. σ_0 is assumed to be the value appropriate for a sample not exposed to any radiation and not subject to any internal electric fields. Field enhancement and radiation enhancement of σ_0 is taken into account by NASCAP internally (if these effects are selected as run options (6.3.6 and 6.3.9)). A value of -1 indicates that the material is a metallic conductor.

4.3.4 ATOMIC NUMBER (PROPERTY 4)

Property 4 is the atomic number for pure elements or the mean atomic number for chemical compounds; e.g., polyethylene $(CH_2)_n$ has a mean atomic number of $(6 + 1 + 1)/3 = 2.7$.

4.3.5 SECONDARY YIELD (PROPERTIES 5 AND 6)

Properties 5 and 6 are the coordinates of the maximum in the secondary electron yield curve of the material. The secondary yield curve is a plot of secondary yield δ

$$\delta = \frac{\text{current of secondary electrons emitted}}{\text{incident primary electron current}}$$

for normally incident electrons, against the incident energy of the primary electron E. This is shown in Figure 4.5. Property 5 contains δ_{max}, and property 6 contains E_{max} in keV.

4.3.6 ELECTRON RANGE (PROPERTIES 7, 8, 9 AND 10)

Part of the secondary electron emission formulation requires an analytical form for the "range" of electrons in the material. The range is the depth to which the electrons can penetrate the material as they are continuously slowed down by losing energy to the material lattice. NASCAP uses a biexponential form. If P_7, P_8, P_9, and P_{10} are properties 7–10 respectively, the range R is given by

$$R = P_7 E^{P_8} + P_9 E^{P_{10}}$$

The four parameters are obtained from fits to stopping power data (Section 4.8). The range is determined in $\mathring{A}$ (10^{-10} m). If no reliable stopping power data or four parameter fits are available, the range may be estimated from Feldman's formula[4] automatically by assigning -1 to property 7. In this mode properties 7–10 are assigned as follows:

P_7 = -1
P_8 = null
P_9 = material density (g cm^{-3})
P_{10} = mean atomic weight (AMU)

The mean atomic weight is calculated in the same way as the mean atomic number (4.3.4) using atomic masses rather than numbers.

4.3.7 ION INDUCED SECONDARY EMISSION (PROPERTIES 11 AND 12)

Secondary emission of electrons due to ion impact is also treated using a two parameter theory (Section 4.8). Parameter 11 contains the yield for 1 keV normally incident protons and parameter 12 the proton energy that produces the maximum electron yield. The secondary emission properties due to impact of ions other than protons are assumed to be identical to the proton values.

4.3.8 PHOTOEMISSION (PROPERTY 13)

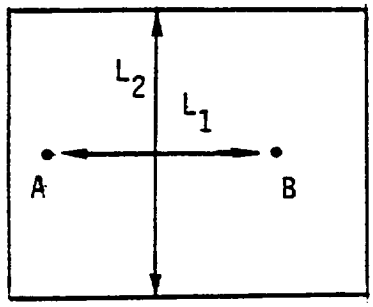
Property 13 contains the yield of photoelectrons from the surface material exposed to the solar spectrum. The intensity is that measured on earth 93,000,000 miles from the sun. (Earth orbit altitudes are negligible by comparison and the intensity of the sun close to earth may be considered constant.)

4.3.9 SURFACE RESISTIVITY (PROPERTY 14)

Property 14 gives the intrinsic surface resistivity in the "ohms per square". This rather odd unit is used to distinguish the resistivity coefficient (property 14) from the actual surface resistance (in ohms) calculated by NASCAP. Consider two points in a plane A and B, a distance L_1 apart. If L_2 is the "width" of the plane

$$\text{surface resistance} = \text{surface resistivity} \times \frac{L_1}{L_2}$$

$$\text{i.e.} \qquad \text{ohms} = (\text{ohms per square}) \times \begin{matrix}\text{dimensionless} \\ \text{geometrical} \\ \text{factor}\end{matrix}$$



NASCAP uses the surface resistivity per square, times a geometrical factor it calculates to determine the surface resistance between two adjacent materials.

The intrinsic surface conductivity is due to the migration of electrons along the surface layer aided by adsorbed impurities and defects. An additional contribution is made by photo electrons "hopping" along the surface. This so-called "photosheath" conductivity is included, if requested using the run option 'EFFCON ON' (Section 6.3.4).

Surface conductivity may be omitted from the current calculations completely by choosing property 14 to be negative.

4.3.10 DISCHARGE ANALYSIS (PROPERTIES 15, 16)

Properties 15 and 16 refer to discharges. Property 15 contains the maximum absolute potential that the material may reach (in volts) before a "blowoff" of charge to space (or tank walls) must occur. Property 16 contains the maximum potential difference (in volts) that can exist between the material surface and an underlying conductor before a "punchthrough" or dielectric breakdown must occur.

If a discharge analysis is requested, upon reaching these limiting potentials NASCAP redistributes the charge in an appropriate way (6.3.3).

4.3.11 PROPERTIES 17, 18, 19, 20 (RADIATION INDUCED CONDUCTIVITY)

These four properties are all used by the radiation-induced conductivity option (6.3.9 and 4.8). The extra bulk conductivity due to irradiation of the sample with high energy electrons σ_r is given by

$$\sigma_r = k \dot{D}^{\Delta}$$

where $\dot{D}$ is the dose rate (energy deposited per unit mass per second) to the material from the high energy electrons. Properties 17 and 18 contain k in ohms^{-1} m^{-1} (m^{2} s^{-3})$^{-1}$ (1 rad s^{-1} = 10^{-2} m^{2} s^{3}) and the power Δ, respectively.

Property 19 contains the density of the material in kg m^{-3} and is used to calculate the dose rate (4.8). Property 20 is used by NASCAP to store the original value of σ_0 entered by the user as property 3. Property 3 is replaced by the value of the overall effective bulk conductivity, including field and radiation enhancement. No significant user input is required for property 20.

4.4 DEFINING MATERIALS

New materials are defined, and their properties assigned inside the object definition file ISAT (3.5). The object definition file is read by NASCAP module OBJDEF. OBJDEF interprets any word that it does not recognize as a building block keyword (or their parameter cards (3.9.6)) as the definition of a new material name. New material names may <u>not</u> appear inside building block definitions (i.e., between a building block keyword and an 'ENDOBJ' statement).

Following the material name OBJDEF expects to find three additional cards specifying 20 constants as the material properties to be associated with the name. The 20 constants correspond to properties 1-20 and are read sequentially; i.e., the first constant read is interpreted as property 1, the second, property 2, and so on. They are arranged sequentially, eight per card, so that cards 1 and 2 each have eight numbers and card 3, four numbers. Formally each number is written in a field of up to ten characters, but NASCAP will read the cards in free format. No units need be specified. NASCAP will assume the units given in Table 4.1 and no others. For properties not requiring any input such as property 20, or properties 17-19 for conductors, some constant <u>must</u> be entered but its value is arbitrary. (NASCAP will not actually use the values entered but expects to read something.)

Once the three material property cards have been read OBJDEF is ready to accept any other keywords or more material names. NASCAP will recognize up to fifteen different materials.

Materials must be defined before they are referred to in any building block definition. For example, if I assign the surface of a sphere to be 'FSTUFF' with the card

```
MATERIAL FSTUFF
```

if 'FSTUFF' and its material properties have not been declared earlier in the object definition file, an error will occur and execution will stop. For this reason all the materials to be used are usually declared at the very beginning of the object definition file. This is shown in Figure 4.1.

4.5 DEFAULT MATERIALS

There is one case where the user can forget to define his or her materials and get away with it. When OBJDEF encounters a material that hasn't been defined already, before an error occurs, it checks the following list of default materials:

ALUMIN
AQUADG
CPAINT
GOLD
INDOX
MAGNES
SCREEN
KAPTON
NPAINT
SIO2
SOLAR
TEFLON
SILVER

```
COMMENT  DEFINITION OF SATELLITE "BIG EARS"

Material Name 1
 {3 material property cards

Material Name 2
 {3 material property cards
    .
    .
    .

COMMENT  DEFINE MAIN BODY

CONDUCTOR 1

QSPHERE
 {parameter cards
ENDOBJ

RECTAN
 {parameter cards
ENDOBJ

    .
    .    more building blocks
    .

COMMENT  DEFINE SOLAR PANEL (SEPARATE CONDUCTOR)

CONDUCTOR 2

PLATE
 {parameter cards
ENDOBJ

    .
    .   more building blocks
    .

COMMENT

CONDUCTOR 3
    .
    .   more conductor segments
    .

ENDSAT
```

Figure 4.1. General form of the object definition file ISAT.

If the material is included in this list, it becomes one of the up to fifteen defined materials and its properties, stored internally, are automatically entered as OBJDEF input by the code. The properties of these materials are shown in Table 4.2. Any further reference to the material will assign the same set of properties to the surfaces concerned. If the material is not found in this list, an error will occur.

If two sets of material properties are defined with the same name, or names with the same first four letters, two of the fifteen possible materials are used up but only the first set of material properties are used. For example, if GOLD is referenced before it is defined in the runstream, the default material properties of gold will be associated with all gold surfaces in the object definition file. If a material called 'GOLD' or 'GOLDPD' or 'GOLDXXXX' is defined later with different properties the number of materials NASCAP thinks it has will be increased by one, but the new properties will be effectively ignored. Multiple definition of materials should be avoided. Note, however, that if any of the default materials are explicitly defined before they are referred to in building block definitions then NASCAP will make no attempt to find them in the list of default materials and the materials will not be multiple defined.

4.6 THE OBJECT DEFINITION FILE - ANOTHER EXAMPLE

We are now ready to bring together Chapters 3 and 4 and examine the structure of the object definition file ISAT. The general form is shown in Figure 4.1. The materials are defined first, followed by the building blocks associated with each separate conductor. The use of COMMENT cards allow the logic of the definition of a complex object to be followed more easily. Finally the whole file is terminated with an 'ENDSAT' statement. An actual example is shown in Figure 4.2. This object is the same as the one used in the worked example described in Chapter 11. It consists of a central RECTANgular body connected to two QSPHERES via two short BOOMS.

```
    1:COMMENT WORKED EXAMPLE (CHAPTER 11)
    2:COMMENT ZONE SIZE IS 0.02 M
    3:COMMENT DEFINE MATERIAL GOLD AND SOLAR
    4:GOLD
    5:1.00      .001      -1.       79.       .88       .8        88.8      .92
    6:53.48     1.73      .413      135.      .000029   -1.       10000.    2000.
    7:1.E-13    1.        1.E+3     20.
    8:SOLAR
    9:3.8       .000179         1.E-17 10.     2.05      .41       77.5      .45
   10:156.1     1.73      .244      230.      .00002          1.E+19 10000.    2000.
   11:1.E-13    1.        1.E+3     20.
   12:COMMENT PROPERTIES OF KAPTON AND ALUMINUM FROM DEFAULT TABLE.
   13:CONDUCTOR 1
   14:COMMENT CENTRAL CUBOID
   15:RECTAN
   16:CORNER -3 -2 -2
   17:DELTAS 6 4 4
   18:SURFACE +X GOLD
   19:SURFACE -X KAPTON
   20:SURFACE +Y KAPTON
   21:SURFACE -Y KAPTON
   22:SURFACE +Z KAPTON
   23:SURFACE -Z KAPTON
   24:ENDOBJ
   25:COMMENT BOOM TO KAPTON SPHERE
   26:BOOM
   27:AXIS 0 0 2 0 0 4
   28:RADIUS 0.05
   29:SURFACE ALUMINUM
   30:ENDOBJ
   31:COMMENT BOOM TO SOLAR SPHERE
   32:BOOM
   33:AXIS 0 0 -2 0 0 -4
   34:RADIUS 0.05
   35:SURFACE ALUMINUM
   36:ENDOBJ
   37:COMMENT KAPTON SPHERE
   38:QSPHERE
   39:CENTER 0  0  5
   40:DIAMETER 3
   41:SIDE 1
   42:MATERIAL KAPTON
   43:ENDOBJ
   44:COMMENT SOLAR SPHERE (ON SEPARATE CONDUCTOR)
   45:CONDUCTOR 2
   46:QSPHERE
   47:CENTER 0 0 -6
   48:DIAMETER 3
   49:SIDE 1
   50:MATERIAL SOLAR
   51:ENDOBJ
   52:ENDSAT
EOF:52
0:)
```

Figure 4.2. Object definition file.

A 3D-VIEW (6.6.1) of the object produced by NASCAP is shown in Figure 4.3. A more detailed discussion of the definition of this object is given in Section 11.2.

4.7 OBJECTS WITHIN OBJECTS: VARIEGATED SURFACES

NASCAP makes it easy to define surfaces that are made up of more than one material. For example, we may want to define one face of a cube to be mainly KAPTON but with a patch of say GOLD in the center (Figure 4.4). We begin by defining the cube with a KAPTON face. The center surface cell is then replaced with GOLD by defining a second smaller cube inside the first cube. The second cube is defined so that one of its faces is coincident with the KAPTON face. The surface common to both cubes is then associated with the material on the face of the second cube, which in this case is GOLD. This is shown in Figure 4.4.

The object definition file associated with this object has the form:

```
COMMENT                 VARIEGATED CUBE
RECTAN
CORNER                  -2  -2  -2
DELTAS                   3   3   3
SURFACE                 +x  KAPTON
SURFACE                 -x  KAPTON
SURFACE                 +y  KAPTON
SURFACE                 -y  KAPTON
SURFACE                 +z  KAPTON
SURFACE                 -z  KAPTON
ENDOBJ
RECTAN                  -1  -1  -1
CORNER
DELTA                    1   1   1
SURFACE                 -z  GOLD
ENDOBJ
ENDSAT
```

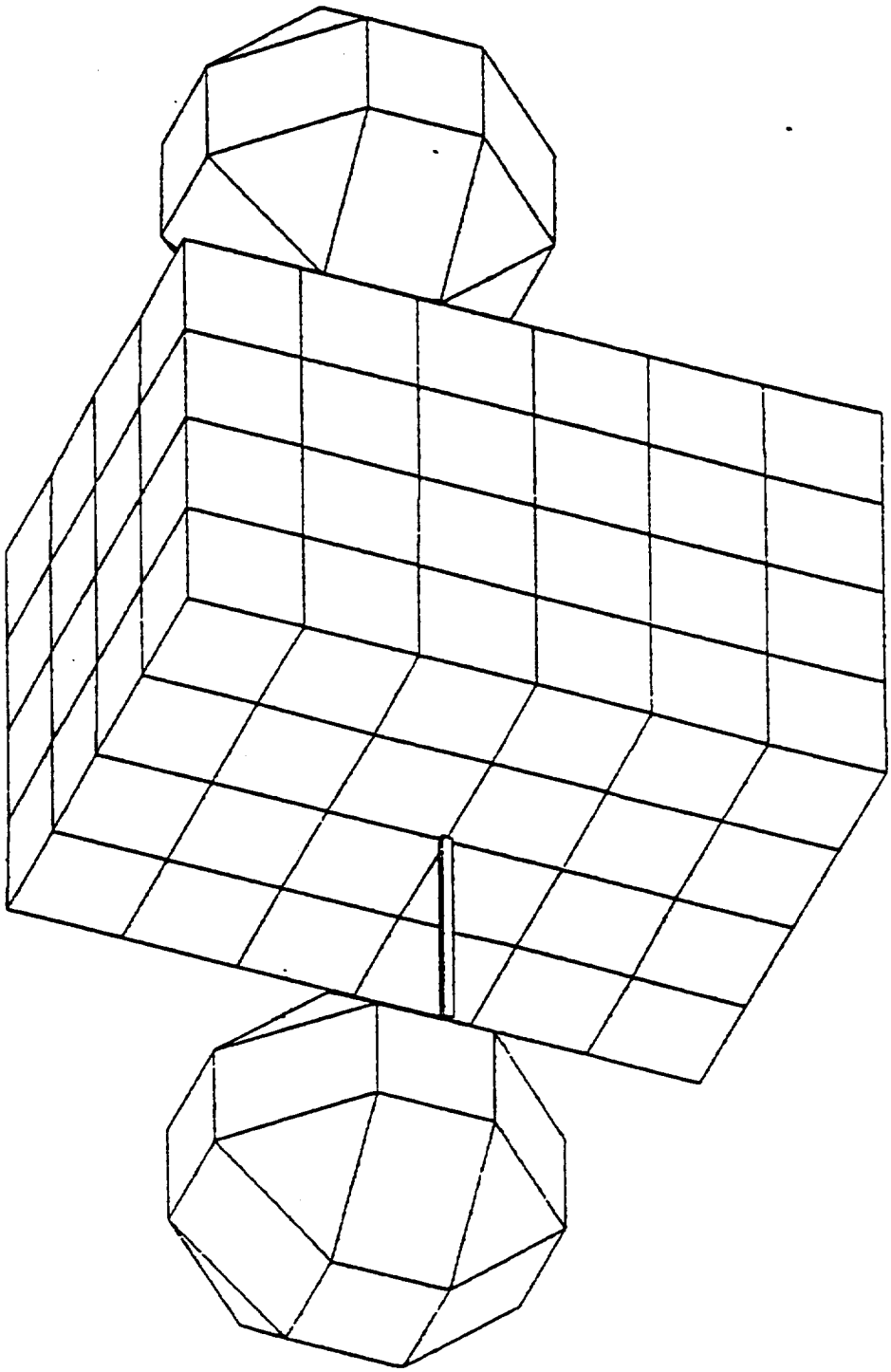
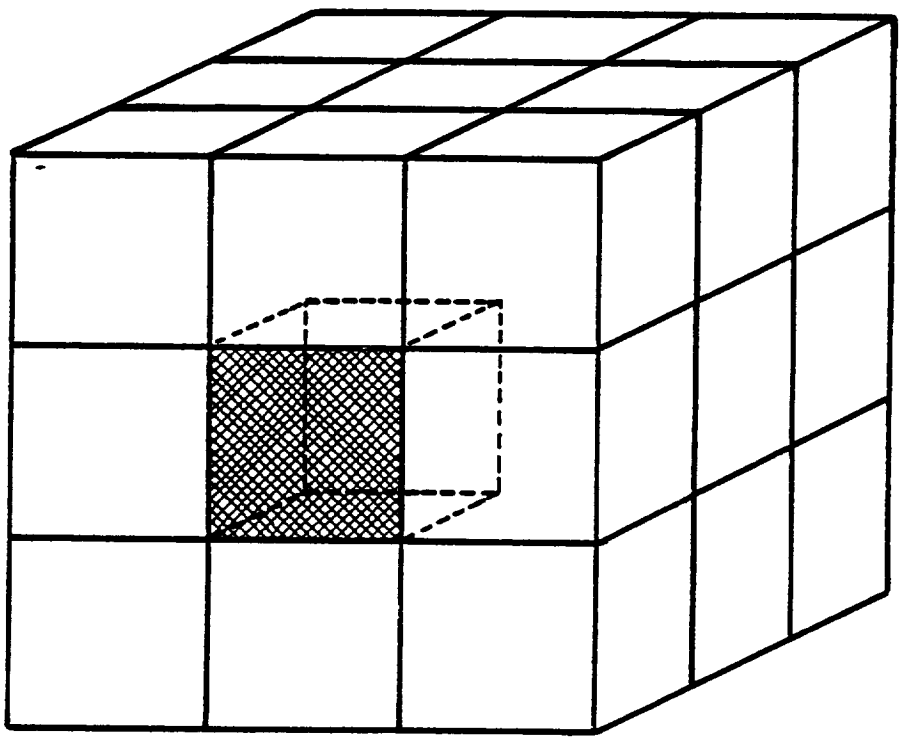
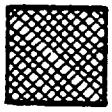
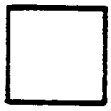


Figure 4.3. 3D-VIEW of object produced by SATPLT (hidden lines).





GOLD



KAPTON

Figure 4.4. A variegated surface definition.

The same principle can be applied to any of the building blocks. Exposed surface cells common to two or more building blocks are assigned to the material of the most recently defined block.

Two special building blocks are supplied specifically to create variegated surfaces. PATCHR and PATCHW define a RECTAN (cuboid) and a WEDGE respectively, that may be used to "patch" other objects without adding to NASCAP's list of filled space. The use of actual RECTAN and WEDGE blocks inside others is also perfectly legitimate, but adds to the internally used list. If the list becomes too long (as it might for a complicated object) shadowing calculations are no longer possible (8.1). The use of PATCHR and PATCHW reduce the likelihood of this problem occurring.

The object shown in Figure 4.4 could also be defined using PATCHR:

```
COMMENT     VARIEGATED CUBE (PATCHR)
RECTAN
CORNER      -2  -2  -2
DELTAS       3   3   3
SURFACE     +X  KAPTON
SURFACE     -X  KAPTON
SURFACE     +Y  KAPTON
SURFACE     -Y  KAPTON
SURFACE     +Z  KAPTON
SURFACE     -Z  KAPTON
ENDOBJ
PATCHR
CORNER      -1  -1  -1
DELTAS       1   1   1
SURFACE     -Z  GOLD
ENDOBJ
ENDSAT
```

4.8 TECHNICAL DISCUSSION

4.8.1 SECONDARY ELECTRON EMISSION DUE TO ELECTRON IMPACT

Secondary electrons are defined as those emitted from the surface due to particle impact with energies below 50 eV. Their energy distribution is usually peaked below 10 eV. We define the secondary yield δ as the ratio of primary to secondary electron current.

$$\delta = \frac{\text{emitted secondary current due to electron impact}}{\text{primary electron current}}$$

NASCAP calculates the secondary electron emission yield, δ, using the empirical formula:[2]

$$\delta(\theta) = C \int_0^R \left| \frac{dE}{dx} \right| e^{-\alpha x \cos\theta} \, dx$$

where x is the path length of penetration of a primary electron beam into the material, R is the "Range", or maximum penetration length, and θ is the angle of incidence of the primary electron.

This equation is based upon a simple physical model:[5]

a. The number of secondary electrons produced by the primary beam at a distance x is proportional to the energy loss of the beam or "stopping power" of the material, $|dE/dx|$.

b. The fraction of the secondaries that migrate to the surface and escape decreases exponentially with depth ($f = e^{\alpha x \cos\theta}$). Thus only those produced within a few multiples of the distance $1/\alpha$ (the depth of escape) from the surface contribute significantly to the observed yield.

The range increases with the initial energy, E_0, of the incident electrons in a way that approximates a simple "power law":[4]

$$R = b\, E_0^n$$

where $1.0 < n < 2.0$.

This equation implies a simple form for the stopping power S(E):

$$S(E) = \left|\frac{dE}{dx}\right| = \left|\frac{dR}{dE_0}\right|^{-1} = \frac{E^{1-n}}{nb}$$

Because the primary beam loses energy as it passes through the material, both E, and hence $S(E_0,x)$, depend on the path length x. Integrating:

$$E^n(x) = E_0^n - \frac{x}{b}$$

$$S(x) = \frac{1}{nb}\left(\frac{b}{R - x}\right)^{1-1/n}$$

The stopping power $S(E_0,x)$ depends upon both the initial electron energy E_0, via R, and the path length x. Figure 4.5a shows schematically $S(E_0,x)$ plotted against x for several values of E_0. Inspection of Figure 4.5a and the equation for S(x) illustrates the following points:

1. $S(E_0,x)$ increases with x, slowly at first, before reaching a singularity as x approaches R.
2. The initial value of $S(E_0,x)$ decreases with increasing initial energy E_0.

Both of these observations are due to the decrease in electron-atom collision cross-section with increasing energy.

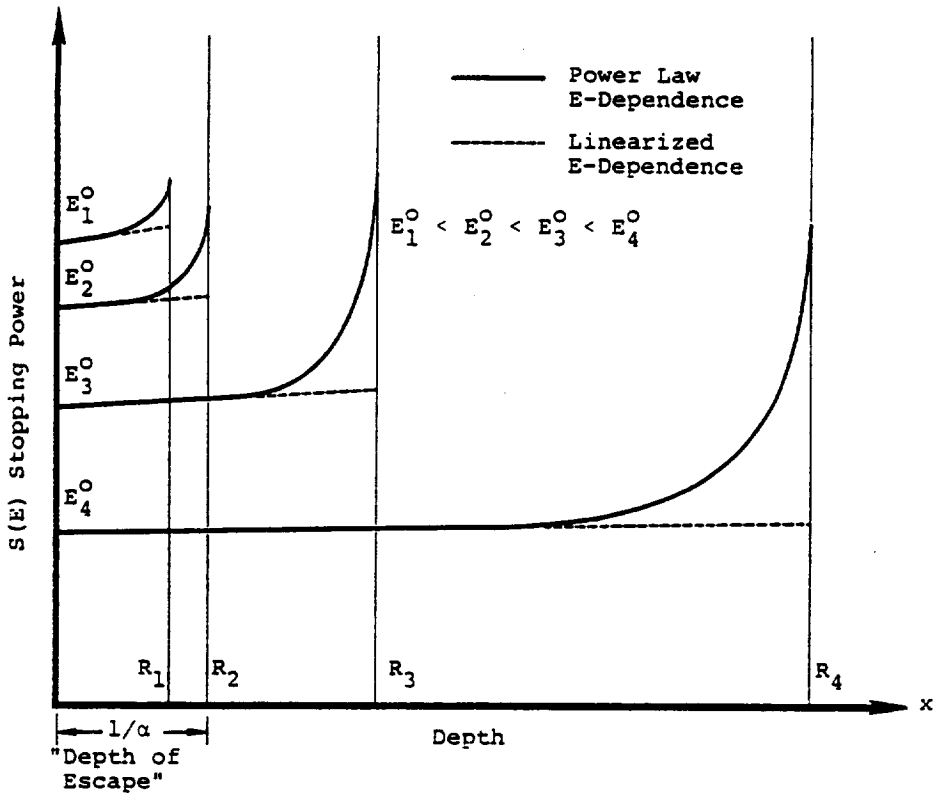


Figure 4.5a. Energy deposition profiles of normally incident primary electrons for incident energies E^o.

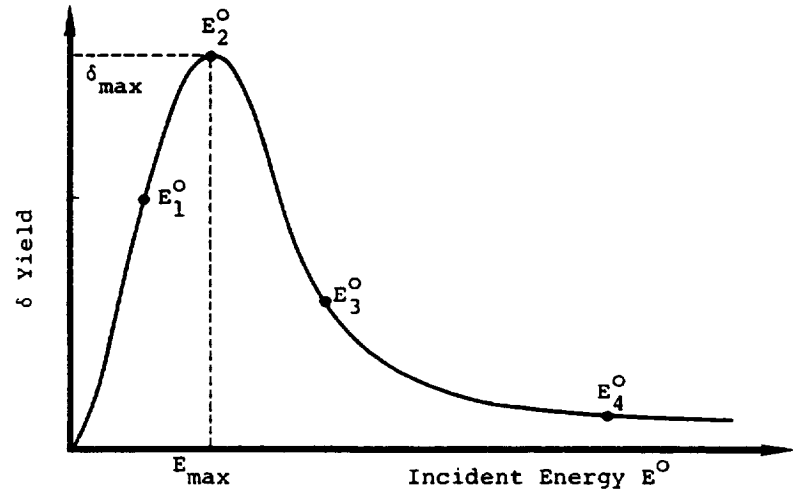


Figure 4.5b. Generalized yield curve.

The yield is only sensitive to the details of the stopping-power depth-dependence for initial energies with ranges of the same order as the escape depth, $R \sim 1/\alpha$ (i.e., about the maximum of the yield curve). For lower energies, $R << 1/\alpha$, and essentially all of the primary energy is available for detectable secondary production, leading to a linear increase in yield with increasing E_0. At higher energies, where $R >> 1/\alpha$, $S(E_0,x)$ remains almost constant, at its initial value, over the depth of escape and so, along with $S(E_0,x)$ the yield decreases as E_0 increases.

NASCAP takes this into account and approximates the stopping power by a linear expansion in x, about x = 0.

$$\frac{dE}{dx} = \left(\frac{dR}{dE_0}\right)^{-1} + \left(\frac{d^2R}{dE_0^2}\right)\left(\frac{dR}{dE_0}\right)^{-3} x$$

NASCAP allows for a bi-exponential range law:

$$R = b_1 E_0^{n_1} + b_2 E_0^{n_2}$$

involving four parameters b_1, b_2, n_1, n_2. The parameters are fit to reproduce range data as accurately as possible. For materials where no suitable data is available, a mono-exponential form is generated using Feldman's empirical relationships,[4] connecting b and n to atomic data.

$$b = 250\ A/\rho Z^{n/2}$$

$$n = 1.2/(1 - 0.29 \log_{10} Z)$$

where A is the atomic or molecular weight of the material, Z is the atomic number, and ρ is the density. The stopping power is then

obtained indirectly via the equation above. Recently good theoretical estimates of the stopping power for a number of materials have become available.[6] Comparison of these values with those implied by the range data showed significant discrepancies, particularly for those materials fit using Feldman's formula.[4] A better approach is to fit the four parameters in the equation for R directly to the stopping power data.

$$S = \left(n_1 b_1 E^{n_1 - 1} + n_2 b_2 E^{n_2 - 1} \right)^{-1}$$

4.8.2 SECONDARY EMISSION DUE TO ION IMPACT

Secondary emission of electrons due to ion impact is treated in a way similar to that for electron impact discussed in 4.9.1. The yield Δ is given by

$$\Delta(\theta) = C \int_0^t \left| \frac{dE}{dx} \right| e^{-\alpha x} \sin\theta \, dx$$

The angular dependence is assumed to be a simple sine form, and the stopping power is assumed to be independent of path length x over the thickness t of the sample.

$$\left| \frac{dE}{dx} \right| = \beta E^{1/2} / (1 + E/E_{max})$$

E_{max} is the energy at the maximum in the yield curve. This is ~50 keV for most materials. A typical yield curve is shown for aluminum in Figure 4.6.

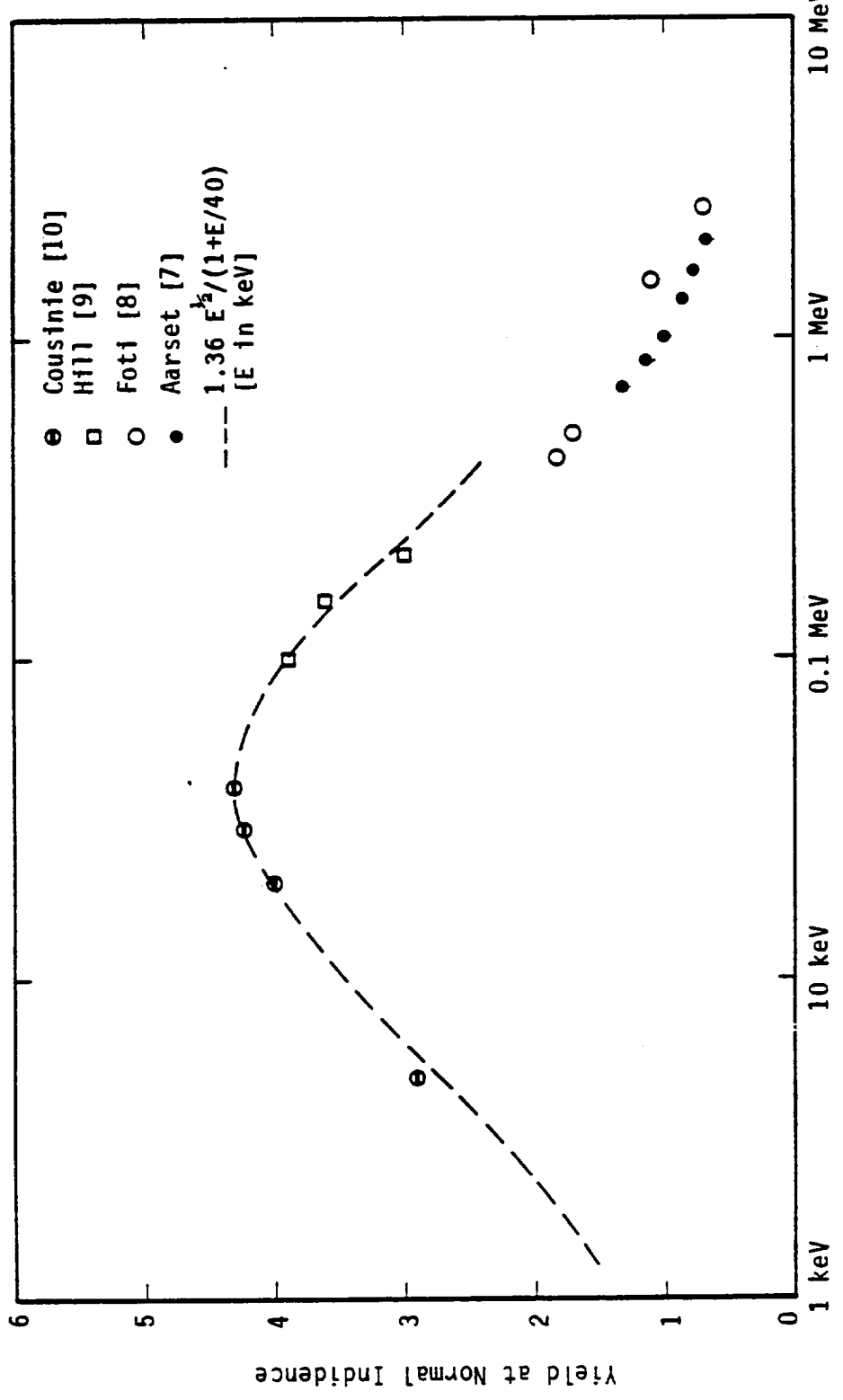


Figure 4.6. Secondary emission by aluminum for proton impact at normal incidence; experimental points as indicated.

4.8.3 BACKSCATTER

Backscattered electrons are those emitted from the surface with energies above 50 eV. Their energy distribution is usually peaked close to the primary incident energy and they may be considered as reflected electrons.

The large-angle scattering theory, together with Monte Carlo data and experiments by Darlington and Cosslett,[11] indicate that the angular dependence of backscattering is well described by

$$\eta(\theta) = \eta(0)\ \exp[\eta_1(1 - \cos\theta)]$$

where the value of η_1 is, within the uncertainty in the data, what would be obtained by assuming total backscattering at glancing incidence, viz. $\eta_1 = -\log \eta_0$. The net albedo for an isotropic flux is then

$$A_0 = 2[1 - \eta_0(1 - \log \eta_0)]/(\log \eta_0)^2 \quad .$$

As the energy is decreased below 10 keV the backscattering increases. Data cited by Shimizu[12] indicate an increase of about 0.1, almost independent of Z. NASCAP approximates this component of backscattering by

$$\delta\eta_0 = 0.1\ \exp[-E/5\ \text{keV}] \quad .$$

At very low energies the backscattering coefficient becomes very small and, below 50 eV, backscattering and secondary emission are indistinguishable. NASCAP takes account of this by a factor of

$$[(E - 50\ \text{eV})/\log 20]\ \log(E/50\ \text{eV}).$$

The formula for energy-dependent backscattering, incorporating these assumptions, is then

$$\eta_0 = \{[\log(E/0.05)\Theta(E - 0.05)\Theta(1.0 - E)/\log(20) + \Theta(E - 1.0)\} \times [0.1 \exp(-E/5) + 1 - (2/e)^{.037Z}]$$

where energies are measured in keV.

4.8.4 PHOTOEMISSION

The user enters the yield (Y), or number of electrons emitted for a surface normally exposed to the solar spectrum, an "earth distance" from the sun. NASCAP calculates the photocurrent from a surface exposed to the sun at an angle e, according to the formula

$$i_{phot} = (\text{Area exposed}) \cdot Y \cdot \cos e$$

This assumes that the yield per photon is, on average, independent of e.

4.8.5 CONDUCTIVITY

The bulk conductivity σ_0 is assumed constant unless the 'RADCON' and 'FLDCON' options are chosen to be 'ON' (6.3.6 and 6.3.9). With these options in force σ is enhanced by both fields across the dielectric film and high energy electron fluxes.

a. FIELD-INDUCED CONDUCTIVITY

Consider a thin dielectric film of thickness d covering an underlying conductor. If the potential of the dielectric surface V_s differs from the potential of the conductor V_c, current will flow due to bulk conductivity.

$$I_c = -\sigma\Delta V = -\sigma(V_s - V_c)$$

σ is the bulk conductivity of the sample in mhos. If $\bar{\sigma}$ is the specific conductivity in mhos m^{-1} and A is the area of the sample in m^2

$$\sigma = \frac{\bar{\sigma}A}{d}$$

i.e. $$I_c = -\frac{\bar{\sigma}A.\Delta V}{d}$$

I_c depends on ΔV in a nonlinear way due to the electric field enhancement of σ. Assuming a thin film, the field E is given by

$$E = \frac{\Delta V}{d}$$

Adamec and Calderwood[13] have shown that σ depends on E in the following way:

$$\sigma(E) = \frac{\sigma_o}{3}\left[2 + \cosh\left(\frac{\beta_f |E|^{1/2}}{2\,kT}\right)\right]$$

where

$$\beta_F = \left(\frac{|q|^3}{\pi\varepsilon}\right)^{1/2}$$

and q is the charge on the electron and ε is the dielectric constant.

b. RADIATION-INDUCED CONDUCTIVITY

Dielectric materials have characteristically small bulk conductivities due to their electron band structure. Unlike metals, the delocalized conduction bands are empty at normal temperatures and electrons are strongly localized in the regions close to individual nuclei. However, under the influence of an exciting source non-conducting electrons can be promoted into the conduction bands,

leading to an increase in the bulk conductivity. High energy electrons passing through the dielectric provide such an excitation source.

While NASCAP treats the non-penetrating ($\leq$50 keV) portion of the plasma spectrum explicitly in calculating the buildup of surface charge, it presently neglects the very low fluxes of higher energy penetrating electrons, since they make a negligible contribution to the total incident charge. Recent studies[14] suggest, however, that the penetrating fluxes may influence the degree of differential charging by increasing the bulk conductivity in this way. This enhancement due to high energy electron fluxes is described as the "radiation-induced" conductivity σ_r.

Frederickson[15] has expressed σ_r in terms of the dose rate $\dot{D}$ and two parameters k and Δ.

$$\sigma_r = k\dot{D}^{\Delta}$$

k and Δ are characteristic of each material and Δ usually lies between 0.5 and 1.0. The dose rate can be estimated from the stopping power S for electrons in the medium of interest.

$$S(E) = dE/dx$$

The dose rate is measured as energy deposited per unit mass per second (i.e., rad s^{-1} = 100 erg g^{-1} s^{-1}). Stopping power is measured as energy deposited per particle per unit thickness of the sample. Dividing S(E) by the density ρ of the sample gives the energy deposited per particle per unit mass of the material multiplied by unit area. The product of this quantity with the flux (particles per unit area per second) gives the required dose rate:

$$\dot{D} = \text{flux} \cdot \frac{S(E)}{\rho}$$

The flux of incident electrons due to a plasma with distribution function f(E) is given by:

$$\langle nf \rangle = \frac{2}{m^2} \int E\, f(E)\, dE$$

$$\therefore \quad \dot{D} = \frac{2}{\rho m^2} \int E\, f(E)\, S(E)\, dE$$

A number of models for the energy spectrum of high energy fluxes in space have been measured.[16,17] All show a Maxwellian like behavior, i.e.,

$$f(E) = N \cdot \left(\frac{m}{2\pi T}\right)^{3/2} e^{-E/T}$$

The AE3 model[17] implies a value of 3×10^2 m^{-3} for the density N and 2.5×10^2 keV for the temperature T at geosynchronous orbit. Electrons in this energy range are relativistic; i.e., their velocity is close to that of light (c) and so the weight function E in the integral above should be replaced by mc^2. This is confirmed by a plot of <nf> against E which shows the same exponential behavior.

$$\therefore \quad \dot{D} = \frac{2c^2}{\rho m} \cdot N \left(\frac{m}{2\pi T}\right)^{3/2} \int_{50}^{\infty} e^{-E/T}\, S(E)\, dE$$

(where we assumed the contribution from non-penetrating electrons with energies below 50 keV is negligible).

The dose rate is calculated in NASCAP for each material by integrating the above equation, using Simpson's rule, between 50 keV and 4 T. If all energies are in keV and S(E) is in keV $\mathring{A}^{-1}$ and I is the value of the integral:

$$\dot{D} = \frac{2c^2}{\rho m} N \left(\frac{m}{2\pi T}\right)^{3/2} \cdot I \text{ keV}^2 \text{ A}^{-1}$$

Substituting:

$$\dot{D} = 1.38 \times 10^3 \frac{N \cdot T}{\rho T^{3/2}} m^2 s^{-3}$$

where N is in units of m^{-3}, ρ (kg m^{-3}) and T is in keV.

Frederickson[15] has pointed out that k is often known to within only 2 orders of magnitude and Δ values are usually close to 1. We assume values of $k = 1 \times 10^{-17}$ mhos cm^{-1} (rad s^{-1})$^{-1}$ $= 1 \times 10^{-13}$ mhos m^{-1} (m^2 s^{-3})$^{-1}$ and $\Delta = 1$ as default material properties 17 and 18, respectively. The density ρ in kg m^{-3} is material property 19. Since the density of plastics and other insulators depends very much on the particular sample and manufacturer, default values are chosen to be 1×10^3 kg m^{-3}.

4.8.6 ATTENUATION OF INCIDENT CURRENT

The net incident particle flux is attenuated as the surface becomes charged (either positively or negatively). This is because the flux of particles with opposite sign to the surface potential is enhanced and the flux of particles with the same sign is decreased. NASCAP assumes a spherical orbit limited particle collection formula. This is a good approximation for convex objects with radius of curvatures smaller than the Debye length of the ambient plasma. This is the major restriction that confines NASCAP to charging problems in the geosynchronous (long Debye length) regime. Spherical orbit limited collection gives the following form for the variation of incident current I with surface potential V:

$$J(E) = J_0 (\epsilon + qV) \left(1 - \frac{qV}{E+qV}\right)$$

where E is the kinetic energy of the repelled particle at the surface, q is the sign of the charge on the particle, and E+qV is the particle's total energy. The same formula holds for attracted particles.

TABLE 4.2. MATERIAL PROPERTIES

MATERIAL 1: ALUM

	PROPERTY	INPUT VALUE	CODE VALUE
1	DIELECTRIC CONSTANT	1.00+000 (NONE)	1.00+000 (NONE)
2	THICKNESS	1.00-003 METERS	1.00-002 MESH
3	CONDUCTIVITY	-1.00+000 MHO/M	-1.00+000 MHO/M
4	ATOMIC NUMBER	1.30+001 (NONE)	1.30+001 (NONE)
5	DELTA MAX >COEFF	9.70-001 (NONE)	9.18+000 (NONE)
6	E-MAX >DEPTH**-1	3.00-001 KEV	3.00-002 ANG-01
7	RANGE	1.54+002 ANG.	1.23+002 ANG.
8	EXPONENT > RANGE	8.00-001 (NONE)	3.87+002 ANG.
9	RANGE > EXPONENT	2.20+002 ANG.	8.00-001 (NONE)
10	EXPONENT	1.76+000 (NONE)	1.76+000 (NONE)
11	YIELD FOR 1KEV PROTONS	2.44-001 (NONE)	2.44-001 (NONE)
12	MAX DE/DX FOR PROTONS	2.30+002 KEV	2.30+002 KEV
13	PHOTOCURRENT	4.00-005 A/M**2	4.00-005 A/M**2
14	SURFACE RESISTIVITY	-1.00+000 OHMS	-8.85-013 V-S/C
15	SPACE DISCHARGE POT'L	1.00+004 VOLTS	1.00+004 VOLTS
16	INTERNAL DISCHARGEPOT'L	2.00+003 VOLTS	2.00+003 VOLTS
17	RADN INDUCEDCOND'YCOEFFT	1.00-013 MHOMS3	1.00-013 MHOMS3
18	RADN INDUCEDCOND'YPOWER	1.00+000 (NONE)	1.00+000 (NONE)
19	DENSITY	1.00+003 KG/M**3	1.00+003 KG/M**3
20		2.00+001	-1.00+000

MATERIAL 2: AQUA

	PROPERTY	INPUT VALUE	CODE VALUE
1	DIELECTRIC CONSTANT	1.00+000 (NONE)	1.00+000 (NONE)
2	THICKNESS	1.00-003 METERS	1.00-002 MESH
3	CONDUCTIVITY	-1.00+000 MHO/M	-1.00+000 MHO/M
4	ATOMIC NUMBER	6.00+000 (NONE)	6.00+000 (NONE)
5	DELTA MAX >COEFF	1.00+000 (NONE)	7.06+000 (NONE)
6	E-MAX >DEPTH**-1	3.00-001 KEV	2.21-002 ANG-01
7	RANGE	-1.00+000 ANG.	5.80+002 ANG.
8	EXPONENT > RANGE	.00 (NONE)	.00 ANG.
9	RANGE > EXPONENT	2.00+000 ANG.	1.55+002 (NONE)
10	EXPONENT	1.20+001 (NONE)	1.00+000 (NONE)
11	YIELD FOR 1KEV PROTONS	4.55-001 (NONE)	4.55-001 (NONE)
12	MAX DE/DX FOR PROTONS	1.40+002 KEV	1.40+002 KEV
13	PHOTOCURRENT	2.10-005 A/M**2	2.10-005 A/M**2
14	SURFACE RESISTIVITY	-1.00+000 OHMS	-8.85-013 V-S/C
15	SPACE DISCHARGE POT'L	1.00+004 VOLTS	1.00+004 VOLTS
16	INTERNAL DISCHARGEPOT'L	2.00+003 VOLTS	2.00+003 VOLTS
17	RADN INDUCEDCOND'YCOEFFT	1.00-013 MHOMS3	1.00-013 MHOMS3
18	RADN INDUCEDCOND'YPOWER	1.00+000 (NONE)	1.00+000 (NONE)
19	DENSITY	1.00+003 KG/M**3	1.00+003 KG/M**3
20		2.00+001	-1.00+000

TABLE 4.2. MATERIAL PROPERTIES (Continued).

MATERIAL 3: CPAI

	PROPERTY	INPUT VALUE	CODE VALUE
1	DIELECTRIC CONSTANT	3.50+000 (NONE)	3.50+000 (NONE)
2	THICKNESS	1.00-003 METERS	1.00-002 MESH
3	CONDUCTIVITY	-1.00+000 MHO/M	-1.00+000 MHO/M
4	ATOMIC NUMBER	5.00+000 (NONE)	5.00+000 (NONE)
5	DELTA MAX >COEFF	2.10+000 (NONE)	4.06+001 (NONE)
6	E-MAX >DEPTH**-1	1.50-001 KEV	8.74-002 ANG-01
7	RANGE	7.15+001 ANG.	4.29+001 ANG.
8	EXPONENT > RANGE	6.00-001 (NONE)	5.52+002 ANG.
9	RANGE > EXPONENT	3.12+002 ANG.	6.00-001 (NONE)
10	EXPONENT	1.77+000 (NONE)	1.77+000 (NONE)
11	YIELD FOR 1KEV PROTONS	4.55-001 (NONE)	4.55-001 (NONE)
12	MAX DE/DX FOR PROTONS	1.40+002 KEV	1.40+002 KEV
13	PHOTOCURRENT	2.00-005 A/M**2	2.00-005 A/M**2
14	SURFACE RESISTIVITY	-1.00+000 OHMS	-8.85-013 V-S/Q
15	SPACE DISCHARGE POT'L	1.00+004 VOLTS	1.00+004 VOLTS
16	INTERNAL DISCHARGEPOT'L	2.00+003 VOLTS	2.00+003 VOLTS
17	RADN INDUCEDCOND'YCOEFFT	1.00-013 MHOMS3	1.00-013 MHOMS3
18	RADN INDUCEDCOND'YPOWER	1.00+000 (NONE)	1.00+000 (NONE)
19	DENSITY	1.00+003 KG/M**3	1.00+003 KG/M**3
20		2.00+001	-1.00+000

MATERIAL 4: GOLD

	PROPERTY	INPUT VALUE	CODE VALUE
1	DIELECTRIC CONSTANT	1.00+000 (NONE)	1.00+000 (NONE)
2	THICKNESS	1.00-003 METERS	1.00-002 MESH
3	CONDUCTIVITY	-1.00+000 MHO/M	-1.00+000 MHO/M
4	ATOMIC NUMBER	7.90+001 (NONE)	7.90+001 (NONE)
5	DELTA MAX >COEFF	8.60-001 (NONE)	2.93+000 (NONE)
6	E-MAX >DEPTH**-1	6.00-001 KEV	2.02-002 ANG-01
7	RANGE	8.88+001 ANG.	8.17+001 ANG.
8	EXPONENT > RANGE	9.20-001 (NONE)	9.25+001 ANG.
9	RANGE > EXPONENT	5.35+001 ANG.	9.20-001 (NONE)
10	EXPONENT	1.73+000 (NONE)	1.73+000 (NONE)
11	YIELD FOR 1KEV PROTONS	4.13-001 (NONE)	4.13-001 (NONE)
12	MAX DE/DX FOR PROTONS	1.35+002 KEV	1.35+002 KEV
13	PHOTOCURRENT	2.90-005 A/M**2	2.90-005 A/M**2
14	SURFACE RESISTIVITY	-1.00+000 OHMS	-8.85-013 V-S/Q
15	SPACE DISCHARGE POT'L	1.00+004 VOLTS	1.00+004 VOLTS
16	INTERNAL DISCHARGEPOT'L	2.00+003 VOLTS	2.00+003 VOLTS
17	RADN INDUCEDCOND'YCOEFFT	1.00-013 MHOMS3	1.00-013 MHOMS3
18	RADN INDUCEDCOND'YPOWER	1.00+000 (NONE)	1.00+000 (NONE)
19	DENSITY	1.00+003 KG/M**3	1.00+003 KG/M**3
20		2.00+001	-1.00+000

TABLE 4.2. MATERIAL PROPERTIES (Continued).

MATERIAL 5: INDO

	PROPERTY	INPUT VALUE		CODE VALUE	
1	DIELECTRIC CONSTANT	1.00+000	(NONE)	1.00+000	(NONE)
2	THICKNESS	1.00-003	METERS	1.00-002	MESH
3	CONDUCTIVITY	-1.00+000	MHO/M	-1.00+000	MHO/M
4	ATOMIC NUMBER	2.44+001	(NONE)	2.44+001	(NONE)
5	DELTA MAX >COEFF	1.40+000	(NONE)	3.32+000	(NONE)
6	E-MAX >DEPTH**-1	8.00-001	KEV	1.49-002	ANG-01
7	RANGE	-1.00+000	ANG.	1.57+002	ANG.
8	EXPONENT > RANGE	.00	(NONE)	.00	ANG.
9	RANGE > EXPONENT	7.18+000	ANG.	2.01+000	(NONE)
10	EXPONENT	5.55+001	(NONE)	1.00+000	(NONE)
11	YIELD FOR 1KEV PROTONS	4.90-001	(NONE)	4.90-001	(NONE)
12	MAX DE/DX FOR PROTONS	1.23+002	KEV	1.23+002	KEV
13	PHOTOCURRENT	3.20-005	A/M**2	3.20-005	A/M**2
14	SURFACE RESISTIVITY	-1.00+000	OHMS	-8.85-013	V-S/C
15	SPACE DISCHARGE POT'L	1.00+004	VOLTS	1.00+004	VOLTS
16	INTERNAL DISCHARGEPOT'L	2.00+003	VOLTS	2.00+003	VOLTS
17	RADN INDUCEDCOND'YCOEFFT	1.00-013	MHOMS3	1.00-013	MHOMS3
18	RADN INDUCEDCOND'YPOWER	1.00+000	(NONE)	1.00+000	(NONE)
19	DENSITY	1.00+003	KG/M**3	1.00+003	KG/M**3
20		2.00+001		-1.00+000	

MATERIAL 6: MAGN

	PROPERTY	INPUT VALUE		CODE VALUE	
1	DIELECTRIC CONSTANT	1.00+000	(NONE)	1.00+000	(NONE)
2	THICKNESS	1.00-003	METERS	1.00-002	MESH
3	CONDUCTIVITY	-1.00+000	MHO/M	-1.00+000	MHO/M
4	ATOMIC NUMBER	1.20+001	(NONE)	1.20+001	(NONE)
5	DELTA MAX >COEFF	9.20-001	(NONE)	7.02+000	(NONE)
6	E-MAX >DEPTH**-1	2.50-001	KEV	2.79-002	ANG-01
7	RANGE	-1.00+000	ANG.	6.96+002	ANG.
8	EXPONENT > RANGE	.00	(NONE)	.00	ANG.
9	RANGE > EXPONENT	1.74+000	ANG.	1.75+000	(NONE)
10	EXPONENT	2.43+001	(NONE)	1.00+000	(NONE)
11	YIELD FOR 1KEV PROTONS	2.44-001	(NONE)	2.44-001	(NONE)
12	MAX DE/DX FOR PROTONS	2.30+002	KEV	2.30+002	KEV
13	PHOTOCURRENT	4.00-005	A/M**2	4.00-005	A/M**2
14	SURFACE RESISTIVITY	-1.00+000	OHMS	-8.85-013	V-S/C
15	SPACE DISCHARGE POT'L	1.00+004	VOLTS	1.00+004	VOLTS
16	INTERNAL DISCHARGEPOT'L	2.00+003	VOLTS	2.00+003	VOLTS
17	RADN INDUCEDCOND'YCOEFFT	1.00-013	MHOMS3	1.00-013	MHOMS3
18	RADN INDUCEDCOND'YPOWER	1.00+000	(NONE)	1.00+000	(NONE)
19	DENSITY	1.00+003	KG/M**3	1.00+003	KG/M**3
20		2.00+001		-1.00+000	

TABLE 4.2. MATERIAL PROPERTIES (Continued).

MATERIAL 7: SCRE

	PROPERTY	INPUT VALUE	CODE VALUE
1	DIELECTRIC CONSTANT	1.00+000 (NONE)	1.00+000 (NONE)
2	THICKNESS	1.00-003 METERS	1.00-002 MESH
3	CONDUCTIVITY	-1.00+000 MHO/M	-1.00+000 MHO/M
4	ATOMIC NUMBER	1.00+000 (NONE)	1.00+000 (NONE)
5	DELTA MAX >COEFF	.00 (NONE)	.00 (NONE)
6	E-MAX >DEPTH**-1	1.00+000 KEV	1.38-001 ANG-01
7	RANGE	1.00+001 ANG.	1.50+001 ANG.
8	EXPONENT > RANGE	1.50+000 (NONE)	.00 ANG.
9	RANGE > EXPONENT	.00 ANG.	1.50+000 (NONE)
10	EXPONENT	1.00+000 (NONE)	1.00+000 (NONE)
11	YIELD FOR 1KEV PROTONS	.00 (NONE)	.00 (NONE)
12	MAX DE/DX FOR PROTONS	1.00+000 KEV	1.00+000 KEV
13	PHOTOCURRENT	.00 A/M**2	.00 A/M**2
14	SURFACE RESISTIVITY	-1.00+000 OHMS	-8.85-013 V-S/Q
15	SPACE DISCHARGE POT'L	1.00+004 VOLTS	1.00+004 VOLTS
16	INTERNAL DISCHARGEPOT'L	2.00+003 VOLTS	2.00+003 VOLTS
17	RADN INDUCEDCOND'YCOEFFT	1.00-013 MHOMS3	1.00-013 MHOMS3
18	RADN INDUCEDCOND'YPOWER	1.00+000 (NONE)	1.00+000 (NONE)
19	DENSITY	1.00+003 KG/M*3	1.00+003 KG/M*3
20		2.00+001	-1.00+000

MATERIAL 8: KAPT

	PROPERTY	INPUT VALUE	CODE VALUE
1	DIELECTRIC CONSTANT	3.50+000 (NONE)	3.50+000 (NONE)
2	THICKNESS	1.27-004 METERS	1.27-003 MESH
3	CONDUCTIVITY	1.00-016 MHO/M	1.00-016 MHO/M
4	ATOMIC NUMBER	5.00+000 (NONE)	5.00+000 (NONE)
5	DELTA MAX >COEFF	2.10+000 (NONE)	4.36+001 (NONE)
6	E-MAX >DEPTH**-1	1.50-001 KEV	8.74-002 ANG-01
7	RANGE	7.15+001 ANG.	4.29+001 ANG.
8	EXPONENT > RANGE	6.00-001 (NONE)	5.52+002 ANG.
9	RANGE > EXPONENT	3.12+002 ANG.	6.00-001 (NONE)
10	EXPONENT	1.77+000 (NONE)	1.77+000 (NONE)
11	YIELD FOR 1KEV PROTONS	4.55-001 (NONE)	4.55-001 (NONE)
12	MAX DE/DX FOR PROTONS	1.40+002 KEV	1.40+002 KEV
13	PHOTOCURRENT	2.00-005 A/M**2	2.00-005 A/M**2
14	SURFACE RESISTIVITY	1.00+016 OHMS	8.85+003 V-S/Q
15	SPACE DISCHARGE POT'L	1.00+004 VOLTS	1.00+004 VOLTS
16	INTERNAL DISCHARGEPOT'L	2.00+003 VOLTS	2.00+003 VOLTS
17	RADN INDUCEDCOND'YCOEFFT	1.00-013 MHOMS3	1.00-013 MHOMS3
18	RADN INDUCEDCOND'YPOWER	1.00+000 (NONE)	1.00+000 (NONE)
19	DENSITY	1.00+003 KG/M*3	1.00+003 KG/M*3
20		2.00+001	1.00-016

TABLE 4.2. MATERIAL PROPERTIES (Continued).

MATERIAL 9: NPAI

	PROPERTY	INPUT VALUE	CODE VALUE
1	DIELECTRIC CONSTANT	3.50+000 (NONE)	3.50+000 (NONE)
2	THICKNESS	5.00-005 METERS	5.00-004 MESH
3	CONDUCTIVITY	5.90-014 MHO/M	5.90-014 MHO/M
4	ATOMIC NUMBER	5.00+000 (NONE)	5.00+000 (NONE)
5	DELTA MAX >COEFF	2.10+000 (NONE)	3.05+001 (NONE)
6	E-MAX >DEPTH**-1	1.50-001 KEV	3.41-002 ANG-01
7	RANGE	-1.00+000 ANG.	1.05+003 ANG.
8	EXPONENT > RANGE	.00 (NONE)	.00 ANG.
9	RANGE > EXPONENT	1.05+000 ANG.	1.51+000 (NONE)
10	EXPONENT	9.80+000 (NONE)	1.00+000 (NONE)
11	YIELD FOR 1KEV PROTONS	4.55-001 (NONE)	4.55-001 (NONE)
12	MAX DE/DX FOR PROTONS	1.40+002 KEV	1.40+002 KEV
13	PHOTOCURRENT	2.00-005 A/M**2	2.00-005 A/M**2
14	SURFACE RESISTIVITY	1.00+013 OHMS	8.85+000 V-S/C
15	SPACE DISCHARGE POT'L	1.00+004 VOLTS	1.00+004 VOLTS
16	INTERNAL DISCHARGEPOT'L	2.00+003 VOLTS	2.00+003 VOLTS
17	RADN INDUCEDCOND'YCOEFFT	1.00-013 MHOMS3	1.00-013 MHOMS3
18	RADN INDUCEDCOND'YPOWER	1.00+000 (NONE)	1.00+000 (NONE)
19	DENSITY	1.00+003 KG/M**3	1.00+003 KG/M**3
20		2.00+001	5.90-014

MATERIAL 10: SIO2

	PROPERTY	INPUT VALUE	CODE VALUE
1	DIELECTRIC CONSTANT	4.00+000 (NONE)	4.00+000 (NONE)
2	THICKNESS	1.27-004 METERS	1.27-003 MESH
3	CONDUCTIVITY	1.00-014 MHO/M	1.00-014 MHO/M
4	ATOMIC NUMBER	1.00+001 (NONE)	1.00+001 (NONE)
5	DELTA MAX >COEFF	2.40+000 (NONE)	1.46+001 (NONE)
6	E-MAX >DEPTH**-1	4.30-001 KEV	2.21-002 ANG-01
7	RANGE	1.16+002 ANG.	9.42+001 ANG.
8	EXPONENT > RANGE	8.10-001 (NONE)	3.41+002 ANG.
9	RANGE > EXPONENT	1.83+002 ANG.	8.10-001 (NONE)
10	EXPONENT	1.86+000 (NONE)	1.86+000 (NONE)
11	YIELD FOR 1KEV PROTONS	4.55-001 (NONE)	4.55-001 (NONE)
12	MAX DE/DX FOR PROTONS	1.40+002 KEV	1.40+002 KEV
13	PHOTOCURRENT	2.00-005 A/M**2	2.00-005 A/M**2
14	SURFACE RESISTIVITY	1.00+019 OHMS	8.85+006 V-S/C
15	SPACE DISCHARGE POT'L	1.00+004 VOLTS	1.00+004 VOLTS
16	INTERNAL DISCHARGEPOT'L	2.00+003 VOLTS	2.00+003 VOLTS
17	RADN INDUCEDCOND'YCOEFFT	1.00-013 MHOMS3	1.00-013 MHOMS3
18	RADN INDUCEDCOND'YPOWER	1.00+000 (NONE)	1.00+000 (NONE)
19	DENSITY	1.00+003 KG/M**3	1.00+003 KG/M**3
20		2.00+001	1.00-014

TABLE 4.2. MATERIAL PROPERTIES (Continued).

MATERIAL 11: SOLA

	PROPERTY	INPUT VALUE	CODE VALUE
1	DIELECTRIC CONSTANT	3.80+000 (NONE)	3.80+000 (NONE)
2	THICKNESS	1.79-004 METERS	1.79-003 MESH
3	CONDUCTIVITY	1.00-017 MHO/M	1.00-017 MHO/M
4	ATOMIC NUMBER	1.00+001 (NONE)	1.00+001 (NONE)
5	DELTA MAX >COEFF	2.05+000 (NONE)	1.31+001 (NONE)
6	E-MAX >DEPTH**-1	4.10-001 KEV	3.17-002 ANG-01
7	RANGE	7.75+001 ANG.	3.49+001 ANG.
8	EXPONENT > RANGE	4.50-001 (NONE)	2.70+002 ANG.
9	RANGE > EXPONENT	1.56+002 ANG.	4.50-001 (NONE)
10	EXPONENT	1.73+000 (NONE)	1.73+000 (NONE)
11	YIELD FOR 1KEV PROTONS	2.44-001 (NONE)	2.44-001 (NONE)
12	MAX DE/DX FOR PROTONS	2.30+002 KEV	2.30+002 KEV
13	PHOTOCURRENT	2.00-005 A/M**2	2.00-005 A/M**2
14	SURFACE RESISTIVITY	1.00+019 OHMS	8.85+006 V-S/C
15	SPACE DISCHARGE POT'L	1.00+004 VOLTS	1.00+004 VOLTS
16	INTERNAL DISCHARGEPOT'L	2.00+003 VOLTS	2.00+003 VOLTS
17	RADN INDUCEDCOND'YCOEFFT	1.00-013 MHOMS3	1.00-013 MHOMS3
18	RADN INDUCEDCOND'YPOWER	1.00+000 (NONE)	1.00+000 (NONE)
19	DENSITY	1.00+003 KG/M**3	1.00+003 KG/M**3
20		2.00+001	1.00-017

MATERIAL 12: TEFL

	PROPERTY	INPUT VALUE	CODE VALUE
1	DIELECTRIC CONSTANT	2.00+000 (NONE)	2.00+000 (NONE)
2	THICKNESS	1.27-004 METERS	1.27-003 MESH
3	CONDUCTIVITY	1.00-016 MHO/M	1.00-016 MHO/M
4	ATOMIC NUMBER	7.00+000 (NONE)	7.00+000 (NONE)
5	DELTA MAX >COEFF	3.00+000 (NONE)	2.27+001 (NONE)
6	E-MAX >DEPTH**-1	3.00-001 KEV	3.83-002 ANG-01
7	RANGE	4.54+001 ANG.	1.81+001 ANG.
8	EXPONENT > RANGE	4.00-001 (NONE)	3.65+002 ANG.
9	RANGE > EXPONENT	2.18+002 ANG.	4.00-001 (NONE)
10	EXPONENT	1.77+000 (NONE)	1.77+000 (NONE)
11	YIELD FOR 1KEV PROTONS	4.55-001 (NONE)	4.55-001 (NONE)
12	MAX DE/DX FOR PROTONS	1.40+002 KEV	1.40+002 KEV
13	PHOTOCURRENT	2.00-005 A/M**2	2.00-005 A/M**2
14	SURFACE RESISTIVITY	1.00+016 OHMS	8.85+003 V-S/C
15	SPACE DISCHARGE POT'L	1.00+004 VOLTS	1.00+004 VOLTS
16	INTERNAL DISCHARGEPOT'L	2.00+003 VOLTS	2.00+003 VOLTS
17	RADN INDUCEDCOND'YCOEFFT	1.00-013 MHOMS3	1.00-013 MHOMS3
18	RADN INDUCEDCOND'YPOWER	1.00+000 (NONE)	1.00+000 (NONE)
19	DENSITY	1.00+003 KG/M**3	1.00+003 KG/M**3
20		2.00+001	1.00-016

TABLE 4.2. MATERIAL PROPERTIES (Concluded).

MATERIAL 13: SILV

	PROPERTY	INPUT VALUE	CODE VALUE
1	DIELECTRIC CONSTANT	1.00+000 (NONE)	1.00+000 (NONE)
2	THICKNESS	1.00-003 METERS	1.00-002 MESH
3	CONDUCTIVITY	-1.00+000 MHO/M	-1.00+000 MHO/M
4	ATOMIC NUMBER	4.70+001 (NONE)	4.70+001 (NONE)
5	DELTA MAX >COEFF	1.00+000 (NONE)	3.09+000 (NONE)
6	E-MAX >DEPTH**-1	8.00-001 KEV	1.58-002 ANG-01
7	RANGE	8.45+001 ANG.	6.93+001 ANG.
8	EXPONENT > RANGE	8.20-001 (NONE)	1.38+002 ANG.
9	RANGE > EXPONENT	7.94+001 ANG.	8.20-001 (NONE)
10	EXPONENT	1.74+000 (NONE)	1.74+000 (NONE)
11	YIELD FOR 1KEV PROTONS	4.90-001 (NONE)	4.90-001 (NONE)
12	MAX DE/DX FOR PROTONS	1.23+002 KEV	1.23+002 KEV
13	PHOTOCURRENT	2.90-005 A/M**2	2.90-005 A/M**2
14	SURFACE RESISTIVITY	-1.00+000 OHMS	-8.85-013 V-S/Q
15	SPACE DISCHARGE POT'L	1.00+004 VOLTS	1.00+004 VOLTS
16	INTERNAL DISCHARGEPOT'L	2.00+003 VOLTS	2.00+003 VOLTS
17	RADN INDUCEDCOND'YCOEFFT	1.00-013 MHOMS3	1.00-013 MHOMS3
18	RADN INDUCEDCOND'YPOWER	1.00+000 (NONE)	1.00+000 (NONE)
19	DENSITY	1.00+003 KG/M**3	1.00+003 KG/M**3
20		2.00+001	-1.00+000

5. TRILIN AND THE PLASMA ENVIRONMENT

5.1 TRILIN

TRILIN is the module that calculates charging. In this sense it is at the core of the NASCAP program. It uses the object definition, capacitance and shadowing information, calculated by the modules OBJDEF, CAPACI, and HIDCEL, to determine the current collected by the object, and the electrical potential throughout the computational space.

TRILIN also reads the Flux Definition file. This is the second major user input file and describes the plasma environment.

5.2 NASCAP ENVIRONMENTS

NASCAP is able to simulate the charging of objects in space and in a test tank. For charging in space the user is able to define the energy distribution function of the ambient plasma (or plasma spectrum) and its angular distribution. In a test tank the ambient plasma is derived from particle guns. Single or multiple gun tests may be simulated, involving electrons, ions or both. Each of these options is examined in detail in the following sections.

5.3 FLUX DEFINITION FILE

Information describing the plasma environment is written in file IFLUX (Chapter 2) and is read by NASCAP module TRILIN. TRILIN is the module that actually carries out the calculations of potentials and currents. Just like the other user input files (2.6) IFLUX contains sequences of secondary keywords and their parameter cards. TRILIN reads and interprets these keywords. The flux definition file IFLUX is best summarized individually for each environment type. Let us examine each of these in turn beginning with plasma spectra.

5.4 PLASMA SPECTRUM

The energy distribution function of a set of like particles i, $f_i(E)$, is the number density having energy between E and E + dE. The flux due to these particles across any plane is given by:

$$I_i(E) = \frac{2\pi E}{m^2} f_i(E)$$

Each set of particles (electrons and ions) may have its own distribution function $f_i(E)$. NASCAP allows two types of analytical representation for $f_i(E)$. An arbitrary definition of $f_i(E)$ is also possible via tabular input of $f_i(E)$ versus E. The two analytical forms are single Maxwellian and double Maxwellian.

5.4.1 SINGLE MAXWELLIAN (TYPE 2)

The SINGLE MAXWELLIAN representation has the form

$$f_i(E) = N_i \left(\frac{m_i}{2\pi T_i} \right)^{3/2} e^{-E/T_i}$$

where N_i is the density of particle species i, T_i is their temperature and m_i their mass.

The user is required to tell NASCAP the density and temperature for both ions and electrons. NASCAP assumes that all ions are <u>protons</u>!

This information is entered in the flux definition file following one of these three keywords.

SINGLE
MAXWELLIAN
TYPE 2 } ≡ call single Maxwellian plasma spectrum

Note that only the first four characters in each word are significant.

Both are equivalent and tell TRILIN to assume a Maxwellian environment for both ions and electrons and to expect at least two parameter cards to follow immediately.

The parameter cards have the form:

"quantity" "units"

Four quantities must be specified on four cards:

Electron Temperature
Ion Temperature
Electron Density
Ion Density

The units understood by TRILIN are as follows:

Density	Temperature
"CGS" (cm^{-3})	"KEV"
"MKS" (m^{-3})	"EV"
	"JOULES"
	"ERGS"
	"KELVIN"

Each card consists of a number followed by a unit. The unit tells TRILIN whether the number refers to a temperature or a density. For example

"5 KEV"

is understood as a temperature of 5 keV. But

"5 MKS"

is understood as a density of 5 m^{-3}.

The first density and temperature read by TRILIN following the single Maxwellian keyword are assigned to the ELECTRONS. The last density and temperature are assigned to the IONS. TRILIN expects to find at least one density and one temperature (in which case both ions and electrons are assumed the same parameters). Any less will cause an error. More than two of either results in middle cards being ignored.

For example,

```
SINGLE
1.  CGS
10.  KEV
END
```

defines a plasma with density 1 cm^{-3} and temperature 10 keV.
The file

```
SINGLE
     0.1 CGS
     3.0E+5 MKS
     2000 EV
     3.5 KEV
     END
```

assigns the following quantities:

Electron density $N_e = 0.1\ cm^{-3}$
Electron temperature $T_e = 2.0$ keV
Ion density $N_i = 0.3\ cm^{-3}$
Ion temperature $T_i = 3.5$ keV

The same effect is brought about with the file:

```
MAXW
2000 EV
0.1 CGS
3.0E+5 MKS
3.5 KEV
END
```

However

```
MAXW
3.5 KEV
2000 EV
0.1 CGS.
3.0E+5 MKS
END
```

reverses the temperatures:

$N_e = 0.1\ cm^{-3}$
$T_e = 3.5\ keV$
$N_i = 0.3\ cm^{-3}$
$T_i = 2.0\ keV$

Note that all plasma definition "blocks" are terminated with an 'END' statement.

5.4.2 DOUBLE MAXWELLIAN (TYPE 4)

The double Maxwellian form is the sum of two single Maxwellians.

$$f_i(E) = N_1^i\left(\frac{m_i}{2\pi\ T_1^i}\right)^{3/2} e^{-E/T_1^i} + N_2^i\left(\frac{m_i}{2\pi\ T_2^i}\right)^{3/2} e^{-E/T_2^i}$$

The user must specify two densities (N_1^i and N_2^i) and two temperatures (T_1^i and T_2^i) for each particle species. Again NASCAP assumes that all ions are protons.

This information is entered in the flux definition file following the keyword:

DOUBLE
TYPE 4 } ≡ call double Maxwellian plasma spectrum

This tells TRILIN to assume a double Maxwellian environment for both ions and electrons. TRILIN then expects four parameter cards to follow immediately.

The parameter cards have the form:

"species quantity units temperature units"

Each card must contain a temperature and a density. Just like the single Maxwellian spectrum definition (5.4.1) the units indicate whether the preceding number is a density or a temperature. The same set of units as for a single Maxwellian are understood by TRILIN for

double Maxwellian. For example

"ELECTRONS 0.1 CGS 1.E6 JOULES"

defines one component of a double Maxwellian for the electrons having a density (N_i^e) = 0.1 cm^{-3}, and a temperature (T_i^e) of 10^6 joules. Note that the density must precede the temperature definition on the card. Four parameter cards completely define the eight parameters required for a double Maxwellian. The order is unimportant since no significance is attached to which density and temperature are associated with Maxwellian components one and two. For example

```
DOUBLE
ELECTRONS   0.2E6 MKS    8 KEV
IONS        6     CGS    0.3 KEV
ELECTRONS   0.5   CGS    6000 EV
PROTONS     1.E6  MKS    10 KEV
END
```

defines a double Maxwellian with the following parameters:

$N_1^e = 0.2\ cm^{-3}$ $\qquad$ $N_1^i = 0.6\ cm^{-3}$

$T_1^e = 8$ keV $\qquad$ $T_1^i = 0.3$ keV

$N_2^e = 0.5\ cm^{-3}$ $\qquad$ $N_2^i = 1.0\ cm^{-3}$

$T_2^e = 6$ keV $\qquad$ $T_2^i = 10$ keV

Note that the words 'IONS' and 'PROTONS' are interchangeable and that the whole "block" is terminated with an 'END' card.

5.4.3 'DIRECT' MODE (TYPE 5)

An arbitrary plasma spectrum may be entered as tabulated data. A list of values for $F_i(E)$, $F_e(E)$ and E can be read by TRILIN and "DIRECTly" integrated (by numerical means) to provide currents. No fitting to analytical forms is involved during the integration, although a rough fit to a Maxwellian is made to provide parameters for the direct numerical integration itself.

The data must be entered in a very specific format. This is given in Figure 5.1. The magnetic field vectors, sun vectors, intensity and angles mentioned are all optional. The remaining information is mandatory. The tabulated data is read from a separate file ISPCTR. The default value for ISPCTR is 9. The flux definition file IFLUX must contain the following cards:

```
DIRECT
YEAR    <year>
DAY     <day>
TIME    <time in seconds>
END
```

The order of the YEAR, DAY and TIME cards are irrelevant. For example

```
DIRECT
DAY     272
YEAR    1981
TIME    60013
END
```

in the flux definition file will cause TRILIN to look in file ISPCTR for the tabulated data set labeled with the date Day 272 1981 and time 60013 seconds. If no such data set exists an error will occur.

'DIRECT' does not work well with data that is not fairly smooth or is highly non-Maxwellian. Both of these properties cause "multiple roots" or more than one equilibrium potential and subsequent potential calculations become unstable. It is usually preferable to fit tabulated data to double Maxwellian terms prior to using the code.

5.5 ANGULAR DISTRIBUTIONS

Plasmas having the spectra described in Section 5.4 (Maxwellian, Double Maxwellian and Direct) may have one of two possible angular distribution functions.

For NASCAP operating in the DIRECT mode to be able to read in the tabulated data it must be prepared according to the following specifications and format:

1. Magnetic Tape Characteristics

   Spectra can be provided on a coded 9 track magnetic tape with the following characteristics:

   unlabelled
   1600 bpi
   EBCDIC or ASCII coded
   fixed length records: 80 characters per record
   fixed block size: 20 records per block

2. Each data tape will consist of header records followed by repeated series of data records. The data will be read by a FORTRAN program using the FORMAT statements indicated below:

HEADER RECORD 1. DETECTOR FORMAT (80A1)

Identifies the detector(s) used to obtain the data.

HEADER RECORD 2. SOURCE FORMAT (80A1)

Identifies the individual(s) responsible for preparing the data.

HEADER RECORDS 3. through 10. COMMENTS FORMAT (80A1)

Any relevant information regarding the data can be included here, such as date data tape was generated, detector mode of operation, and what corrections have been applied to the raw data.

HEADER RECORD 11. $YEAR_0$, DAY_0, SEC_0, $Year_1$, DAY_1, SEC_1 FORMAT (10F8.0)

$YEAR_0$, DAY_0, SEC_0 = time of earliest spectrum on tape

$YEAR_1$, DAY_1, SEC_1 = time of latest spectrum on tape

Each series of data records will represent a complete energy scan by the detector.

Figure 5.1. Format for tabulated spectral data.

DATA RECORD 1. YEAR, DAY, SEC, NBINS, DELTA, VSAT, $|\vec{S}|$, SX, SY, SZ FORMAT (10F8.0)

YEAR, DAY, SEC = time energy scan was begun

NBINS = number of distinct energy bins in the scan

DELTA = time (seconds) between each data point in the scan of the spectrum

VSAT = satellite potential during scan (volts)

$|\vec{S}|$ = sun intensity (1.0 = full sun)

SX, SY, SZ = normalized sun direction vector components at start of scan

DATA RECORDS 2. through (NBINS+1). ENERGY, $\log_{10}(F_i)$, $\log_{10}(F_e)$, Ω, α, BX, BY, BZ FORMAT (10F8.0)

Each of these records represents a data point on the scan of the energy range

ENERGY = energy (eV)

F_i = ion distribution function (sec^3/m^6)

F_e = electron distribuition function (sec^3/m^6)

Ω = detector view angle (degrees)

α = pitch angle (degrees)

BX, BY, BZ = magnetic field vector components ($nT = 10^{-9}$ W/m^2)

(The α value is redundant since it can be calculated from Ω and the magnetic field vector.)

DATA RECORD NBINS+2. (END OF DATA MARKER) FORMAT (10F8.0)

This record will contain any negative real number to indicate the end of the spectral scan. (This record is redundant since NBINS is known.)

Figure 5.1. Format for tabulated spectral data (concluded).

5.5.1 ISOTROPIC INCIDENCE

NASCAP assumes an isotropic angular distribution function by default. This means that all angles of incidence (θ) for collected particles are equally probable; i.e., the angular distribution function $f(\theta)$ is a constant. No keywords or other statements are required to specify isotropic incidence.

5.5.2 ANISOTROPIC INCIDENCE

NASCAP allows for an anisotropic angular distribution function $f(\phi)$ of the form

$$f(\phi) = a + b \cos^2\phi.$$

This describes a superposition of an isotropic (spherical) component and a directional (dumb-bell) component. The theoretical background to this model is discussed in Section 5.10.1 . The angle ϕ is the angle between a particle velocity and the magnetic field vector. The direction of the magnetic field (and hence the "aligned" direction) is chosen by the user as a run option ("B FIELD" - 6.4.1). The default direction is along the Z axis.

The remaining parameters "a" and "b" are actually just one parameter (R) for a normalized function $f(\phi)$. The parameter R is the ratio of directional to isotropic flux (current) components.

$$R = 3\ b/a.$$

R may have different values for ions and electrons. R and hence the degree of anisotropy may also depend on the energy of the particles.

An anisotropic angular distribution function is specified by including the keyword 'ANISOTROPIC' before the END card of a plasma spectrum block. TRILIN reads the 'ANISOTROPIC' card and then expects

to find at least two parameter cards defining values for R. For example, the flux definition file:

```
SINGLE
0.1 KEV
0.3 KEV
0.1 CGS
0.2 CGS
ANISOTROPIC
KEV 1.  ERATIO 0.5
KEV 2.  IRATIO -0.2
END
END
```

defines plasma with a single Maxwellian spectrum with densities and temperatures

$N^e = 0.1\ cm^{-3}$
$T^e = 0.1\ keV$
$N^i = 0.2\ cm^{-3}$
$T^i = 0.3\ keV$

The angular distribution is the standard anisotropic form with a ratio

R = 0.5 (electrons)

and

R = -0.2 (ions).

Parameter cards defining ratios for electrons have the form:

"units number ERATIO number"

For ions the form is similar but with keyword 'IRATIO'

"units number IRATIO number"

TRILIN expects to find at least two cards, one defining a ratio for electrons and one defining a ratio for ions. For any less than this an error will occur.

The ratio R may range from -0.9 to ∞. Negative values give "loss-cone" distributions, positive values give "gain-cone" distributions and R = 0 describes an isotropic distribution. This is discussed further in Section 5.10.1.

The first two parameters on the card specify an energy to be associated with the R value. The units of energy accepted are 'ERGS', 'JOULES', 'KEV', 'EV' and 'KELVIN'. Up to ten RATIO cards may be included in the plasma spectrum block for each species. In this way R may depend on energy. The R values known for particular energies may be entered on different cards and NASCAP will linearly interpolate between them for intermediate energies. For example, the cards

```
ANISOTROPIC
1 KEV  ERATIO 1
3 KEV  ERATIO 0.5
5000 EV  ERATIO 0.9
0.1 KEV  IRATIO 0
END
```

give the following energy dependence for R for the electrons

Energy (keV)	R Value
0	1
0.5	1
1.0	1
2.0	0.75*
3.0	0.5
3.5	0.6*
4.0	0.7*
5.0	0.9
100.0	0.9

*linearly interpolated values.

Note that all energies equal to and below the lowest declared energy (1.0 keV) are assigned the same R value. In the same way all energies equal to and above the highest declared energy are assigned the same associated R value. Thus if only one ratio card is declared (such as for the ions in the example above) the energy value is irrelevant since all energies are assigned the same R value.

In our example the ions are chosen to have isotropic incidence.

NASCAP does not order the cards according to energy. For sensible results the cards for each species must be entered in ascending order of energy. It is possible to read the anisotropic flux ratio (or parameter) cards from a separate file. This is achieved by including a file number after the keyword 'ANISOTROPIC', e.g.,

ANISOTROPIC 19

will cause TRILIN to look for parameter cards in file 19. As soon as an 'END' card is encountered TRILIN returns to the file containing the 'ANISOTROPIC' card and continues to read from there. Blocks of anisotropic flux ratio cards must always be terminated with an END card.

If no file number is included following the 'ANISOTROPIC' keyword, TRILIN expects the ratio cards to follow immediately in the same file. An 'END' card is still needed however. Note in our first example the presence of two 'END' cards: one for the anisotropic flux and one for the plasma spectrum. Figure 5.2a,b,c show three sample files associated with a DIRECT plasma spectrum and an ANISOTROPIC angular distribution.

5.6 UPDATE

In Chapter 1 we discussed how NASCAP calculates currents and potentials for sequences of timesteps. Each timestep has a chosen duration of 'DELTA' seconds. A single NASCAP run may be made specifying that 'NCYC' cycles or timesteps should take place. The elapsed time of the charging simulation at the end of the run would then be NCYC x DELTA seconds. Parameters NCYC and DELTA are chosen by the user as run options (6.2.2 and 6.2.7). For example if NCYC is chosen to be 5 and DELTA is chosen to be 10 seconds, then at the end of the NASCAP run the elapsed time would be 5 x 10 = 50 seconds and 5 timesteps would have taken place. Sometimes NASCAP adjusts the timestep for one or two timesteps itself to accommodate rapid changes in potential (LONGTIMESTEP - Section 6.2.6). If this happens the

```
[nP!
 1:DETECTOR>NORTH/SOUTH ON SC-9
 2:SOURCE  >J. DAVID NICHOLS/ UCSD
 3:COMMENTS>BACKGROUND COUNT SET AT 100
 4:COMMENTS>POTENTIAL ESTIMATED FROM DISTRABUTION FUN
 5:COMMENTS>NO SUN VECTOR OR ABSOLUTE ATTITUDE INFORM
 6:COMMENTS>I TRIED TO GIVE MORE CLOSELY SPACED DATA WHEN
 7:COMMENTS>THE POTENTIAL IS CHANGING MOST RAPIDLY
 8:COMMENTS>WE COME OUT OF ECLIPSE ABOUT 17:15
 9:COMMENTS>FOR ABOUT 10 MINUTES AFTER THIS POTENTIALS ARE
10:COMMENTSONLY ROUGH ESTIMATES - HIGHLY UNCERTAIN
11:     1979      87    59400     1979      87   63053
12:     1979      87    59473       64    0.25      0.   -1.00     0.00     0.00     0.00
13:    -3.90    0.00     0.00     0.00   96.20   -12.09 -173.27    90.26
14:    -1.60    0.00     0.00     0.00   86.50   -11.80 -162.32   108.95
15:     1.00    0.00   -11.18     0.00   86.50   -11.80 -162.32   108.95
16:     4.00    0.00   -12.91     0.00   86.50   -11.80 -162.32   108.95
17:     7.40    0.00   -14.34     0.00   86.50   -11.80 -162.32   108.95
18:    11.40    0.00   -14.86     0.00   86.80   -11.80 -149.58   126.12
19:    16.00    0.00   -15.20     0.00   86.80   -11.80 -149.58   126.12
20:    21.20    0.00   -15.64     0.00   86.80   -11.80 -149.58   126.12
21:    27.20    0.00   -15.82     0.00   86.80   -11.80 -149.58   126.12
22:    34.00    0.00   -15.92     0.00   87.00   -12.09 -134.77   141.54
23:    41.90    0.00   -16.03     0.00   87.00   -12.09 -134.77   141.54
24:    50.90    0.00   -16.00     0.00   87.00   -12.09 -134.77   141.54
25:    61.30  -12.22   -16.08     0.00   87.00   -12.09 -134.77   141.54
26:    73.10    0.00   -16.14     0.00   87.20   -12.09 -118.75   155.79
27:    86.60  -12.52   -16.16     0.00   87.20   -12.09 -118.75   155.79
28:   102.20    0.00   -16.20     0.00   87.20   -12.09 -118.75   155.79
29:   119.90    0.00   -16.27     0.00   87.20   -12.09 -118.75   155.79
30:   140.30  -12.94   -16.31     0.00   87.50   -12.09 -100.98   167.95
31:   163.60  -12.77   -16.36     0.00   87.50   -12.09 -100.98   167.95
32:   190.30  -12.48   -16.32     0.00   87.50   -12.09 -100.98   167.95
33:   220.90  -13.33   -16.35     0.00   87.50   -12.09 -100.98   167.95
34:   255.90  -12.83   -16.37     0.00   87.70   -12.09  -82.02   178.04
35:   295.90  -12.96   -16.43     0.00   87.70   -12.09  -82.02   178.04
36:   341.80  -13.41   -16.47     0.00   87.70   -12.09  -82.02   178.04
37:   394.40  -12.97   -16.55     0.00   87.70   -12.09  -82.02   178.04
38:   454.60  -13.65   -16.59     0.00   87.90   -12.09  -62.18   185.80
39:   523.50  -13.28   -16.70     0.00   87.90   -12.09  -62.18   185.80
40:   602.40  -13.39   -16.85     0.00   87.90   -12.09  -62.18   185.80
41:   692.70  -13.19   -16.94     0.00   87.90   -12.09  -62.18   185.80
42:   796.20  -13.48   -17.03     0.00   88.10   -12.09  -41.71   191.44
43:   914.60  -13.71   -17.14     0.00   88.10   -12.09  -41.71   191.44
44:  1050.20  -13.59   -17.26     0.00   88.10   -12.09  -41.71   191.44
45:  1205.50  -13.63   -17.38     0.00   88.10   -12.09  -41.71   191.44
46:  1383.30  -13.52   -17.50     0.00   88.30   -12.09  -20.39   195.00
47:  1586.90  -13.83   -17.70     0.00   88.30   -12.09  -20.39   195.00
48:  1820.00  -13.62   -17.89     0.00   88.30   -12.09  -20.39   195.00
49:  2087.00  -13.51   -18.06     0.00   88.30   -12.09  -20.39   195.00
50:  2392.60  -13.63   -18.20     0.00   88.40   -12.39    1.05   196.19
51:  2742.50  -13.95   -18.33     0.00   88.40   -12.39    1.05   196.19
52:  3143.20  -14.07   -18.58     0.00   88.40   -12.39    1.05   196.19
53:  3602.00  -14.14   -18.90     0.00   88.40   -12.39    1.05   196.19
54:  4127.30  -14.01   -19.07     0.00   88.40   -12.69   22.37   195.00
55:  4728.70  -14.37   -19.32     0.00   88.40   -12.69   22.37   195.00
56:  5417.40  -14.33   -19.74     0.00   88.40   -12.69   22.37   195.00
57:  6206.00  -14.46   -19.85     0.00   88.40   -12.69   22.37   195.00
58:  7108.30  -14.46   -20.28     0.00   88.50   -12.98   43.40   191.44
59:  8142.70  -14.55   -20.72     0.00   88.50   -12.98   43.40   191.44
60:  9326.40  -14.59   -20.97     0.00   88.50   -12.98   43.40   191.44
61: 10681.70  -14.67   -20.96     0.00   88.50   -12.98   43.40   191.44
62: 12233.60  -14.79   -21.22     0.00   88.50   -13.28   63.87   185.51
63: 14010.50  -14.89   -21.24     0.00   88.50   -13.28   63.87   185.51
64: 16045.00  -15.05   -21.48     0.00   88.50   -13.28   63.87   185.51
65: 18374.60  -15.37   -22.22     0.00   88.50   -13.28   63.87   185.51
66: 21041.90  -15.34   -21.91     0.00   88.40   -13.58   83.71   177.44
67: 24096.00  -15.49   -21.76     0.00   88.40   -13.58   83.71   177.44
68: 27592.90  -15.70   -21.78     0.00   88.40   -13.58   83.71   177.44
69: 31596.90  -15.80   -22.17     0.00   88.40   -13.58   83.71   177.44
70: 36181.50  -16.08     0.00     0.00   88.50   -13.58  102.96   167.06
71: 41430.90  -16.10   -22.88     0.00   88.50   -13.58  102.96   167.06
72: 47441.40  -16.02   -23.30     0.00   88.50   -13.58  102.96   167.06
73: 54323.40  -16.47   -22.69     0.00   88.50   -13.58  102.96   167.06
74: 62203.30  -16.65   -23.23     0.00   88.40   -13.87  120.48   154.90
75: 71225.80  -17.08     0.00     0.00   88.40   -13.87  120.48   154.90
76: 81556.60  -17.51   -23.28     0.00   88.40   -13.87  120.48   154.90
77:    -1.
78:     1979      87    59673       64    0.25      0.   -1.00     0.00     0.00     0.00
79:    -3.90    0.00     0.00     0.00   90.40     0.36 -174.39   -87.35
80:    -1.70    0.00     0.00     0.00   90.30     0.95 -163.43   -106.53
81:     1.00    0.00   -11.15     0.00   90.30     0.95 -163.43   -106.53
82:     4.00    0.00   -12.96     0.00   90.30     0.95 -163.43   -106.53
83:     7.40    0.00   -13.68     0.00   90.30     0.95 -163.43   -106.53
84:    11.40    0.00   -14.24     0.00   90.20     1.25 -150.40   -123.70
85:    16.00    0.00   -14.70     0.00   90.20     1.25 -150.40   -123.70
86:    21.20    0.00   -15.05     0.00   90.20     1.25 -150.40   -123.70
87:    27.20    0.00   -15.27     0.00   90.20     1.25 -150.40   -123.70
88:    34.00    0.00   -15.55     0.00   89.80     0.95 -135.88   -139.72
89:    41.90  -11.89   -15.72     0.00   89.80     0.95 -135.88   -139.72
90:    50.90    0.00   -15.90     0.00   89.80     0.95 -135.88   -139.72
91:    61.20    0.00   -16.01     0.00   89.80     0.95 -135.88   -139.72
```

Figure 5.2a. File 9 (ISPCTR).

```
DIRECT
TIME 59473
DAY 87
YEAR 1979
ANISOTROPIC 19
END
```

Figure 5.2b. File 22 (IFLUX).

```
KEV  0.1     ERATIO  0.9
KEV  0.5     ERATIO  0.5
KEV  0.2     ERATIO -0.2
KEV 10.0     ERATIO -0.01
KEV 50.0     ERATIO  0.0
EV  1000     IRATIO -0.02
EV  3000     IRATIO -0.05
EV  40000    IRATIO  0.06
END
```

Figure 5.2c. File 19 (IANISO).

elapsed time might be less than 50 seconds. The elapsed time is not always under the control of the user.

Usually TRILIN reads the first environment description it finds in the flux definition file (IFLUX) and uses this same plasma spectrum and angular distribution for all of the timesteps requested (NCYC). However for extended simulations of charging, the plasma environment experienced by a spacecraft may change, sometimes quite rapidly. NASCAP is able to change plasma descriptions automatically between timesteps when operated in 'UPDATE' mode.

'UPDATE' mode is selected by including the keywords

UPDATE ON

in the options file (6.4.14). Once NASCAP is in UPDATE mode, TRILIN looks for a fresh environment after every timestep. TRILIN looks for environment parameter cards in the file ISPCTR. ISPCTR may be chosen to be any file number as a run option (6.7). The default is file 9. TRILIN begins the first timestep by reading the flux definition file however. Here it expects to find two cards:

Plasma-type keyword
TIME seconds

The first card is one of the plasma-type keywords such as 'DOUBLE' or 'DIRECT'. This tells TRILIN what type of plasma spectrum it will be looking for in ISPCTR. The second card tells TRILIN the time in seconds to begin the simulation. No 'END' card is needed to terminate the file. For example the file

DOUBLE
TIME 58003

tells TRILIN to expect parameter cards for a double Maxwellian plasma in file ISPCTR and to begin the simulation at absolute time 58003 seconds on the day of interest.

File ISPCTR contains blocks of parameter cards labeled with the times (in seconds) that the spectra they represent are associated with. The general form is given by:

```
TIME  n
 {parameter cards
END

TIME n'
 {parameter cards
END

TIME n''
  .
  .
  .
  .
  .
```

For example:

```
TIME  57050
ELECTRONS  0.1 CGS     1.2 KEV
ELECTRONS  0.1 CGS     2.2 KEV
IONS       0.1 CGS     3.0 KEV
IONS       0.1 CGS     1.0 KEV
END

TIME 58000
ELECTRONS  0.2 CGS     5.0 KEV
ELECTRONS  0.1 CGS     3.6 KEV
IONS       0.3 CGS     1.8 KEV
IONS       0.2 CG S    4.2 KEV
END

TIME 58050
  .
  .
  .
  .
  .
```

For the first timestep, beginning at 58003 TRILIN looks in file ISPCTR for the most recent spectrum before 58003 seconds. In our example this would be the one for 58000 seconds, since the next occurs at a time later than 58003. The four cards following the 'TIME 58000' card are read and the double Maxwellian environment parameters set. Since no anisotropic parameters are included in the 58000 block the angular distribution is assumed to be isotropic. Suppose that after the first timestep the elapsed time has been increased by 10 seconds. The new value is 58013. TRILIN again searches ISPCTR for the most recent environment before the elapsed time. Again this is the one for 58000 so the same set of parameters are read in once more. If after several timesteps the elapsed time exceeds 58050 then the next environment in the file would be read in and the parameters would change.

In this way the most up-to-date environment is always the one used by TRILIN for each cycle.

If the time chosen in the flux file to begin the simulation is before the earliest time in ISPCTR an error will occur. If the elapsed time exceeds the latest time the environment will remain the same as the latest available.

The environment description included in file ISPCTR must be in ascending time order. Anisotropic parameter cards may be included but they must be part of the block and not in a separate file; i.e.,

```
ANISOTROPIC ianiso
```

will cause trouble in an update ISPCTR file if IANISO ≠ ISPCTR.

Files of 'DIRECT' tabulated data are perfectly acceptable. In fact the ISPCTR file shown in Figure 5.2a as an example needs no modification to be read in UPDATE mode (no 'TIME' cards are needed since each block is already labeled). 'DIRECT', 'UPDATE' and 'ANISOTROPIC' cannot all be used together, however.

5.7 TEST TANK

The particle pushing test tank environment was among the first features of NASCAP. It was restricted to a single electron gun at the -Z boundary of the computational space firing at a convex target. The input was so complex that only a handful of guns were ever defined. A description of the original test tank capability may be found in the 1982 version of this manual. More recently, an analytic (Type 6) test tank was incorporated in NASCAP. This new facility, described in Section 5.9, allowed multiple beam electron and ion guns at arbitrary grounded locations, in or out of the computational space, and had simple, flexible input. Being an analytic method, it was fast and free of the sampling errors inherent in particle techniques. However, as it assumed a simple form for electron and magnetic fields, it was of questionable accuracy for non-convex or differentially charged objects.

During 1983 a new formulation, replacing the original Type 1, was written with the full multigun capability of the analytic method while retaining the ability to faithfully treat complex geometry and field structure by particle tracking. Efficient data storage and buffering schemes keep the time and storage requirements within practical limits, and new current sharing algorithms ameliorate sampling errors. This capability greatly expands the applicability and use of NASCAP for simulation of charging by low intensity electron and ion beams.

5.8 TEST TANK (TYPE 1)

5.8.1 USAGE

The usage of the new (Type 1) test tank simulation is nearly identical to the analytic (Type 6) capability. For definition of gun characteristics, etc., refer to NASCAP Programmer's Reference Manual, Section 5.9. Note that for both Type 1 and Type 6, the environment is specified by the TANK module prior to calling TRILIN, and the environment TYPE must be specified in the option (RDOPT) input.

The differences between Type 1 and Type 6 usage are:

a. In the flux (TANK module) input, the NOSHADOW option should be specified. Omission of this will result in an unnecessary shadowing calculation (and accompanying plot) for each gun.

b. In the options (RDOPT module) input, the TANKTRAJ OFF or TANKTRAJ ON specifications may be used to obtain particle trajectory plots. Presently only the X-Z projection is plotted. (Current density plots are neither available nor planned.)

c. Three new keywords are available in the flux (TANK module) input which relate to particle tracking. These are shown in Table 5.1. The default values should be acceptable in most cases. Values within the recommended ranges will usually result in avoiding either excessive time or excessive inaccuracy in the particle current calculations.

TABLE 5.1. PARTICLE TRACKING KEYWORDS

Keyword	Default	Recommended Range	Meaning
VCODE	0.2	0.1 < VCODE < 0.3	Initial code velocity (mesh units per δt)
NSTEPS	500	200 < NSTEPS < 1000	Maximum number of pushing steps per particle
NTHETA	8	5 < NTHETA < 15	Number of particles per beam is approximately $(\pi/4)\text{NTHETA}^2$

The parameter VCODE governs the accuracy of particle tracking, with smaller values giving more accuracy. VCODE is the initial code velocity for each particle, and will increase for attracted particles and decrease for repelled particles. We recommend that

$$(E_f/E_i)^{1/2} \text{ VCODE} \lesssim 0.5$$

for attracted particles, and

$$(E_f/E_i) \text{ VCODE} \gtrsim 0.1$$

for repelled particles, where E_i and E_f are the initial and estimated final kinetic energies.

NSTEPS is the maximum number of steps for each particle. Ample steps should be allowed for the particle to cross the computational space; a smaller VCODE requires a larger NSTEPS.

NTHETA is the number of angular points across the beam, and determines how many particles are tracked. It should be set by

$$D \tan (2W/\text{NTHETA}) \lesssim 1$$

where D is the approximate gun-target distance (grid units), and W is the half-angle of the beam.

5.8.2 EXAMPLE

Figures 5.3 and 5.4 show particle trajectories and resulting potential contours for four guns illuminating a partially covered octagon. Note that the figures show the correct octagonal symmetry.

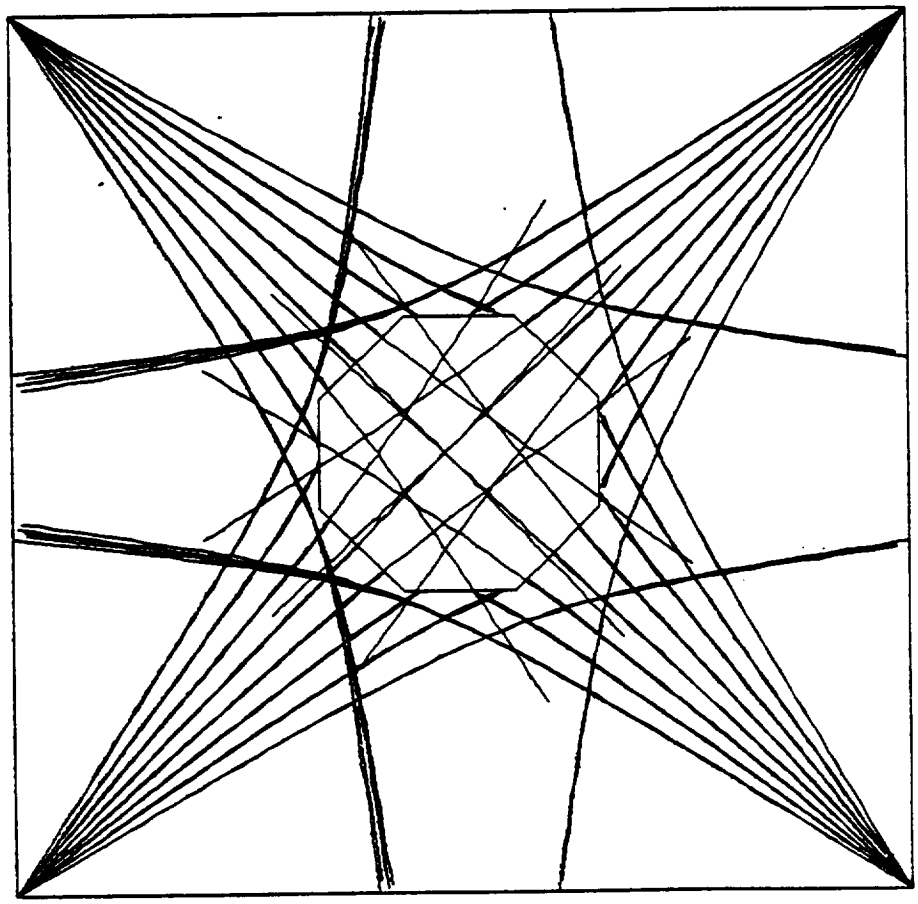


Figure 5.3. Particle trajectories for Type 1 test tank (four single-beam guns) example.

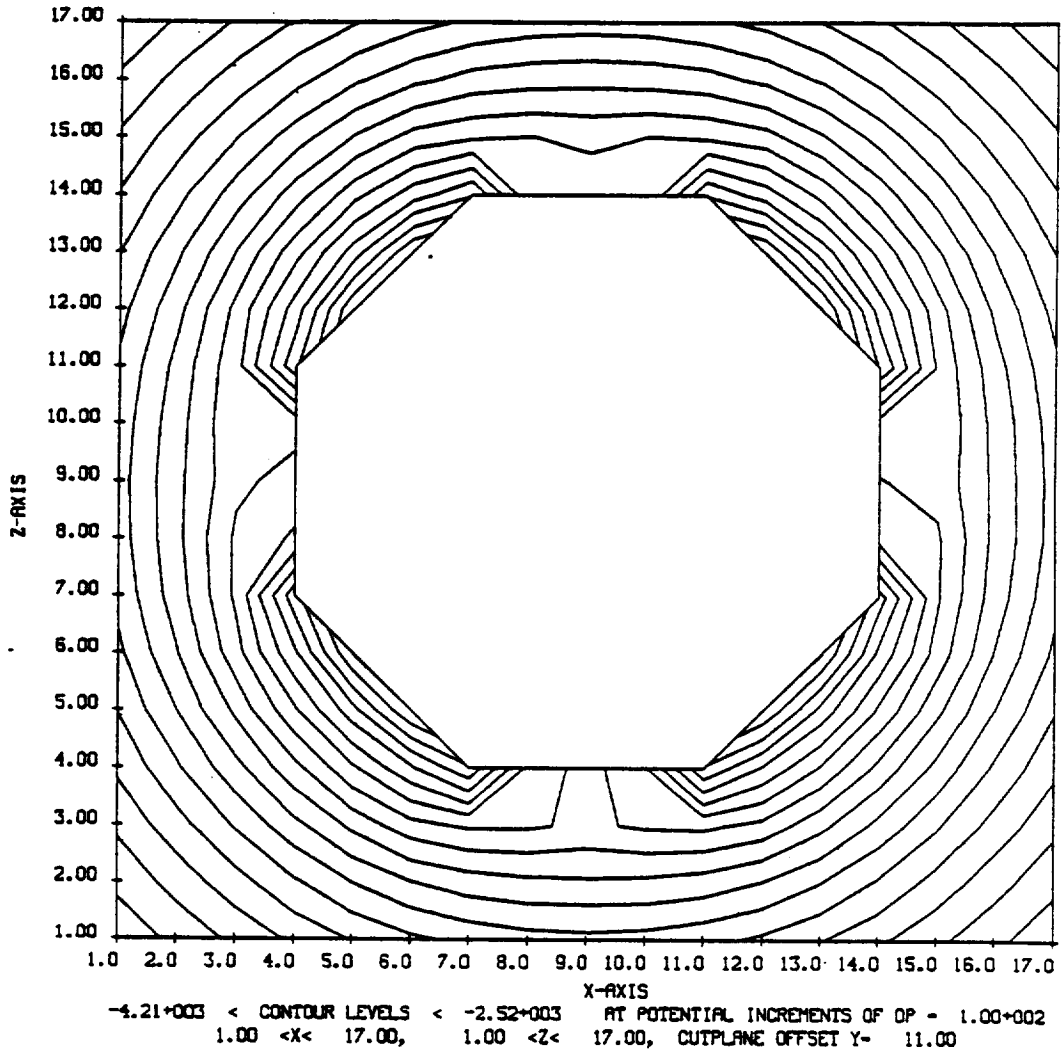


Figure 5.4. Potential contours for Type 1 test tank example.

5.8.3 COMPARISON - TYPE 1 VERSUS TYPE 6

It was originally expected that the new Type 1 would require far more computer time than Type 6, especially for multibeam cases. Initial experience indicates that the time difference is very moderate, with the difference very small compared to the total NASCAP running time. Also, the sampling and sharing techniques used in the new Type 1 seem successful at minimizing particle noise. In the example above, for which both methods should be reasonably accurate, nearly identical results were obtained.

We suggest that Type 1 should usually be used whenever potentials are suspected of being sufficiently non-monopole-like to affect the results. The advantage of Type 6 is that, while Type 1 guns must be located at grounded points or outside a grounded outer boundary, Type 6 calculations can often be run in fewer (usually one) grids using monopole boundary conditions (IOUTER = 2). The number of grids in the computational space is a very significant factor in the cost of running NASCAP.

PAGES 158 THROUGH 167 INTENTIONALLY LEFT BLANK

PAGES 158 THROUGH 167 INTENTIONALLY LEFT BLANK

5.9 TEST TANK-6 (TYPE 6) - MODULE "TANK"

5.9.1 GENERAL CONSIDERATIONS

Test Tank-6 (TYPE 6) allows for multiple guns emitting multiple beams. Each gun may emit either electrons or ions. The currents to the surface of the object are calculated analytically rather than by particle tracking (Section 5.8) and the calculation is both faster and more economical than Test Tank-1. However no trajectory or density plots are generated and the calculation is less accurate for highly non-spherical objects (i.e., objects that are much larger in one direction than another - like a thin rod) or for cases with a great deal of differential charging.

For objects that have parts that may shield some of its surfaces from the beam particles (non-convex objects (Section 6.4.2)), optical shadowing calculations are carried out using the HIDCEL module (8.1). HIDCEL determines the fraction of each surface cell that is effectively exposed to the beam(s) and hence the fraction of the theoretical incident current actually collected. This shadowing information is stored in file IOBPLT (default file number 19).

Because of the way NASCAP is constructed it is not practical to execute HIDCEL from inside TRILIN. Instead a separate module called 'TANK' is provided to read the flux definition file IFLUX and make any calls to HIDCEL before TRILIN is called to actually carry out the potential calculation. Since TRILIN does not read IFLUX in a Test Tank-6 case the flux type, telling NASCAP that this is a Test Tank-6 run, must be included as a run option. The card

TYPE 6

must be included in the options file (6.4.13).

A sample runstream might have the form:

```
@XQT NASCAP*NASCAP.ABS  (UNIVAC ONLY)
RDOPT   { file includes TYPE 6 card }
OBJDEF
CAPACI
TANK    { reads IFLUX and calls HIDCEL }
TRILIN  { carries out potential calculations using
        { information read by TANK
END
```

If the object in the tank is to be illuminated with UV light (sunlight) then any calls to HIDCEL, SPIN or ROTATE (Chapter 8) must come after the call to TANK, but before the call to TRILIN. 'TANK' destroys any previous shadowing information; e.g.,

```
@XQT NASCAP*NASCAP.ABS.
RDOPT
OBJDEF
CAPACI
TANK
HIDCEL
TRILIN
END
```

The calls to HIDCEL made by TANK as part of the particle current calculation are made automatically and require no user intervention.

Subsequent Test Tank-6 runs, using the same object and the same gun and tank arrangements, may be made without a call to TANK, providing that

a. Shadowing information on file IOBPLT(19) is saved from previous runs (i.e., IOBPLT is a restart file), or
b. the object is convex and no shadowing takes place.

For example:

```
@XQT NASCAP*NASCAP.ABS
RDOPT    (Option file with 'TYPE 6' card)
TRILIN
END
```

5.9.2 TEST TANK-6 FLUX DEFINITION FILE

The flux definition file IFLUX, read by TANK, consists of a series of blocks, each defining a gun. Each block consists of a 'GUN AT' keyword card to start things off, followed by four parameter cards, specifying the energy, width, current and direction of the beam, or beams, the gun is to emit. These commands are summarized in Figure 5.5. The general form is as follows:

```
<species> GUN AT  x  y  z
ENERGY  e1  e2  ... en unit.
BEAMWIDTH  bi  b2  ... bn unit.
CURRENT  c1  c1  ... cn unit
DIRECTION  x  y  z

<species>  GUN AT  x'  y'  z'
    .
    .
    .
    .
    .
END
```

OFFSET ix iy iz

Should be first card in file. Defines position relative to which gun locations are defined. Default is mesh center. OFFSET 0 0 0 will make gun positions defined in "absolute" grid location.

GUN AT x y z

ELECTRON GUN AT x y z

ION GUN AT x y z

Defines position and type of gun. If gun type not specified, electron gun is assumed.

ENERGY / ENERGIES $e_1 \ldots e_n$ unit

Defines beam energies of gun. Unit is 'EV' or 'KEV'. The default unit is 'KEV'.

BEAMWIDTH(S) $b_1 \ldots b_n$ unit

Defines half-angle of beam. Unit is assumed to be radians, unless 'DEGREES' is specified.

ALL BEAMWIDTHS b unit

Assigns b as the beamwidth for all beams of this gun.

CURRENT(S) $c_1 \ldots c_n$

Specifies beam currents in amperes.

ALL CURRENTS c

Assign c as current for all beams of this gun.

NOSHADOW

Indicates that file IOBPLT [19] already exists for guns at these locations.

ION MASS m unit

Defines mass for an ion gun. Unit is assumed kilograms unless 'AMU' is specified.

DIRECTION x y z

Specifies direction in which gun is pointing.

END

Ignore subsequent cards.

Figure 5.5. Summary of TEST TANK (Type 1 or Type 6) flux definition cards. (See also Table 5.1.)

Notes:

1. <species> GUN AT x y z

   <species> is optional and may be 'ELECTRON' or 'ION' to define an electron or ion gun, respectively. Omission of any <species> assumes an ELECTRON gun.

   <x y z> define the coordinates of the gun location (in object definition inner grid coordinates - 3.2). For example:

   'GUN AT -2 0 -8'

   defines an electron gun at x = -2, y = 0 and z = -8.

   The gun may be located outside the computational space.

2. ENERGY e_1 e_2 e_3 ... e_n unit

   This card defines the energy of the beam(s) to be emitted from the gun. Up to 30 beams may be defined. These can all come from one gun or be shared by up to ten separate guns. Each number entered after the parameter keyword 'ENERGY' defines another energy beam, and hence another beam. The <units> at the end of the energies is optional. The default units are 'KEV'. The only other acceptable unit is EV.

3. BEAMWIDTH b_1 b_1 ... b_n <units>

   This card has exactly the same syntax as the ENERGY card. The number of beamwidths defined must correspond exactly however to the number of energies (and currents) previously defined for this particular gun. The beamwidth is the half angle of the conical beam. The unit is assumed to be RADIANS unless DEGREES is specified as <units>.

4. CURRENT c_1 c_2 ... c_n

   Again the syntax is similar to that for ENERGY and BEAMWIDTH. The currents of the beams must all be in amps.

5. DIRECTION x y z

This card specifies the direction in which the gun is pointing. (i.e., in coordinates with origin at the gun location, the gun is aimed at the point x y z.

The four parameter cards may be in any order. As emphasized above, the ENERGY, BEAMWIDTH and CURRENT cards must all indicate the same number of beams.

5.9.3 'ALL' CARDS

When a set of beams all have the same energies, currents or widths, it is sometimes convenient to declare these quantities using the 'ALL' keyword; e.g.,

```
ALL ENERGIES  e  units
ALL CURRENTS  c
ALL BEAMWIDTHS  b  units
```

The 'ALL' cards may only be used after at least one parameter card in conventional format has been declared to establish the number of beams. For example

```
BEAMWIDTHS  b1  b1
ALL CURRENTS  c
ALL ENERGIES  e EV
```

is part of a block defining a gun having two beams. The same definition will fail if written in the form

```
ALL CURRENTS  c
BEAMWIDTHS  b1  b2
ALL ENERGIES  e  EV
```

because the current is defined before the BEAMWIDTHS card establishes the number (2) of beams.

5.9.4 'OFFSET'

Sometimes it is convenient to change the coordinate system from the 0 0 0 centered one that is active by default to some other, before the guns are defined. (Say the absolute system.) This is achieved with the OFFSET command

'OFFSET ix iy iz'

OFFSET works in the Test Tank-6 flux definition file in exactly the same way as it does in the object definition file. This is explained in Section 3.9.3.

5.9.5 'NOSHADOW'

The shadowing information calculated by HIDCEL depends only on the location of the guns defined. For multiple NASCAP runs involving the same number of guns at the same locations illuminating the same object the shadowing calculations need not be repeated. If keyword 'NOSHADOW' appears in the flux definition file read by TANK, no calls to HIDCEL will be made. Instead NASCAP will assume that the required shadowing information has been written to (and saved on) file IOBPLT (19) by a previous run. This feature is particularly useful for series of runs where the user wishes to change the currents, energies and/or widths of the beam, but not the location of the guns on the tank.

5.9.6 THE SHAPE OF THE TANK

Like Test Tank-1 the walls of the tank are defined by the boundary of the computational space (3.2). There are no restrictions on gun placement for Test Tank-6. Likewise the computational space and hence the tank itself may be any NASCAP allowed size and shape. The cylindrical tank option (6.4.12) applies to Test Tank-6 as well as Test Tank-1. If the tank walls are grounded this must be reflected in the NASCAP calculation by choosing run option IOUTER to be 0 (6.4.5).

'IOUTER 0'

5.9.7 TEST TANK-6 EXAMPLES

The first example defines four guns pointing at the mesh center, each from a distance of 22.6 grid units. After echoing the gun definition input (which concludes with an 'END' card or end-of-file condition), the gun characteristics are echoed for each gun, and for each beam. It is then indicated that a shadowing calculation is being performed for each gun.

The second example defines an ion gun. As the 'NOSHADOW' specification is included, the purpose of this input is presumably to change the beamwidth, current, or energy.

Example three defines a two-beam electron gun with different current and beamwidth for each energy. Example four defines a three-beam electron gun with equal currents and beamwidths.

```
1.                  GUN AT 0 16 16
2.                  ENERGY 6. KEV
3.                  CURRENT 5.E-6
4.                  BEAMWIDTH 30 DEGREES
5.                  DIRECTION 0 -1 -1
6.                  GUN AT 0 -16 16
7.                  ENERGY 6. KEV
8.                  CURRENT 5.E-6
9.                  BEAMWIDTH 30 DEGREES
10.                 DIRECTION 0 1 -1
11.                 GUN AT 0 -16 -16
12.                 ENERGY 6. KEV
13.                 CURRENT 5.E-6
14.                 BEAMWIDTH 30 DEGREES
15.                 DIRECTION 0 1 1
16.                 GUN AT 0 16 -16
17.                 ENERGY 6. KEV
18.                 CURRENT 5.E-6
19.                 BEAMWIDTH 30 DEGREES
20.                 DIRECTION 0 -1 1
21.                 END
```

Gun definition input for example 1.

```
1.                  ION GUN AT -44., 0.5, 6.2
2.                  NOSHADOW
3.                  ION MASS 14 AMU
4.                  BEAMWIDTH 20 DEGREES
5.                  CURRENT 5.E-6
6.                  ENERGY 5000 EV
7.                  DIRECTION 3. 0. 1.
8.                  END
```

Gun definition input for example 2.

```
1.                  ELECTRON GUN AT -20 0. 0.
2.                  DIRECTION 1 0 0
3.                  ENERGIES 0.1  10 KEV
4.                  BEAMWIDTHS  40  10  DEGREES
5.                  CURRENTS 1.E-6  0.5E-6
6.                  END
```

Gun definition input for example 3.

```
1.                  ELECTRON GUN AT 50 35 4
2.                  DIRECTION -2 -1 0
3.                  ENERGIES 5 10 20 KEV
4.                  ALL BEAMWIDTHS 25 DEGREES
5.                  ALL CURRENTS 1.E-6
6.                  END
```

Gun definition input for example 4.

```
******TANK 5

  OBJECT DEFINITION INFORMATION BEING READ FROM FILE

A SHADOWING TABLE WAS PREVIOUSLY GENERATED
 FOR THIS OBJECT USING THE GUNS OPTION
GUN AT 0 16 16
ENERGY 6. KEV
CURRENT 5.E-6
BEAMWIDTH 30 DEGREES
DIRECTION 0 -1 -1
GUN AT 0 -16 16
ENERGY 6. KEV
CURRENT 5.E-6
BEAMWIDTH 30 DEGREES
DIRECTION 0 1 -1


GUN AT 0 -16 -16
ENERGY 6. KEV
CURRENT 5.E-6
BEAMWIDTH 30 DEGREES
DIRECTION 0 1 1
GUN AT 0 16 -16
ENERGY 6. KEV
CURRENT 5.E-6
BEAMWIDTH 30 DEGREES
DIRECTION 0 -1 1
END

 GUN DEFINITION ------
GUN  1 HAS BEEN DEFINED AS AN ELECTRON GUN
GUN IS LOCATED AT GRID COORDINATES   9.00  25.00  25.00
GUN DIRECTION IS     .00  -1.00  -1.00
BEAM  1: ENERGY=  6.00+003 EV    CURRENT=  5.00-006 AMPS   CUT-OFF ANGLE= 30.0000 DEGREES

 GUN DEFINITION ------
GUN  2 HAS BEEN DEFINED AS AN ELECTRON GUN
GUN IS LOCATED AT GRID COORDINATES   9.00  -7.00  25.00
GUN DIRECTION IS     .00   1.00  -1.00
BEAM  1: ENERGY=  6.00+003 EV    CURRENT=  5.00-006 AMPS   CUT-OFF ANGLE= 30.0000 DEGREES

 GUN DEFINITION ------
GUN  3 HAS BEEN DEFINED AS AN ELECTRON GUN
GUN IS LOCATED AT GRID COORDINATES   9.00  -7.00  -7.00
GUN DIRECTION IS     .00   1.00   1.00
BEAM  1: ENERGY=  6.00+003 EV    CURRENT=  5.00-006 AMPS   CUT-OFF ANGLE= 30.0000 DEGREES

 GUN DEFINITION ------
GUN  4 HAS BEEN DEFINED AS AN ELECTRON GUN
GUN IS LOCATED AT GRID COORDINATES   9.00  25.00  -7.00
GUN DIRECTION IS     .00  -1.00   1.00
BEAM  1: ENERGY=  6.00+003 EV    CURRENT=  5.00-006 AMPS   CUT-OFF ANGLE= 30.0000 DEGREES
SHADOWING BEING CALCULATED FOR GUN   1
 DISTANCE EQUALS  22.627417

FINAL NA1 =    20
SHADOWING BEING CALCULATED FOR GUN   2
 DISTANCE EQUALS  22.627417

FINAL NA1 =    20
SHADOWING BEING CALCULATED FOR GUN   3
 DISTANCE EQUALS  22.627417

FINAL NA1 =    20
SHADOWING BEING CALCULATED FOR GUN   4
 DISTANCE EQUALS  22.627417

FINAL NA1 =    20
```

Gun definition (INGUNS and GUNSHD) output for example 1.

```
******TANK 5
ION GUN AT -44., 0.5, 6.2
NOSHADOW
ION MASS 14 AMU
BEAMWIDTH 20 DEGREES
CURRENT 5.E-6
ENERGY 5000 EV
DIRECTION 3. 0. 1.
END


 GUN DEFINITION ------
GUN  1 HAS BEEN DEFINED AS AN ION GUN WITH AN ION MASS=  2.34-026 KILOGRAMS.
GUN IS LOCATED AT GRID COORDINATES -35.00   9.50  15.20
GUN DIRECTION IS   3.00    .00   1.00
BEAM  1: ENERGY=  5.00+003 EV    CURRENT=  5.00-006 AMPS   CUT-OFF ANGLE= 20.0000 DEGREES
```

Gun definition (INGUNS and GUNSHD) output for example 2.

```
******TANK 5
ELECTRON GUN AT -20 0. 0.
DIRECTION 1 0 0
ENERGIES 0.1  10 KEV
BEAMWIDTHS  40  10  DEGREES
CURRENTS 1.E-6  0.5E-6
END

 GUN DEFINITION ------
GUN  1 HAS BEEN DEFINED AS AN ELECTRON GUN
GUN IS LOCATED AT GRID COORDINATES -11.00   9.00   9.00
GUN DIRECTION IS   1.00    .00    .00
BEAM  1: ENERGY=  1.00+002 EV    CURRENT=  1.00-006 AMPS   CUT-OFF ANGLE= 40.0000 DEGREES
BEAM  2: ENERGY=  1.00+004 EV    CURRENT=  5.00-007 AMPS   CUT-OFF ANGLE= 10.0000 DEGREES
SHADOWING BEING CALCULATED FOR GUN   1
 DISTANCE EQUALS  20.000030

FINAL NA1 =    16
```

Gun definition (INGUNS and GUNSHD) output for example 3.

```
******TANK 5
ELECTRON GUN AT 50 35 4
DIRECTION -2 -1 0
ENERGIES 5 10 20 KEV
ALL BEAMWIDTHS 25 DEGREES
ALL CURRENTS 1.E-6
END

 GUN DEFINITION ------
GUN  1 HAS BEEN DEFINED AS AN ELECTRON GUN
GUN IS LOCATED AT GRID COORDINATES  59.00  44.00  13.00
GUN DIRECTION IS  -2.00  -1.00    .00
BEAM  1: ENERGY=  5.00+003 EV    CURRENT=  1.00-006 AMPS   CUT-OFF ANGLE= 25.0000 DEGREES
BEAM  2: ENERGY=  1.00+004 EV    CURRENT=  1.00-006 AMPS   CUT-OFF ANGLE= 25.0000 DEGREES
BEAM  3: ENERGY=  2.00+004 EV    CURRENT=  1.00-006 AMPS   CUT-OFF ANGLE= 25.0000 DEGREES
SHADOWING BEING CALCULATED FOR GUN   1
 DISTANCE EQUALS  61.163713

FINAL NA1 =    28
```

Gun definition (INGUNS and GUNSHD) output for example 4.

5.10 TECHNICAL DISCUSSION

5.10.1 ANISOTROPIC FLUX

The NASCAP model by default allows for incident electron and ion fluxes that are isotropic; i.e., all incident directions are considered equally likely. This is not usually true for orbiting satellites.

Injection of a charged particle into a static magnetic field causes the particle to follow a spiraling trajectory about the magnetic lines of force. The component of its velocity $\vec{v}_{||}$ along the field direction is unchanged and the radius of the spiral trajectory r_L depends on the perpendicular component $\vec{v}$

$$r_L = \frac{mv_\perp}{qB}$$

Thus for a fixed velocity magnitude, $|v|$, injection of a flux of charged particles into a magnetic field will lead to fast moving particles (in the field direction) with small Larmor radii (r_L), and slower particles with large radii.

Similar events occur in the earth's magnetic field. Plasma is injected into normally low-density regions and the particles begin an orbiting trajectory along the field lines. A satellite bathed in this orbiting plasma will experience a flux with two principal components:

a. A background, essentially isotropic, flux consisting of the pre-existing low density plasma, and particles from the injected plasma, that have r_L much greater than the spacecraft's dimensions.

b. A directional flux, aligned with the terrestrial field, consisting of particles with r_L smaller than the spacecraft dimensions. This can be a negative contribution. If some of the injected plasma has passed the poles several times, the faster moving particles will have been "filtered out" leaving a reduced flux in the field direction (a "loss-cone").

This model is too simplistic to account for all of the varied magnetic phenomena that can occur in earth orbit. However, it does illustrate the features that are desirable in a model incorporating anisotropic flux distribution.

The form introduced into the NASCAP model consists of a background isotropic component and a $\cos^2\theta$ distribution aligned with the field direction. The shape of such a form depends on just one parameter: the ratio of integrated flux for each component, R.

5.10.1.1 The Coordinate System. The most convenient coordinate system in which to represent the aligned component is the "fan"-like system shown in Figure 5.6. The angle of incidence β of an incoming vector $\vec{r}$ is related to the two angles of rotation shown, θ and ϕ, by the relationship

$$\cos\beta = \cos\theta \cos\phi$$

Rotating the "fan" from a plane containing the surface normal to a plane containing the vector $\vec{r}$ only partially defines the angle θ. The choice of θ becomes unique when the second rotation (ϕ) within the plane of the "fan", to reach $\vec{r}$, is specified. The coordinate system is chosen so that the magnetic field direction $\vec{B}$ has $\phi = 0$. This provides a reference point for all other vectors in the space above the surface, and hence fully defines the θ, ϕ coordinate system.

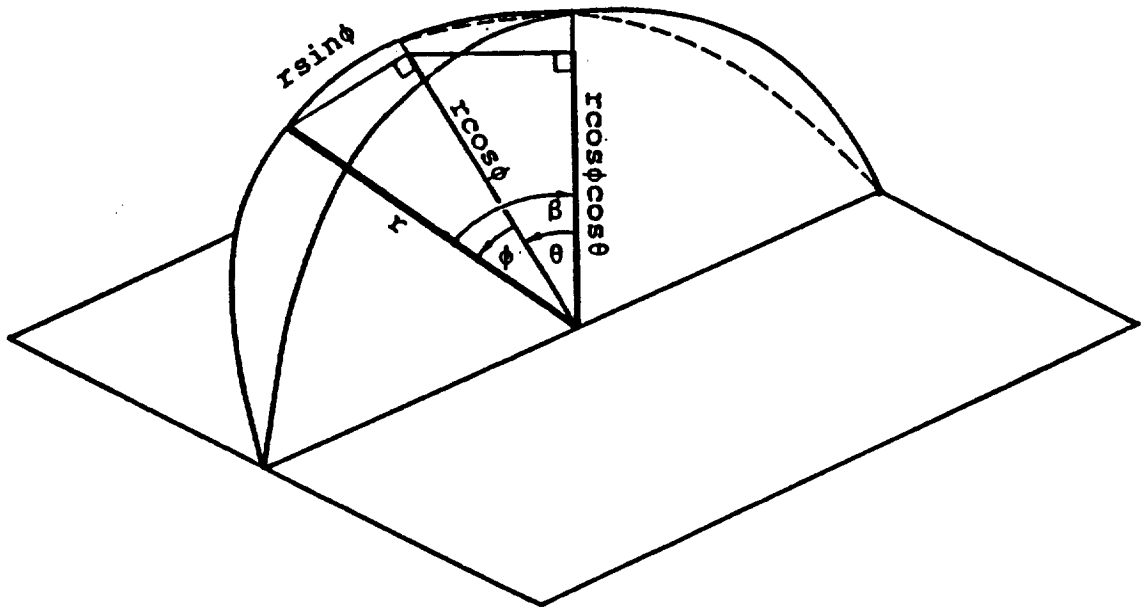


Figure 5.6. The projection of an incident vector $\vec{r}$ upon the surface normal, in the "fan-like" coordinated system.

5.10.1.2 Angular Distribution Function. The angular distribution function is assumed to be symmetric about the field direction, and so the aligned component depends only upon the angle ψ made between a vector $\vec{r}$ and $\vec{B}$, the field direction

$$\cos\psi = \cos(\theta-\theta_0)\cos\phi$$

The form we choose for the aligned component is simply $\cos^2\psi$, i.e., the angular distribution function $f(\theta,\phi)$ becomes

$$f(\theta,\phi) = a + b\cos^2(\theta-\theta_0)\cos^2\phi$$

Integration over the half-sphere must be normalized to 2π.

$$\int_{1/2} f(\theta,\phi)d\omega = 2\pi$$

In the "fan" coordinate system:

$$d\omega = \cos\phi\, d\phi\, d\theta$$

$$\therefore \int_{-\pi/2}^{\pi/2}\int_{-\pi/2}^{\pi/2} \left(a + b\cos^2(\theta-\theta_0)\cos^2\phi \cos\phi\, d\theta\, d\phi = 2\pi\right)$$

$$\therefore \quad 2\pi a + \frac{2\pi b}{3} = 2\pi$$

i.e.,

$$a + \frac{b}{3} = 1$$

We define the ratio of integrated fluxes R as

$$R = b/3a$$

$$\therefore \quad a = 1/(1 + R)$$

$$b = 3R/(1 + R)$$

Thus overall the angular distribution function depends only upon two parameters:

1. The angle θ_o between the field direction $\vec{n}_B$ and the surface normal $\vec{n}$.
   $\cos\theta_o = \vec{n}_B \cdot \vec{n}$.
2. The ratio R.

While this form for $f(\theta,\phi)$ cannot represent exactly all possible angular distributions it does, in a simple way, model the most commonly observed situations of enhancement of flux incident along the field lines (R is positive) and a "loss-cone" along the field direction (R is negative). This is illustrated in Figs. 5.7 to 5.10. As R increases from -0.35 to 0.5 the distribution changes from a "doughnut" shaped loss-cone to a "dumb-bell" aligned flux form.

NASCAP allows for a table of R(E) values for different incident energies to be entered. The code then automatically takes the variation in anisotropy as a function of energy into account when calculating currents.

5.10.1.3 Current Collection. For particles incident with an energy E, the incoming current FIN(E) is given by:

$$FIN(E) = F(E)\int_{-\pi/2}^{\pi/2}\int_{-\pi/2}^{\pi/2}\left(a(E)+b(E)\cos^2(\theta-\theta_o)\cos^2\phi \;\; \cos\theta\cos^2\phi\, d\theta\, d\phi\right)$$

where for a Maxwellian

$$F(E) = \frac{N}{\pi}\left(\frac{T}{2\pi m}\right)^{1/2} e^{-E/T}$$

Integrating gives

$$FIN(E) = F(E)\left[a(E) + \frac{3b(E)}{8}\left(1 + \frac{\cos 2\theta_0}{3}\right)\right]$$

Integrating over the plasma energy spectrum gives the observed incident current FIN. The emitted current is more complex since all of the integrals cannot be performed analytically.

$$FOUT(E) = \frac{F(E)}{\pi}\int_{-\pi/2}^{\pi/2}\int_{-\pi/2}^{\pi/2} \delta(\beta)(E)\left[a(E)+b(E)\cos^2(\theta-\theta_0)\cos^2\phi\right]$$

$$\cos\theta \cos^2\phi \, d\theta \, d\phi$$

$$= 2\,F(E)\,A(E)\,\delta_{ISO}(E) + \kappa(E)$$

For secondary electron emission, expanding $\cos^2(\theta-\theta_0)\cos^2\phi$:

$$\kappa(E) = \kappa_1(E) + \kappa_2(E)$$

$$\kappa_1(E) = -2b(E)\cos(2\theta_0)F(E)C$$

$$\cdot\left[\frac{C1}{Q}\left(\frac{2}{Q^3} - e^{-Q}\left(\frac{1}{Q} + \frac{2}{Q^2} + \frac{2}{Q^3}\right) - \frac{1}{3}\right)\right.$$

$$\left. + \frac{C2}{Q^2}\left(\frac{3}{Q^2} - e^{-Q}\left(1 + \frac{3}{Q} + \frac{3}{Q^2}\right) - \frac{1}{2}\right)\right]$$

where

$$\delta(\beta) = C \cdot \left[C1 \left(\frac{1-e^{-Q\cos\beta}}{Q\cos\beta} \right) - C2 \left(\frac{1-\cos\beta+1)e^{-Q\cos\beta}}{Q^2\cos^2\beta} \right) \right]$$

$Q = \alpha R$ (R is the range of electrons of energy E).

$$\kappa_2(E) = \sin^2\theta_o \frac{F(E)}{\pi} b(E)\, C\left[C1 \cdot I_1 + C2 \cdot I_2 \right]$$

The integrals I_1 and I_2 are integrated numerically and tabulated for various values of Q. Interpolation finds the value of each for an unknown Q.

$$I_1 = \int_{-\pi/2}^{\pi/2} \int_{-\pi/2}^{\pi/2} \left(\frac{1-e^{-Q}}{Q} \right) \cos^4\phi \cos\theta \, d\theta \, d\phi$$

$$I_2 = \int_{-\pi/2}^{\pi/2} \int_{-\pi/2}^{\pi/2} \left(\frac{1+(Q+1)e^{-Q}}{Q^2} \right) \cos^4\phi \cos\theta \, d\theta \, d\phi$$

By dividing the values of FOUT(E) so calculated by the incident current normalization ANGF(E)

$$\text{ANGF(E)} = \frac{\text{FIN(E)}}{\text{F(E)}} = a(E) + \frac{3b(E)}{8} \left(1 + \frac{\cos^2\theta_o}{3} \right)$$

we obtain the anisotropic yield for secondary emission

$$\delta_{\text{ANISO}} = \frac{\text{FOUT(E)}}{\text{ANGF(E)}}$$

The proton secondary emission is much simpler to calculate since FOUT(E) is independent of angle:

$$\delta^{\text{proton}}_{\text{ANISO}}(E) = \frac{\text{FOUT}(E)}{\text{ANGF}(E)} = \frac{\text{FOUT}_{\text{ISO}}(E)}{\text{ANGF}(E)}$$

The backscatter requires an additional tabulated integral:

$$\eta(\theta) = \eta_0 \, e^{-\log\eta_0} \, e^{\log\eta_0 \cos\beta}$$

$$\therefore \quad \text{FOUT}(E) = \frac{F(E)}{\pi} \, \eta_0(E) \, e^{-\log\eta_0(E)} \, K_\eta$$

where

$$K_\eta = \int_{-\pi/2}^{\pi/2} \int_{-\pi/2}^{\pi/2} e^{\gamma \cos\theta \cos\phi} \cos^2(\theta-\theta_0) \cos^4\phi \cos\theta \, d\phi \, d\theta$$

where

$$\gamma = \log\eta_0$$

Separating as before:

$$K_\eta = J_1 + J_2$$

$$J_1 = 2 \cos 2\theta_0 \left[e^{\gamma} \left(\frac{6}{\gamma^4} - \frac{6}{\gamma^3} + \frac{3}{\gamma^2} - \frac{1}{\gamma} \right) - \frac{6}{\gamma^4} \right]$$

$$J_2 = \sin^2\theta_0 \int_{-\pi/2}^{\pi/2} \int_{-\pi/2}^{\pi/2} e^{\gamma \cos\theta \cos\phi} \cos^4\phi \cos\theta \, d\theta \, d\phi$$

J_2 is tabulated for values of η_0.

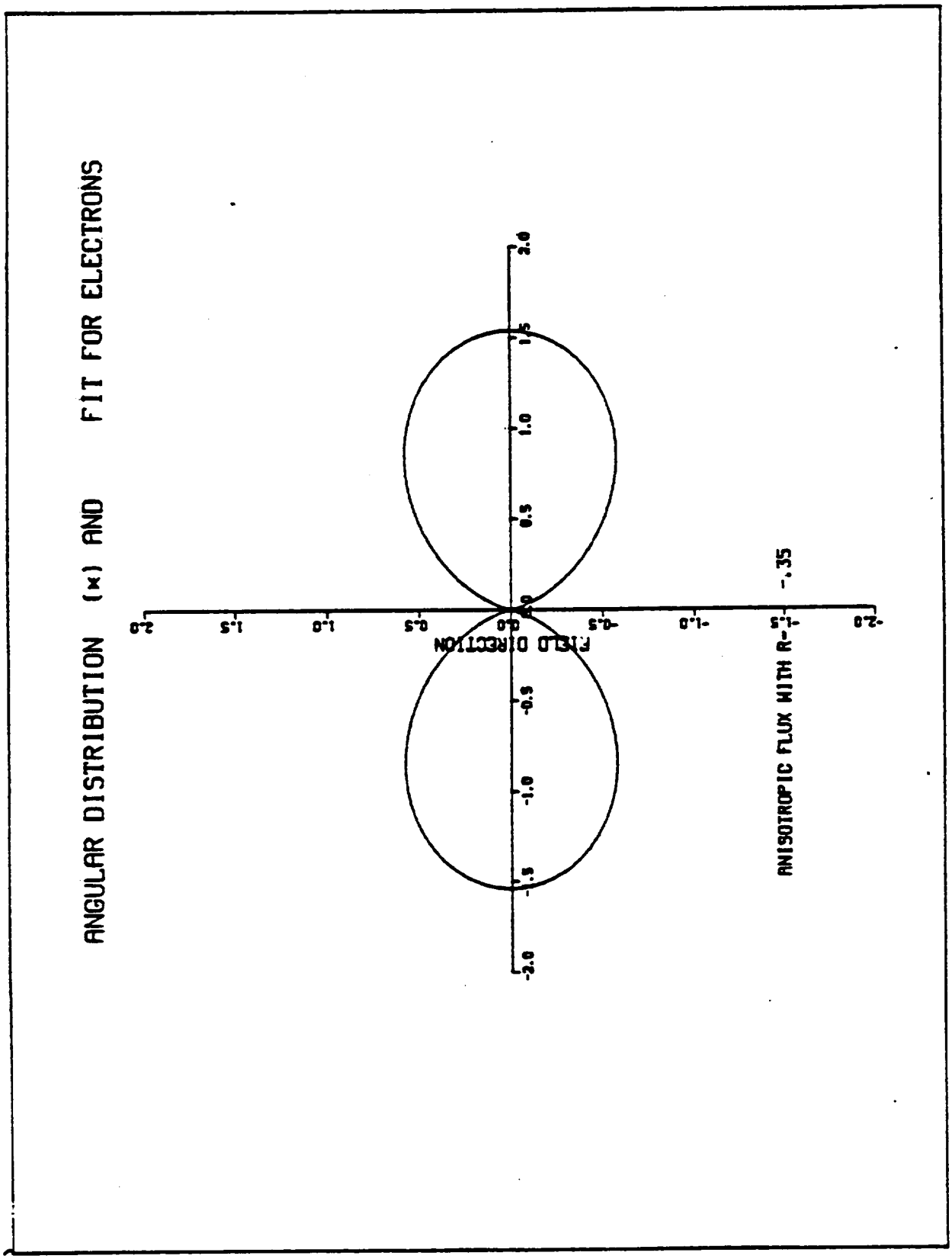


Figure 5.7. Anisotropic flux distribution with R = -0.35.

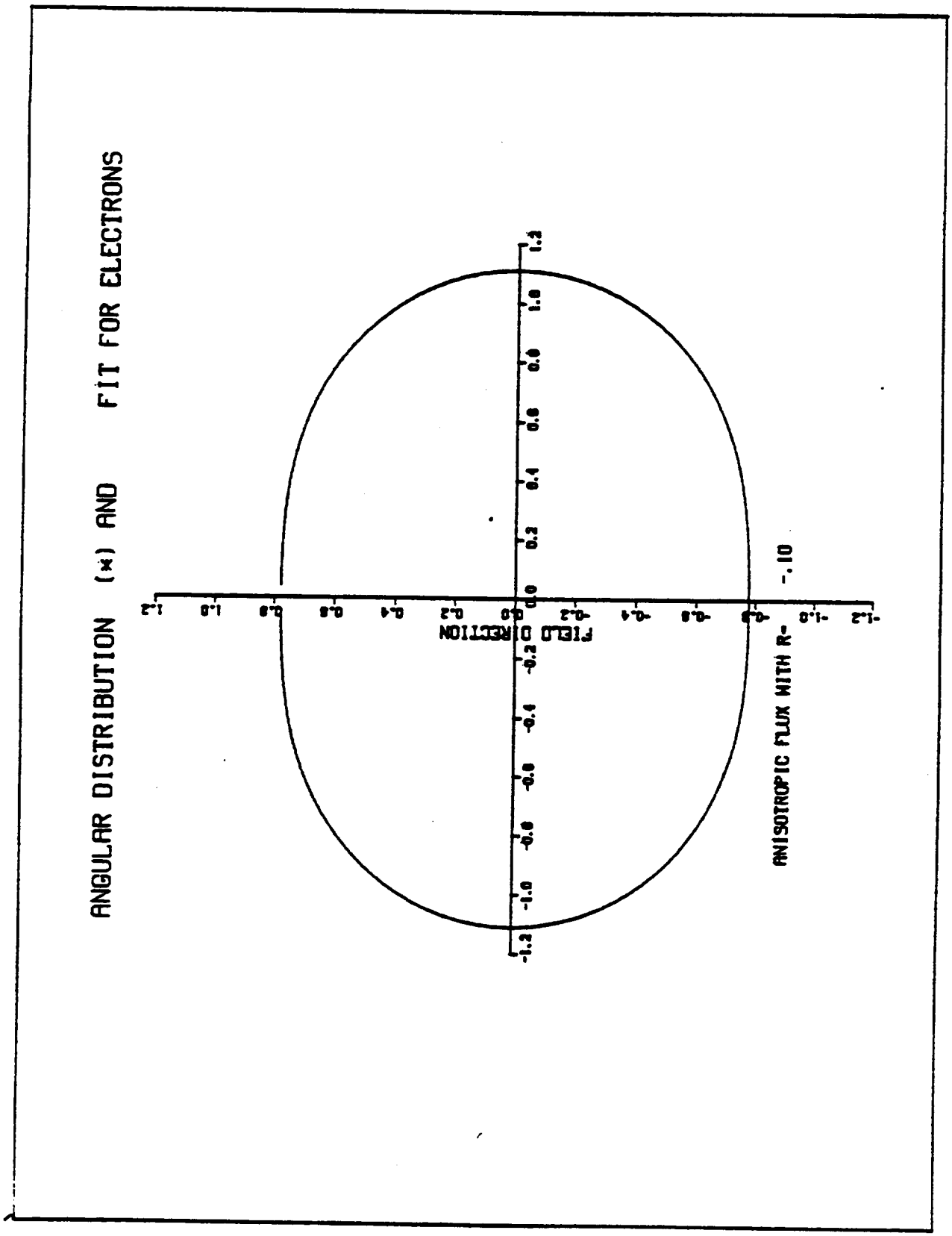


Figure 5.8. Anisotropic flux distribution with R = -0.10.

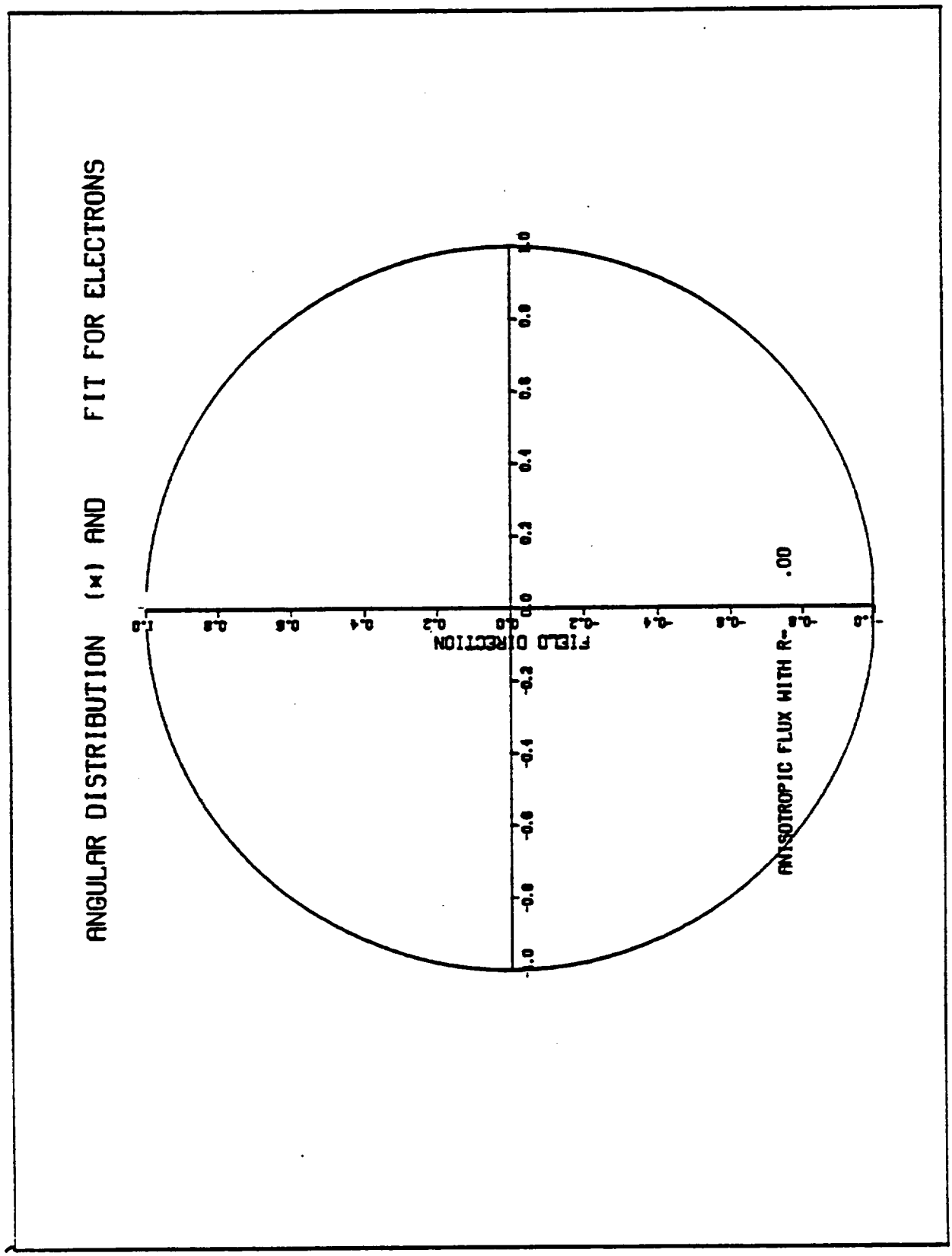


Figure 5.9. Isotropic flux distribution.

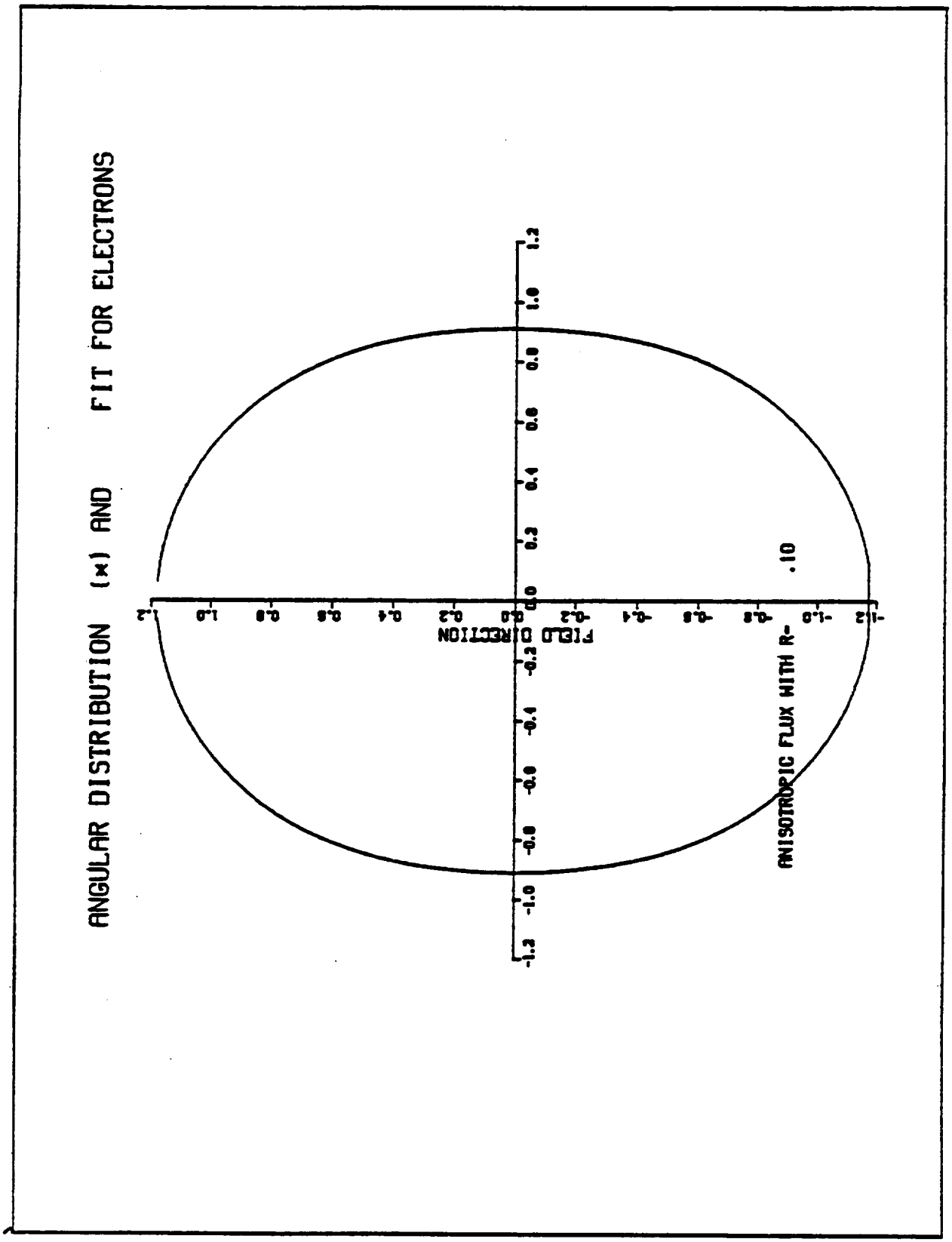


Figure 5.10. Anisotropic flux distribution with R = 0.10.

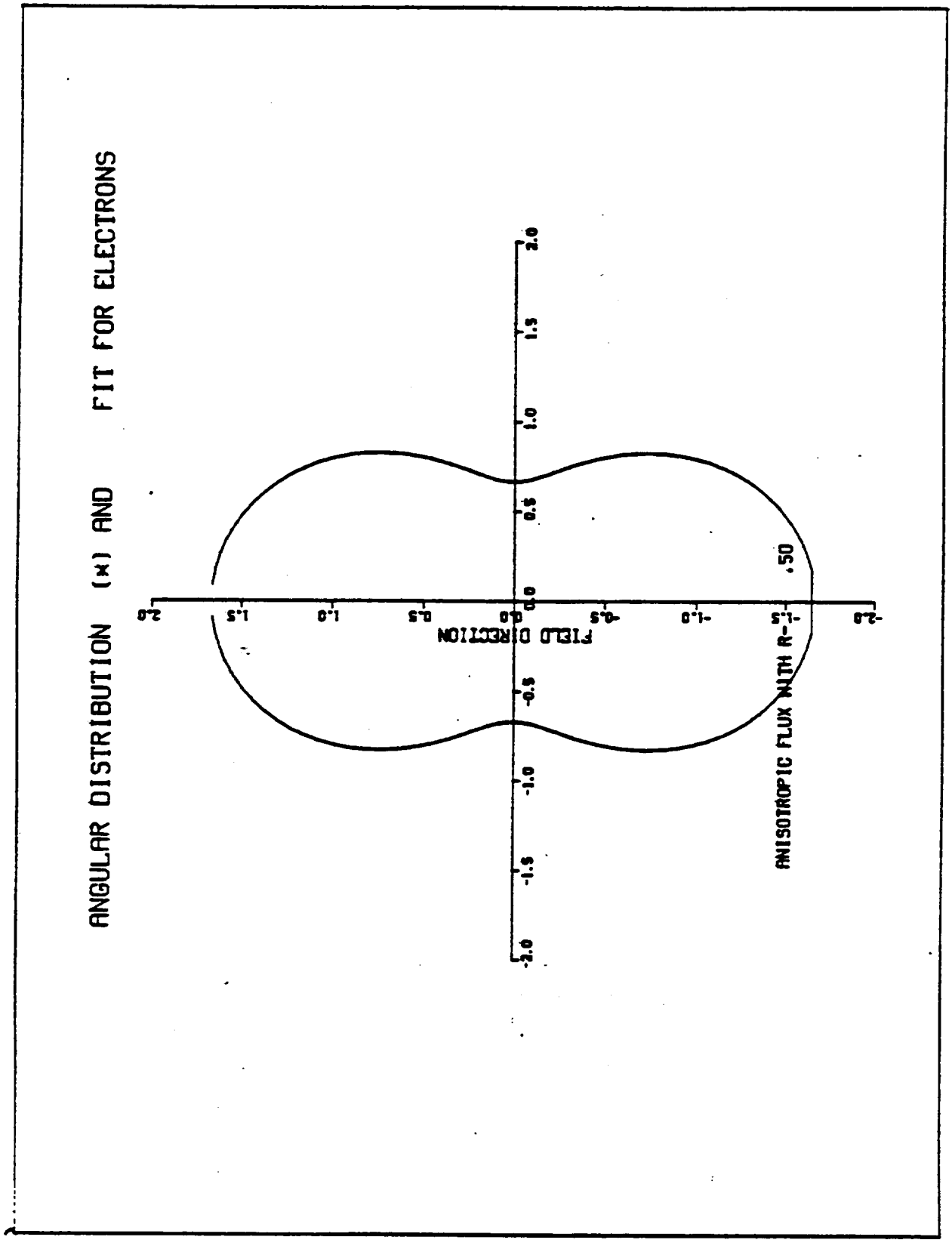


Figure 5.11. Anisotropic flux distribution with R = 0.50.

5.10.2 TEST TANK-6 (ITYPE 6)

Test Tank-1 uses particle tracking techniques to simulate an electron gun. With this method the beam electron trajectories are approximated by calculating the actual trajectories of representative beam particles. While, in principle, enough particles could be followed to make the results as accurate as desired, in practice, computer time used to calculate each representative orbit places severe restrictions on the number of test particles followed.

Following the basic philosophy that has been successful throughout NASCAP we opted to use a simplified representation of the space potentials which allows direct integration of particle orbit. Particle shadowing is included in an approximate manner using HIDCEL with the "viewer" located at the gun position. The potential is modeled by keeping only one monopole term in the multipole expansion. This is a reasonable approximation for gun to satellite distance large compared to satellite radius.

To implement the proposed method of approach, consider a point source at a distance r_o from the center of force (Figure 5.12). The rate at which the source emits electrons with kinetic energy E_o into the interval dE_o and the solid angle $d\Omega_o$ is denoted by

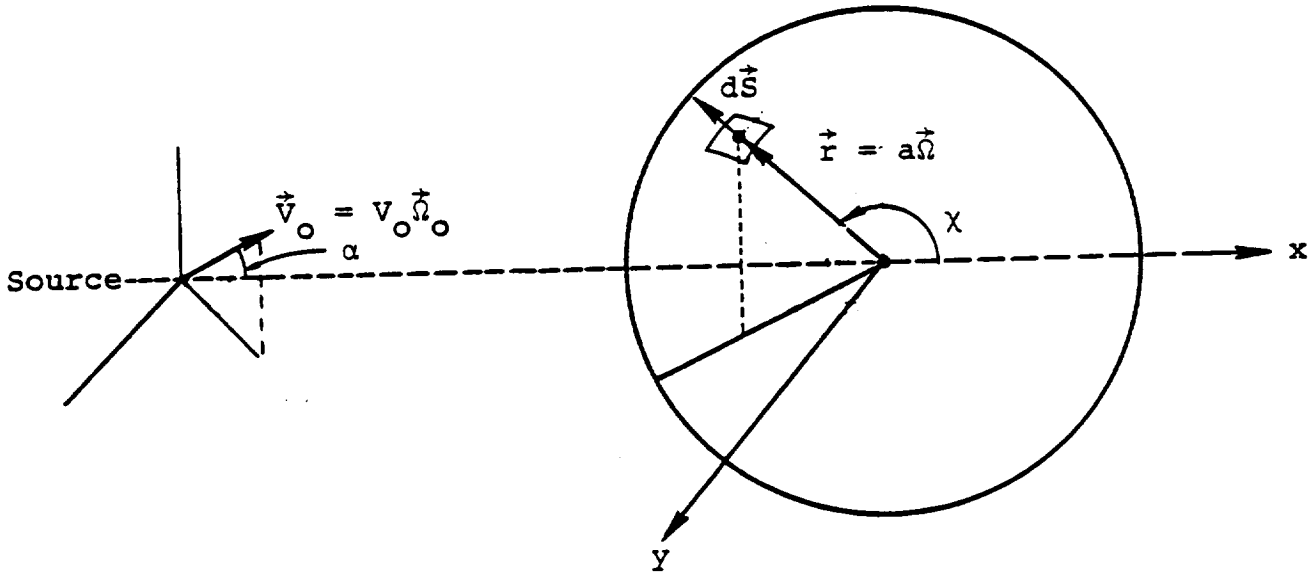


Figure 5.12. Geometry for electron gun aimed at a sphere.

$$\frac{d^2I}{dE_o d\Omega_o}(E_o,\vec{\Omega}_o)\, dE_o\, d\Omega_o$$

Particles leaving the source in the range $dE_o\, d\Omega_o$ about $(E_o,\vec{\Omega}_o)$ cross a surface element of area $d\vec{S}$ about the point $\vec{r} = \vec{r}(E_o,\vec{\Omega}_o)$ on a sphere of radius a with energies in the range dE. In a steady state particle conservation requires that

$$\int_{(\Delta E_o,\Delta\Omega_o)} \frac{d^2I}{dE_o d\Omega_o}\, dE_o d\Omega_o = \int_{(\Delta E,\Delta S)} \vec{j}\cdot d\vec{S}\, dE$$

$$= a^2 \int_{(\Delta E,\Delta\ )} \vec{j}\cdot\vec{n}\, dE\, d\Omega$$

where $\vec{j}$ is the current density per unit energy at $\vec{r},\Delta\Omega = \Delta S/a^2$ in the solid angle subtended by ΔS at the center of force, and $\vec{\Omega} = \vec{n} = \vec{r}/r$ is the unit vector normal to the surface of the sphere of radius r with center at the center of force. Since ΔE_o and $\Delta\Omega_o$ are arbitrary

$$|j\cdot n| = \frac{1}{a^2}\frac{d^2I}{dE_o d\Omega_o}\frac{1}{|J|}$$

where

$$J = \frac{\partial}{\partial}\left(\frac{E,\ \vec{\Omega}}{E_o\vec{\Omega}_o}\right)$$

Once $|j \cdot n|$ is determined, the current density $\vec{j}$ per unit energy follows from

$$\vec{j} = |\vec{j} \cdot n| \frac{V}{\vec{V} \cdot \vec{\Omega}}$$

where $\vec{V} = \vec{V}(E_o, \vec{\Omega}_o)$ is the velocity at $\vec{r} = \vec{r}(E_o, \vec{\Omega})$.

The primary problem in the determination of $\vec{j}$ is the evaluation of the Jacobian. Consider first the case of no magnetic field and a repulsive potential $V = k/r$. The particles follow a hyperbolic path with the center of force at the focus. The geometry of the encounter is shown in Figure 5.13 where we also introduce the angular coordinate θ in terms of which the orbit is given by[18]

$$\frac{1}{r} = -\frac{mk}{\ell^2}(1 + \varepsilon \cos\theta) .$$

Here θ is measured from the symmetry axis of the orbit, m is the particle mass, $\ell = mv_o r_o \sin\alpha = (2mE_o)^{1/2} r_o \sin\alpha$ is the angular momentum, and

$$\varepsilon = \left[1 + 4\left(1 + \frac{E_o}{V_o}\right)\frac{E_o}{V_o}\sin^2\alpha\right]^{1/2}$$

where $V_o = k/r_o$. In the following we shall use the orbit equation in the form

$$\cos\theta = -\frac{1}{\varepsilon}\left(\frac{2E_o}{V_o}\frac{\sin^2\alpha}{x} + 1\right)$$

with $x = r/r_o$.

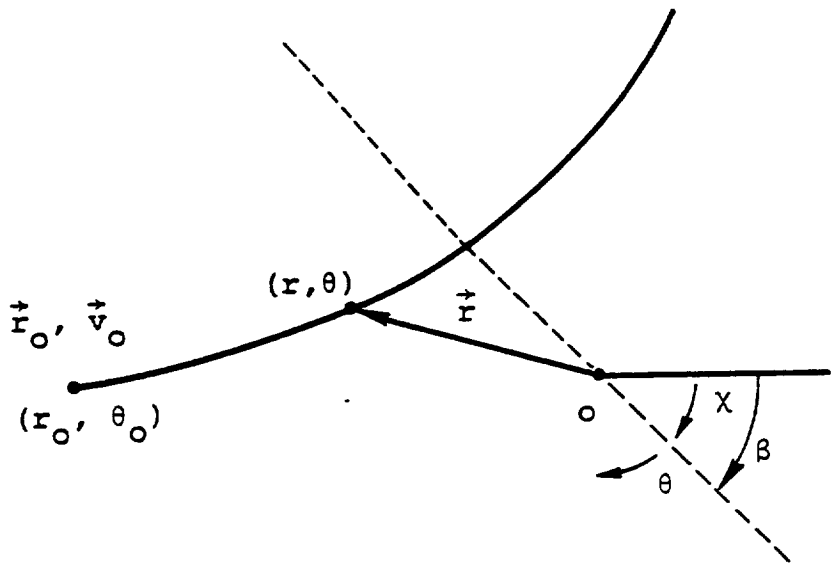


Figure 5.13. Geometrical quantities used to calculate current density.

For the present problem the required Jacobian is

$$J = \frac{\partial(\cos\chi)}{\mu}$$

where

$$\cos\chi = -\cos(\theta-\theta_0)$$

$$= -(\cos\theta\cos\theta_0 + \sin\theta\sin\theta_0)$$

$$\mu = \cos\alpha$$

and $\cos\theta_0$ is obtained from the equation given earlier with $x = 1$. We find

$$J = -\frac{1}{\varepsilon}\left[\left(-\frac{\varepsilon}{\mu}\cos\theta + \frac{4E_0}{V_0}\frac{\mu}{x}\right)(\cos\theta_0 - \sin\theta_0\,\mathrm{ctn}\theta)\right.$$

$$\left. + \left(-\frac{\varepsilon}{\mu}\cos\theta_0 + \frac{4E_0}{V_0}\mu\right)(\cos\theta - \sin\theta\,\mathrm{ctn}\theta_0)\right]$$

with

$$\frac{\varepsilon}{\mu} = -\frac{4}{\varepsilon}\left(1 + \frac{E_0}{V_0}\right)\frac{E_0}{V_0}\mu$$

In the presence of a constant magnetic field, $\vec{B}$, spherical symmetry of the force field is lost and the simple analytic expressions for the particle orbit are not known. The problem simplifies considerably however if the magnetic field is small in a sense that will become clear as we consider the motion observed in a system rotating at a constant angular velocity $\vec{\omega}$. In the rotating

system the effective force is[19]

$$F_{eff} = q\left[\vec{E} + \frac{\vec{V}_s x \vec{B}}{c}\right] - 2m(\omega x \vec{V}_r) - m\vec{\omega}x(\vec{\omega}x\vec{r})$$

where

$$\vec{V}_r = \vec{V}_s - \omega x \vec{r}$$

and $\vec{V}_s$ and $\vec{V}_r$ are the velocities of the particle relative to the space and rotating axes respectively. If we choose

$$\vec{\omega} = -\frac{q\vec{B}}{2mc}$$

then

$$\vec{F}_{eff} = q\vec{E} + m\vec{\omega}x(\vec{\omega}x\vec{r})$$

Neglecting terms of second and higher order in the $\vec{B}$ field, the equation of motion in the rotating system becomes

$$m\frac{d\vec{V}_r}{dt} = q\vec{E} .$$

Thus, to the considered degree of approximation, in the rotating frame the effects of the magnetic field vanish and to the rotating observer the particle moves in a 1/r potential.

To find where a given particle strikes the body we can consider that during the particle's flight time the body rotates with constant angular velocity $-\vec{\omega}$. The magnitude of the rotation requires a knowledge of the flight time, which to the required order of accuracy

is given by

$$t = \int_{r}^{r_o} \frac{dr}{|\dot{r}|}$$

where

$$|\dot{r}| = \left[\frac{2}{m}\left(E_o - V_o\left(1 - \frac{r_o}{r}\right) - E_o \frac{r_o^2}{r^2} \sin^2\alpha\right)\right]^{1/2}$$

The foregoing expressions have been programmed to determine where a particle of given initial energy and direction strike the object that is being charged. The magnitude of the current striking the body is calculated as if there were no magnetic field. Corrections for the effect of $\vec{B}$ on the current striking the object could be made, but in view of the rough nature of the initial monopole approximation, such corrections are not warranted.

5.10.3 PHYSICAL CHARACTERISTICS OF TRANSPARENT ANTENNAS

Many spacecraft have, as a dominant feature, large mesh antennas which are largely transparent to light and particles. Examples of such spacecraft include the ATS-6 satellite and the Galileo orbiter. The mesh must be conductive (in order to function as an antenna), and thus may be either pure conductor (or, equivalently, conductively coated dielectric), or dielectric-coated conductor. The main effect of this structure is to set the electrostatic potential over its area. However, although it is considered transparent as seen by the rest of the spacecraft, it does intercept some fraction of the particles and light incident on it, which, particularly in the dielectric-coated case, affects the antenna's own potential.

In NASCAP we consider an antenna mesh to intercept 20 percent of the incident fluxes. (This should be made a RDOPT parameter at some future time.) For charging purposes, the area of an antenna surface is considered to be the full surface area. Thus differential charging will take place more slowly on antenna surfaces than on solid surfaces.

6. RUN OPTIONS

6.1 INTRODUCTION

NASCAP requires three major types of information from the user. The first two, definitions of the object and the plasma environment, are described in Chapters 3 and 5. In this chapter we describe the third type, the RUN OPTIONS, in detail.

Like the object and environment definitions, the run options are understood by NASCAP as keywords, read from their own file. The run options are read by a special module RDOPT from the options file, IKEYWD. The default file number for IKEYWD is 26. The RDOPT module must always be the first module to be executed in any NASCAP run. A new run always sets all the run options to their default values. Subsequent calls to RDOPT do not cancel options set in previous calls in the same run however. The options file is read until an END card or an end-of-file condition is encountered.

The run options can be classified into six groups according to their functions. These are:

1. Options that control the way the program proceeds.
2. Options that define electrical connections.
3. Options that define features of the environment.
4. Options that control printed output.
5. Options that control graphical output.
6. Options that define logical unit numbers.

The keyword and parameter syntax for all of the run options are summarized in Table 6.1. Tables 6.2-6.7 classify the options according to the six functions above. Let us take each group and each option in turn and examine it in detail.

TABLE 6.1. NASCAP USER OPTIONS

USER OPTIONS—FILE 26

Supplied in file 26—OPT file. In this section, "#" indicates integers. "< >" indicates optional input. Ellipses "..." indicate continue on same line. The most important options are RESTART, DELTA, LONGTIMESTEP, NCYC, and MESH. Options are set sequentially as read. They are remembered throughout the steps of a NASCAP execution, and may be changed by RDOPT calls at any time.

SYNTAX	MEANING	DEFAULT	EXAMPLE
3D-VIEW x y z	new SATPLT view	3 default views	3D-VIEW 4.2 4.9 -8
3D-VIEW NONE	clear view table	3 default views	3D-VIEW NONE
APRT grids#	number grids potential print	0	APRT 2
BFIELD bx by bz	constant mag field—Webers/m²	0, 0, 0	BFIELD .01 1.E-5 1.E-5
BIAS cond# volts	conductor bias relative to conductor 1	no bias	BIAS 2 -500
CIJ conda# condb# farads	mutual conductor capacitance	stray capacitance only	CIJ 3 4 1.E-4
COMMENT <anything>	comment—no effect	none	COMMENT SEPT 25 CHANGES
CONTOURS NONE	clear contour table	no contours	CONTOURS NONE
CONTOURS STANDARD	3 center cuts	no contours	CONTOURS STANDARD
CONTOURS (x/y/z) cut# ... ... <GRIDS ng# MOD mod#>	additional contour cut	no contours	CONTOURS Y -1 GRIDS 3 MOD 4
CONTOURS (x/y/z) cut# OFF	clear specific cut	no contours	CONTOURS X 0 OFF
CONVEX	convex object, self-shadowing only	HIDCEL must be called for nonzero sun intensity	CONVEX
CONVERGENCE PLOTS ON CONVERGENCE PLOTS OFF	potential solver printer plots	off	CONVERGENCE PLOTS ON CONVERGENCE PLOTS OFF
DEADLINE hhmmss#	finish before time of day	none	DEADLINE 234500
DEBYE	activates Debye screening	no screening	DEBYE
DELFAC factor	timestep = timestep * factor	1.	DELFAC 1.5
DELTA timestep	initial timestep (seconds)	1.	DELTA .01
DESTINATION dest	plot destination	none	DESTINATION CALCOMP
DIPOLE MOMENT px py pz ... AT x y z	magnetic dipole moment (A – M²) and location	none	DIPOLE MOMENT 1.E-2, 1.E-2, 0 AT 0, 0, 5
DISCHARGE relax	perform discharge analysis	no discharge analysis	DISCHARGE .5
EFFCON ON EFFCON OFF	effective surface conductivity	off	EFFCON ON EFFCON OFF
EMITTER unit#	activate particle emitter	NOEMIT	EMITTER 23
END	end of input file	none	END
FIXP cond# volts	fix conductor potential	conductor floats	FIXP 2 -3000
FLOAT	remove all previous FIXP and BIAS	previous status	FLOAT
FLOAT cond#	float previously fixed or biased conductor	previous status	FLOAT 3
IOUTER (0/2)	0—grounded outer boundary 2—monopole outer boundary	2, i.e., 1/r potentials	IOUTER 2

TABLE 6.1. NASCAP USER OPTIONS (Concluded)

SYNTAX	MEANING	DEFAULT	EXAMPLE
LONGTIMESTEP <dvlim>	implicit charging, <voltage limit per timestep>	NOLONG	LONGTIMESTEP 2000
MATVIEW $\pm\begin{pmatrix}x\\y\\z\end{pmatrix}$ cuta# cutb#	additional material plot	6 default plots	MATVIEW −Z −5 +5
MATVIEW NONE	clears MATVIEW table	6 default plots	MATVIEW NONE
NCYC steps#	number timesteps to run	1	NCYC 5
NG grids#	number computational grids	2	NG 3
NOEMIT	turn off previously defined emitter	previous status	NOEMIT
NOLONG	see LONGTIMESTEP	explicit charging	NOLONG
NOPRINT modulename	see PRINT	no extra printout	NOPRINT POTENT
NOSCALE	see SCALE	SCALE	NOSCALE
NOSHEATH	see SHEATH	no sheath plot	NOSHEATH
NOTIME	see TIMER	no timer	NOTIME
NZ zdiv#	z grid size	33	NZ 29
OFFSET x# y# z#	moves coordinate origin	center of mesh (9, 9, 17)	OFFSET 0 0 0
POTCON decades	convergence of potential solver	8—CAPACI, 4—TRILIN	POTCON 3
PRINT modulename	diagnostic prints; modulename is LIMCEL, POTENT, HIDCEL, or OBJDEF	NOPRINT	PRINT POTENT
REPEAT times#	plot repetition factor (IGS only)	1	REPEAT 3
RESTART	next timestep—old problem	new problem	RESTART
RIJ	interconductor resistance	∞	RIJ 1 2 3.E8
SCALE	potential solver scales potential and boundary conditions	SCALE	SCALE
SECONDARY <EMISSION> ANGLE	secondary formulation	ANGLE	SECONDARY ANGLE
SECONDARY <EMISSION> NORMAL	secondary formulation	ANGLE	SECONDARY EMISSION NORMAL
SHEATH	plot space charge density	NOSHEATH	SHEATH
SUNDIR x y z	sun direction vector	1, 1, 1	SUNDIR 1, 0, 2.5
SUNINT intens	sun intensity	0	SUNINT 0.8
SURFACE CORNER x# y# z# ... ... <norx# nory# norz#>	surface cell of interest (previous object definition required)	none	SURFACE CORNER 3, 3, 2 −1, 0, 0
SURFACE CELL cell#	surface cell of interest	cell #1	SURFACE CELL 541
TANKCUR OFF TANKCUR ON	tank current contour plots	off	TANKCUR OFF TANKCUR ON
TANKTRAJ OFF TANKTRAJ ON	tank particle trajectory plots	off	TANKTRAJ OFF TANKTRAJ ON
TIMER	execution time each module	NOTIME	TIMER
TITLE	plot title	NASCAP	TITLE P78-2
TYPE type#	environment type	2 (single Maxwellian)	TYPE 6
XMESH unit	physical grid spacing (meters)	0.1	XMESH .03
ZTRUNCATE zlo# zhi#	truncation of outer grid	full grid. -16 to +16	ZTRUNCATE -12 +12

TABLE 6.2. RUN OPTIONS THAT CONTROL PROGRAM PROCEDURE

DEADLINE

DELFAC

DELTA

EMITTER

END

LONGTIMESTEP/NOLONG

NCYC

POTCON

RESTART

SCALE/NOSCALE/DSCALE

TABLE 6.3. RUN OPTIONS THAT DEFINE ELECTRICAL CONNECTIONS

BIAS

CIJ

DISCHARGE

EFFCON

FIXP

FLDCON

FLASHOVER

FLOAT

RADCON

RIJ

TABLE 6.4. RUN OPTIONS THAT DEFINE FEATURES OF THE ENVIRONMENT AND COMPUTATIONAL SPACE

BFIELD
CONVEX
DEBYE
DIPOLE MOMENT
IOUTER
NG
NZ
OFFSET
SECONDARYEMISSION
SUNDIR
SUNINT
TANK AXIS
TANK RADIUS
TYPE
UPDATE
XMESH
ZTRUNCATE

TABLE 6.5. RUN OPTIONS THAT CONTROL PRINTED OUTPUT

APRT
CONVERGENCE PLOTS
PRINT
SURFACE AT
SURFACE CELL
SURFACE CORNER
TIMER/NOTIMER

TABLE 6.6. RUN OPTIONS THAT CONTROL GRAPHICAL OUTPUT

3D-VIEW

CONTOURS

DESTINATION

MATVIEW

REPEAT

SHEATH/NOSHEATH

TANKCUR

TANKTRAJ

TITLE

TABLE 6.7. RUN OPTIONS THAT DEFINE LOGICAL UNIT NUMBERS

IAREA

IAUN

ICNOW

IDIV

IFLUX

IKEYWD

ILTBL

IOBJ

IOBPLT

IP

IPART

IPQCND

IR

IROUS

ISAT

ISPARE

ISPCTR

IU

6.2 OPTIONS THAT CONTROL PROGRAM PROCEDURES

6.2.1 DEADLINE

The card:

DEADLINE hhmmss

tells NASCAP to finish its run before the time 'hhmmss', e.g.

DEADLINE 234500

causes NASCAP to exit cleanly before 11:45 p.m. (For example, there may be computer hardware maintenance scheduled for midnight.) The present cycle is finished, files are closed and output is printed. This enables the user to RESTART the run later. The default behavior (i.e., when no DEADLINE card is included in the options file) is to keep running until all of the requested cycles have been completed, or until NASCAP determines there is insufficient run time left to continue, regardless of the time of day.

6.2.2 DELTA

The card:

DELTA d

sets the length of each of the timesteps requested, to "d" seconds, e.g.,

DELTA 10

sets the length to 10 seconds. The default value (if a DELTA card is omitted completely) is 1 second.

6.2.3 DELFAC

The card:

DELFAC f

causes the length of the computational timestep DELTA to be increased by the factor f at <u>end</u> of each cycle. For example the cards

DELTA 10

DELFAC 2

will cause a 10 second timestep for cycle 1, a 20 second timestep for cycle 2, a 40 second timestep for cycle 3, and so on. The default value of DELFAC is 1.

6.2.4 EMITTER

Including the card

EMITTER n

in the options file establishes a particle emitter input file n. The default value of n is 5 (the NASCAP runstream). If the EMITTER card is found by RDOPT, TRILIN will look for input defining one or more particle emitters in file n. This is discussed in detail in Chapter 7. An existing emitter can be turned off with the card

NOEMIT

The default behavior is to assume no emitters.

6.2.5 END

Indicates end of options file.

6.2.6 LONGTIMESTEP/NOLONGTIMESTEP

The rate of change of the potential V of an object being charged by a net current I is inversely proportional to its capacitance C.

$$\frac{dV}{dt} = \frac{I}{C}$$

A spacecraft usually has a very small capacitance to infinity compared with the capacitances between its dielectric surfaces and their underlying conductors. This leads to at least two very different charging timescales. For a given current the rate of charging of the whole

spacecraft with respect to the surrounding plasma is typically orders of magnitude greater than the rate of differential charging between different surfaces of the spacecraft. For example an initially uncharged satellite exposed to a magnetic substorm at geosynchronous orbit (i.e., exposed to a charging plasma) might charge to 3 or 4 kV in perhaps 0.1 seconds, before reaching a quasi-equilibrium based on its capacitance to infinity. However, over the next 1000 seconds differential potentials may develop between the dielectric surfaces and other parts of the spacecraft as these larger capacitances become charged.

These widely differing charging rates make the choice of timestep duration (DELTA) a delicate one. If the timestep is chosen to be much longer than the charging timescale, wild oscillations about the equilibrium potential are likely. If the timestep is chosen to be much smaller than the charging timescale, nothing physically interesting will happen until many timesteps (and much valuable computer time) have been expended. The ideal solution is to choose very short timesteps for the first few cycles, when the satellite is charging rapidly, and then to increase them once the first quasi-equilibrium is achieved and differential charging is occurring on a longer timescale. This can be done explicitly by the user, or as an alternative, NASCAP provides an option that maintains the charging rate and adjusts the timestep duration internally to avoid potential overshoot and oscillations: The card:

LONGTIMESTEP <dvlim>

activates this option (called the LONGTIMESTEP option). The LONGTIMESTEP option is deactivated by default, or it may be explicitly "turned off" by the card

NOLONG (or NOLONGTIMESTEP)

The parameter <dvlim> is the maximum change in the magnitude in volts of any conductor potential that may occur during a timestep. For example, consider a surface expected to reach an equilibrium potential of -4 kV in 1 second, if dvlim is chosen to be 2000 V, and DELTA is chosen to be say 10 seconds, then LONGTIMESTEP will cut the length of

the timestep back from DELTA (10 s) to approximately 0.5 seconds, a time enough for the surface to reach -2 kV and no more. Equilibrium will not be reached until the second cycle.

If dvlim had been chosen to be 1000 V then equilibrium would be reached in approximately 4 cycles with duration of around 0.25 seconds, and so on. The smaller dvlim is chosen to be the more timesteps NASCAP will take to reach equilibrium and the better resolved will be the transient charging response of the satellite. The default value of dvlim is 1000 V.

If dvlim is chosen to be too large (i.e., greater than the expected quasi-equilibrium potential) and DELTA is chosen to be longer than the active charging timescale then oscillations in the potential may still occur.

The advantage of the LONGTIMESTEP option is that it allows timesteps appropriate to the phenomena of interest. For example, a user interested only in the final steady-state potentials can cover the transient response with relatively few timesteps. These arguments apply of course to charging and discharging equally well. It is generally recommended that most users use the LONGTIMESTEP option most of the time.

6.2.7 NCYC

The card:

NCYC *n*

sets the number of charging cycles for the TRILIN module. If no card is included in the options file NCYC is assumed to be 1. Any (integral) number of cycles may be requested but it is a good practice to break a long simulation up into a number of runs of perhaps 5 or 10 cycles at most. This enables the user to more closely monitor the results and to adjust DELTA, <dvlim> (6.2.2 and 6.2.6) and other parameters where necessary.

6.2.8 POTCON

The card

POTCON n

says that n orders of magnitude convergence are required of the Scaled Conjugate Gradient potential solver. If not set in the options file, it will be set to 8 by CAPACI, or to 6 by IPS, or to 4 by TRILIN. These defaults have been found to be a good compromise between accurate electric field determinations (i.e., more convergence) and fast run times (i.e., less convergence).

6.2.9 RESTART

Including the card

RESTART

in the options file causes NASCAP to continue a previous run. For example, if 5 cycles were requested for a new NASCAP run and all the restart files were saved (2.7) a subsequent run with the same object, etc. would, by default, start with cycle 1 and the potentials all at zero; i.e., the first 5 cycles would be repeated. If, however, a 'RESTART' card is included in the options file of the second run, potential calculations will begin with cycle 6 and the first run will be continued - just as if more than 5 cycles had been originally requested. This enables the user to break up a long (many cycle) charging simulation into a number of smaller, more manageable runs.

A run cannot be restarted unless the restart files discussed in Section 2.7, saved from the previous run, are assigned to the restart file numbers. In other words the restarted run must be able to access the information stored in the restart files.

6.2.10 SCALE/NOSCALE/DSCALE

The potentials in the space surrounding the object are determined iteratively from the potentials remembered from the previous timestep [Section 3.15.1] (=0 for the first timestep). The further away the initial potentials are from their iterative solution more iterations are required to achieve convergence. To a zeroth approximation the potentials in free space are proportional to the total amount of charge collected by the object. Hence a better starting point for the initial potentials in each timestep is given by scaling the values from the previous timestep as follows:

$$\text{Initial guess for potentials in timestep } n = \frac{\text{Total charge collected up to and including timestep } n}{\text{Total charge collected up to and including timestep } n-1} \times \text{final potentials for timestep } n-1$$

For a floating spacecraft this is automatically carried out by default, or by including the card

SCALE

Scaling is turned off if conductor 1 is at fixed potential, or if the card

NOSCALE

is encountered. The DSCALE option counts only charge on dielectric surfaces and is appropriate to a grounded object (i.e., in a test tank). The user need rarely specify any of these options, as NASCAP defaults are almost always adequate.

6.3 RUN OPTIONS THAT DEFINE ELECTRICAL CONNECTIONS

6.3.1 BIAS

The card:

BIAS i v

causes conductor i to be biased by v volts relative to conductor 1. Conductor 1 is usually the spacecraft ground. For example the card

BIAS 3 -1000

causes conductor 3 to always be 1000 volts more negative than conductor 1. If conductor 1 were floating at -300 V then conductor 3 would have a potential of -1300 V. The BIAS cards for each conductor must be entered in ascending order. Thus any card for conductor 3 will be rejected unless conductor 2 has been biased. Cards need only be included for those conductors that the user wants to be biased. The default behavior for a conductor not biased or fixed (see FIXP) is to float independently.

6.3.2 CIJ

There are two sources of capacitance between conductors. The stray capacitances are determined by the throughspace electric fields and geometrical relationships between conductors and are calculated by NASCAP automatically. However, the larger capacitances due to conductors being glued together or separated by dielectric films must be specified by the user. The card:

CIJ k l c

sets this "mechanical connection" capacitance between conductor number k and l to c farads. For example the card:

CIJ 2 3 1.E-8

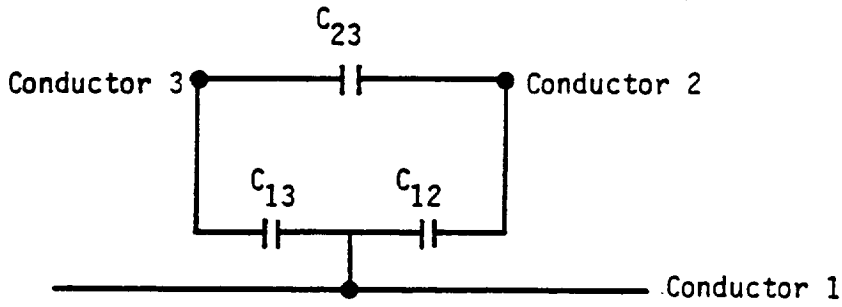
sets the "mechanical" capacitance between conductor 2 and 3 to 1×10^{-8} farads. This value is then added as a parallel capacitance to the stray capacitance already calculated by NASCAP.

The mechanical value usually dominates the stray value. Failure to define the mechanical value may cause differential charging between the two conductors in question to occur unrealistically fast.

When multiple definitions of capacitances are made NASCAP includes implicit as well as explicit connections in its calculation. For example

```
CIJ  1  2  1.E-3
CIJ  1  3  2.E-3
CIJ  2  3  3.E-4
```

defines explicit capacitive connections between conductors 1 and 2, 1 and 3 and 2 and 3. However, 1 is also connected to 3 via 2, and so on. The circuit diagram used by NASCAP has the form:



Stray capacitances are calculated only between the ground conductor (1) and each of the other 14. Stray capacitance between conductors 2 and 3, 3 and 4, etc. are assumed negligible.

6.3.3 DISCHARGE

A discharge analysis, to take place in the LIMCEL (LONGTIMESTEP) phase of a TRILIN timestep, may be requested by the RDOPT input card

```
DISCHARGE d
```

where d is a real number, $0 < d < 1$. This will result in the default discharge analysis, i.e., all four types of discharges may take place

through all space, and all materials will have d as a relaxation factor. Figure 6.1 shows an example of the default discharge parameter specification.

The discharge analysis takes place in the order (1) blowoffs, (2) discharges to space (determined by material property 15), (3) punchthroughs (determined by material property 16) and (4) flashovers. Only one blowoff or discharge to space is allowed per timestep. However, the punchthrough-flashover routine will be called repeatedly until all allowed punchthrough or flashover discharges have taken place.

6.3.3.1 The BLOWOFF Discharge. The BLOWOFF discharge is a new type of discharge incorporated into NASCAP because it is believed to be a common type of small discharge occurring on spacecraft, and having a relatively low threshold voltage. The discharge occurs on a surface which is primarily insulating, but has some exposed conductor. When the insulator is sufficiently positive relative to the conductor, electrons will be accelerated outward from the conductor sufficient to raise the conductor potential to near plasma ground. Also, sufficient electrons will land on nearby insulator to partially discharge it, and electrons will also land on distant portions of the spacecraft.

6.3.3.2 Discharge to Space. Material property 15 (4.3.10) contains the maximum negative potential in volts that any surface covered with that material can reach before charge is blown off into space. On entering the discharge analysis, NASCAP searches for all surface cells with potentials more negative than their property 15 value. The ratio of their potential to property 15 defines the severity of the discharge.

$$\text{Severity of discharge for cell}_i = \frac{\text{potential of cell}_i}{\text{property 15 of cell}_i}$$

```
DISCHARGE .6
END
```

(a) RDOPT input for example 1 (default options).

```
DISCHARGE .6
END
```

(b) RDOPT output for example 1 (default options).

```
DISCHARGE PARAMETERS:

DISCHARGE REGION:     1<X< 17
                      1<Y< 17
                      1<Z< 33
DISCHARGE CATEGORIES:          BLOWOFF-        YES
                               TO SPACE -      YES
                               PUNCHTHROUGH    YES
                               FLASHOVER -     YES
CONDUCTORS:           1-YES     2-YES     3-YES     4-YES     5-YES
                      6-YES     7-YES     8-YES     9-YES    10-YES
                     11-YES    12-YES    13-YES    14-YES    15-YES
MATERIAL      RELAX       BLOWOFF
  ALUM        .600        1.0+005
  KAPT        .600        1.0+005
  TEFL        .600        1.0+005
  GOLD        .600        1.0+005
  SOLA        .600        1.0+005
```

(c) LIMCEL output for example 1 (default options).

Figure 6.1. Discharge specification example 1 (default options).

Starting with the most severe discharge the potential on the cell is reduced to (1 - d) times its property 15 value. The charge lost is assumed blown off into space. Recall that the parameter "d" is included as part of the 'DISCHARGE' card. It gives the fraction of the potential on the surface cell that is lost during the discharge ($0.1 < d < 1.0$).

6.3.3.3 Punchthrough Discharges. The second stage of the analysis is to search for the surface cells with the most severe "punchthrough" possibilities. A "punchthrough" occurs when the potential difference between a dielectric surface and its underlying conductor exceeds the value stored by material property 16. The severity of a punchthrough is given by the ratio of the potential difference to property 16. The punchthrough reduces the surface potential to (1-d) times its property 16 value. The charge is partially blown off and partially redistributed to the conductor and other surfaces. After each punchthrough analysis and each charge redistribution, the cells are searched again for the most severe punchthrough condition and the analysis repeated. This continues until all punchthroughs are resolved.

6.3.3.4 FLASHOVER Discharges. Finally different potentials between neighboring surface cells are scanned for those that exceed the FLASHOVER threshold. This is 10,000 volts by default. It may be adjusted by including the card

'FLASHOVER f'

in the options file, where f is the threshold in volts. The potential difference is reduced to (1-d) of the value f and charge is redistributed to more positive surface cells. (See also Section 6.3.7.)

6.3.3.5 Revising the DISCHARGE Specifications. To revise the discharge parameter specification, use the card

DISCHARGE d lun

where d is a real number as above, and lun is the logical unit from which discharge specifications are to be read. If lun is specified as

less than or equal to zero, specifications will be read from the same options file from which the DISCHARGE card was read.

6.3.3.5.1 The RESTRICT Command. RESTRICT is used to limit discharges either to a particular region of space, in which case it takes the form

RESTRICT xmin xmax ymin ymax zmin zmax

where xmin, etc. are integers, or to a particular conductor, by the form

RESTRICT CONDUCTOR n

The meaning of the space restriction is that only surface cells whose associated volume cells (as denoted by their low-indexed corner) lie within the region are considered as discharge candidates. The space restriction does not apply to discharges occurring on booms.

6.3.3.5.2 The IGNORE Command. The IGNORE command is used to instruct NASCAP to neglect possible discharges of a particular type, on a particular conductor, or on a particular material. The possible forms are

IGNORE BLOWOFF
IGNORE SPACE
IGNORE PUNCHTHROUGH
IGNORE FLASHOVER
IGNORE CONDUCTOR n
IGNORE matl

6.3.3.5.3 Material Commands. Material commands are used to set the BLOWOFF threshold or the relaxation factor for individual materials. Possible forms are

matl IGNORE
matl x bt
matl bt x
matl x
matl bt

where bt is the blowoff threshold (volts, bt > 1) and x is the relaxation factor (0 < x < 1). If x is specified but not bt, bt will be set to 100,000 volts. If bt is specified but not x, x will be set to one-half.

6.3.3.5.4 The END Command. The END command says to ignore subsequent cards (if in a separate file, in which case an EOF condition will accomplish the same thing) or to return to normal option reading (if in the OPTION file).

6.3.3.5.5 The FLASHOVER Option. FLASHOVER continues to be a regular option read by RDOPT, and having the form

FLASHOVER volts

Material-dependent thresholds are not implemented, but the region and conductor restrictions will apply. The relaxation factor will be that specified in the DISCHARGE option card. The default flashover threshold is 10,000 volts.

6.3.3.5.6 Example. The following example (Figure 6.2) illustrates specification of discharge options. Five materials (ALUM, KAPT, TEFL, GOLD, and SOLA) have been defined. (The default options were shown above in Figure 6.2.)

```
DISCHARGE .7 5
IGNORE PUNCHTHROUGH
IGNORE SPACE
RESTRICT CONDUCTOR 2
KAPTON .8
TEFLON 2500
SOLAR 2800 .4
NPAINT  .9 4000
END
END
```

(a) RDOPT input for example 3.

```
          KEYWORD INPUT
DISCHARGE .7 5
IGNORE PUNCHTHROUGH
IGNORE SPACE
RESTRICT CONDUCTOR 2
KAPTON .8
TEFLON 2500
SOLAR 2800 .4
NPAINT  .9 4000
END

  DISCHARGE OPTION SUMMARY
        REGION RESTRICTION:              1<X<  17
                                         1<Y<  17
                                         1<Z<  33

        COND- 1  NO      COND- 2  YES     COND- 3  NO      COND- 4  NO      COND- 5  NO
        COND- 6  NO      COND- 7  NO      COND- 8  NO      COND- 9  NO      COND-10  NO
        COND-11  NO      COND-12  NO      COND-13  NO      COND-14  NO      COND-15  NO

        BLOWOFF ONLY -     YES
        TO SPACE -         NO
        PUNCHTHROUGH -     NO
        FLASHOVER -        YES
        KAPT    FRAC=  .80     BLOWOFF AT  1.00+005VOLTS
        TEFL    FRAC=  .50     BLOWOFF AT  2.50+003VOLTS
        SOLA    FRAC=  .40     BLOWOFF AT  2.80+003VOLTS
        NPAI    FRAC=  .90     BLOWOFF AT  4.00+003VOLTS
END
```

(b) RDOPT output for example 3.

```
***WARNING*** DISFIL - MATERIAL NPAI NOT FOUND.

DISCHARGE PARAMETERS:
       DISCHARGE REGION:     1<X< 17
                             1<Y< 17
                             1<Z< 33
       DISCHARGE CATEGORIES:          BLOWOFF-        YES
                                      TO SPACE -      NO
                                      PUNCHTHROUGH    NO
                                      FLASHOVER -     YES
       CONDUCTORS:           1-NO     2-YES    3-NO     4-NO     5-NO
                             6-NO     7-NO     8-NO     9-NO    10-NO
                            11-NO    12-NO    13-NO    14-NO    15-NO
      MATERIAL      RELAX       BLOWOFF
        ALUM        .700        1.0+005
        KAPT        .800        1.0+005
        TEFL        .500        2.5+003
        GOLD        .700        1.0+005
        SOLA        .400        2.8+003
```

(c) LIMCEL output for example 3.

Figure 6.2. Discharge specification example 3.

6.3.4 EFFCON

The card:

EFFCON ON

activates the photosheath contribution to the surface conductivity. The intrinsic surface conductivity, (material property 14 (4.3.9)) due to the properties of the surface material itself, is automatically included in current calculations. An additional contribution may arise when a dielectric surface emits photoelectrons and their escape is inhibited by a positive electric field. The trajectory of the emitted electron then no longer extends to infinity but instead is turned around and the electron returns to another neighboring surface cell. The magnitude of this so-called "photosheath" conductivity depends on the emitted current and the normal and transverse electric fields.

The default operation (and the card)

EFFCON OFF

cause the photosheath conductivity to be omitted from NASCAP current calculations. Including the effect can cause oscillations in surface cell potentials from cycle to cycle. This undesirable result can often be controlled by reducing DELTA (6.2.2) and/or dvlim (6.2.5). Persistent oscillation can sometimes only be overcome however by abandoning the use of the EFFCON option. In general 'EFFCON ON' should only be used when absolutely necessary, and then with care.

6.3.5 FIXP

The card:

FIXP n v

fixes the potential of conductor #n to v volts. For example

FIXP 4 -6000

sets conductor 4 to a potential of -6000 volts, where it remains, fixed for all future potential calculations. The most common use of this option is to ground conductor 1 in a test tank:

FIXP 1 0.

The default behavior is for all conductors to float freely. (See BIAS, 6.3.1.)

6.3.6 FLDCON

The card:

FLDCON ON

activates the field-induced contribution to the bulk conductivity. The default behavior is to omit this contribution. The card:

FLDCON OFF

does this explicitly. The field-induced contribution to the bulk conductivity is discussed in detail in Chapter 4 (4.8.5).

6.3.7 FLASHOVER

The card:

FLASHOVER f

sets the potential difference threshold for flashover between two charged surfaces to f volts. For example

FLASHOVER 5000

sets the threshold to 5000 volts. The default value is 10,000 volts. Flashover analysis is described in Section 6.3.3.

6.3.8 FLOAT

The card:

FLOAT <cond #>

removes the effect of all previous BIAS's and FIXP's affecting the specified conductor number. For example

FLOAT 4

allows a previously biased or fixed conductor 4 to float freely again. This is necessary because options FIXP and BIAS are remembered from previous calls to RDOPT within the same run. The card:

FLOAT

with no "cond# " causes all previous FIXP and BIAS commands to be cancelled for all conductors; i.e., all conductors float freely.

6.3.9 RADCON

The card:

RADCON ON

activates the radiation-induced contribution to the bulk conductivity for dielectrics. The default behavior is to omit this contribution. Omission may be specified explicitly with the card

RADCON OFF

The radiation-induced conductivity is discussed in detail in Section 4.8.5.

6.3.10 RIJ

NASCAP/GEO now has the capability of treating explicitly specified conduction among the various conducting segments. Inter-conductor resistances are specified in the RDOPT module in a similar manner to interconductor capacitances by the card

RIJ i j r

where i, j are conductor indices, and r is the direct interconductor resistance in ohms. Resistances less than 1Ω will be ignored (i.e., considered infinite).

The RIJ and CIJ keywords differ in that, while the CIJ values have instantaneous effect, changes in interconductor resistance (RIJ) take effect only upon subsequent call to OBJDEF or NEWMAT. Like the CIJ values, all RIJ's are defaulted to zero (i.e., zero conductivity or infinite resistivity) at the beginning of each NASCAP execution, and values are remembered until exit from NASCAP. However, resistivity values processed by OBJDEF or NEWMAT, which are the only values used in actual computation, are remembered from run to run.

Use of very low resistivities to effectively short two conductors together is not recommended.

6.4 RUN OPTIONS THAT DEFINE FEATURES OF THE ENVIRONMENT AND COMPUTATIONAL SPACE

6.4.1 BFIELD

The card:

BFIELD B_x B_y B_z

sets the magnetic field vector in the vicinity of the satellite to B_x, B_y, B_z where the Cartesian components B_x, B_y, B_z are all in Webers m^{-2}. The default is no magnetic field; i.e.,

BFIELD 0 0 0

For example, the card:

BFIELD 1.E-5 1.E-5 0.

describes a field pointing between the positive X and Y axes in the XY plane with magnitude $\sqrt{2} \times 10^{-5}$ W m^{-2} (0.14 gauss).

The module ROTATE rotates the magnetic field direction as well as the sun direction with respect to the satellite (8.2).

6.4.2 CONVEX

The card:

CONVEX

causes the shadowing of surface cells from sunlight to be calculated on the basis of simple self-shadowing only - without calls to HIDCEL (8.1). Self-shadowing assumes that illumination depends only on the angle between the surface normal of a cell and the sun direction θ.

degree of illumination $\propto \cos\theta$.

The default behavior is to demand a call to HIDCEL to determine cell shadowing.

6.4.3 DEBYE

The card:

DEBYE

activates the Debye screening option. The default behavior is to

assume that the space around the object has zero charge density. This is a good approximation for environments with a Debye length λ much greater than a mesh unit XMESH (6.4.15). The Debye length is defined for Maxwellian environments as

$$\lambda = \left(\frac{\varepsilon_o kT}{ne^2} \right)^{1/2} = 7.43 \times 10^3 \left(\frac{\theta}{n} \right)^{1/2}$$

where θ is the plasma temperature (eV) and n is the density (m^{-3}),

or for a double Maxwellian with components 1 and 2:

$$\frac{1}{\lambda^2} = \frac{1}{\lambda_1^2} + \frac{1}{\lambda_2^2}$$

The Debye screening option assumes a charge density ρ linear in the potential ϕ:

$$\frac{\rho}{\varepsilon_o} = - \frac{\phi}{\lambda^2}$$

This is a good approximation when the Debye length λ is between about 2 and 20 mesh units, and the potential is at most comparable to the temperature. It can only be used with single or double Maxwellian plasma spectra (Chapter 5.4).

When the DEBYE option is specified, CAPACI (8.5) must be executed subsequently, before any new calls to TRILIN, since space-charge affects the capacitance of the object to infinity. CAPACI reads the flux definition file in this case.

For environments with λ less than about 2 mesh units spatial oscillations of the potential are likely to occur. NASCAP is not designed for this physical regime and should not be used in these circumstances.

6.4.4 DIPOLE MOMENT

The card:

DIPOLE MOMENT p_x p_y p_z AT x y z

defines a magnetic dipole with moment components p_x, p_y and p_z in A-m^2 located at grid point x y z. For example the card:

DIPOLE MOMENT 0.01 0.0 0.01 AT 5 1 2

defines a moment pointing between the X and Z axes in the XZ plane centered at grid point 5 1 2. The default is no magnetic dipoles present.

Definition of dipole moments is an additional way of specifying the magnetic field on the satellite. (See BFIELD, 6.4.1). The magnetic dipoles are usually derived from part of the satellite.

6.4.5 IOUTER

The parameter IOUTER controls the boundary conditions and may take one of two values. The card:

IOUTER 0

sets the potentials on the boundary of the computational space to zero. This so-called "grounded" outer boundary condition is usually used for TEST TANK runs.

The default behavior and the card:

IOUTER 2

activate "monopole" outer boundary conditions where the boundary potentials are set to be proportionate to 1/r (where r is the distance from the mesh center). The default IOUTER = 2 is usually used for space environment cases.

6.4.6 OFFSET

The card:

OFFSET x y z

changes the origin of the coordinate system from the center of the mesh to 9-x, 9-y, 17-7 (for nz = 33). This works in exactly the same way in the options file as the command 'OFFSET' described in Section 3.9.3 works in the object definition file.

6.4.7 NG

The card:

NG n

sets the number of nested grids in the computational space to be n. The nesting of grids is explained in Section 3.2. While there is no theoretical limit on the number of grids n, practical considerations of storage space and execution time suggest n = 5 as an effective extreme upper limit. The default value of n is 2. One grid may be used if the object does not occupy most of it (i.e., the object on one grid is surrounded by an excess of empty space) and its differential potential does not become very large. Too little computational space causes poor representation of electrostatic fields and barrier effects, but gives greatly enhanced execution speed.

6.4.8 NZ

The card:

NZ 4n + 1

sets the number of mesh units in the Z direction for all grids to 4n + 1; i.e., allowable values are 17, 21, 25, 29, 33. Thirty-three is the maximum value, and the value by default. The dimensions of the grids in the X and Y directions are fixed at 17. For example the card

NZ 17

sets the number of mesh units in the Z direction to 17.

6.4.9 SECONDARYEMISSION

By default, and explicitly with the card:

SECONDARYEMISSION ANGLE

NASCAP calculates the secondary emission yield δ as a function of angle and integrates $\delta(\theta)$ over an appropriate incident flux distribution $f(\theta)$ to obtain the overall yield Δ.

$$\Delta = \int f(\theta)\ \delta(\theta)\ d\theta$$

The card:

SECONDARYEMISSION NORMAL

causes $\delta(\theta)$ to be set to $\delta(0)$, the value for normal incidence while the incident flux is still treated as isotropic, i.e.,

$$\Delta = \delta(0) \int f(\theta)\ d\theta$$

Since the yield is at a minimum for normal incidence this has the effect of suppressing the positive current, and effectively leads to a more "charging" environment (see 4.1).

The ANGLE secondary formulation is the physically correct one and should be used for all realistic charging simulations.

6.4.10 SUNDIR

The card:

SUNDIR x y z

sets the direction from the spacecraft toward the sun. The magnitude is not relevant. For example

SUNDIR 2.0 2.0 0.

sets the direction of the sun between the positive X and Y axes on the XY plane. The default value is 1, 1, 1. The sun direction need only be defined when the object is to be sunlit.

6.4.11 SUNINT

The card:

SUNINT intens

sets the sun intensity as a fraction or multiple of the natural sun intensity one earth distance from the sun. For any earth orbit exposed to the sun this should be 1.0, since orbit altitudes are negligible compared with the distance from the earth to the sun. Sun intensities differing from 1.0 (and 0.0) are used mainly for simulations of test tank experiments using artificial UV sources, or for interplanetary spacecraft. For example

SUNINT 0.6

sets the sun intensity to 0.6 times its natural earth value.

The default value is 0.0.; i.e., the sun is "turned off" and the object is in shadow.

6.4.12 TANK RADIUS AND TANK AXIS

The card:

TANK RADIUS x <METERS>

defines a cylindrical test tank environment with radius x mesh units or meters. If the word "METERS" is explicitly included on the card RDOPT assumes that x is in meters. If "METERS" is absent it assumes that x is in mesh units.

The orientation of the tank by default is with its cylindrical axis along the Z direction. The other two axis directions may be chosen as the axis by including a card of the form:

TANK AXIS a

where a is X Y or Z

The height of the cylindrical tank is given by the dimensions of the computational space in the axis direction. For example if Z is the direction of the tank axis and NZ (6.4.8) is chosen to be 25, and

the number of grids (NG) (6.4.7) is chosen to be 2, then the cylinder will be 25 outer mesh units long or 25x2xXMESH meters (see 6.4.15 for XMESH). The cylindrical tank is compatible with the ZTRUNCATE option.

The circular cross-section of the cylinder may lie outside the computational space, but this leads to its truncation (Figure 6.3), eventually becoming rectangular once more.

Specification of a cylindrical tank automatically sets IOUTER (6.4.5) to 0. In potential contour plots the tank walls are represented by a double (blue) line.

6.4.13 TYPE

The cards

TYPE 6 or TYPE 1

are used to specify a TEST TANK environment, and must be included in the options file when using the TANK module (5.9). The TYPE must be specified as 2 or 3 when using the DETECT module, and 2 or 4 when using the DEBYE option.

6.4.14 UPDATE

The card:

UPDATE ON

activates the UPDATE feature. UPDATE allows NASCAP to automatically select the most recent environment, from a list provided by the user, as the time elapses from cycle to cycle. This is explained in detail in Section 5.6. The default behavior is to operate without the UPDATE feature activated. The same effect is brought about with the card:

UPDATE OFF

6.4.15 XMESH

The card:

XMESH n

sets the size of one inner mesh unit (see Section 3.2) to n meters.

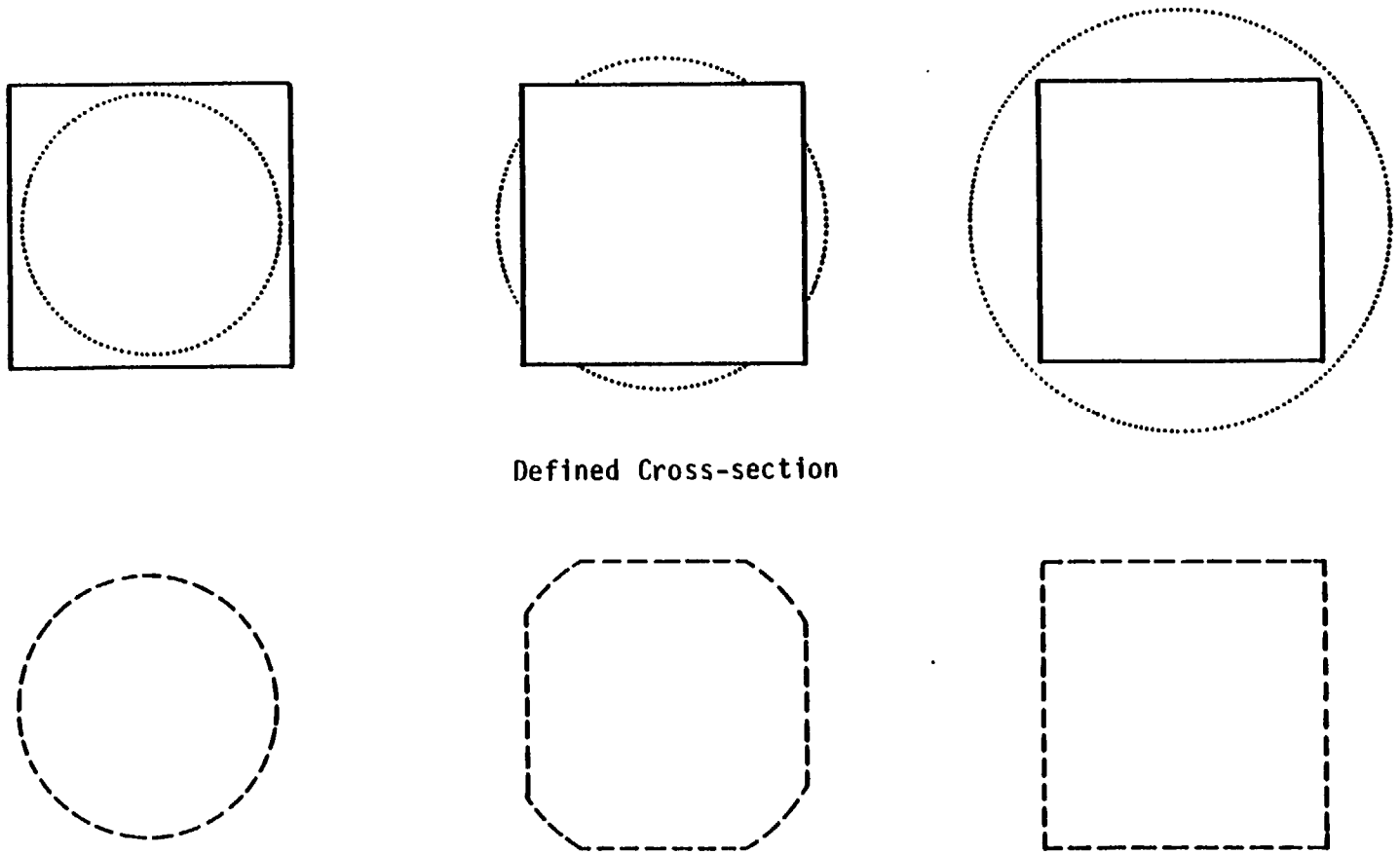


Figure 6.3. Cross-section of a cylindrical tank compared with the computational space.

For example

XMESH 0.2

sets the inner mesh unit to 0.2 m. Thus a computational space consisting of two nested 17 x 17 x 33 grids will be 17 x 2 x 0.2 = 6.8 meters wide in the X and Y direction and 33 x 2 x 0.2 = 13.6 meters wide in the Z direction.

The default value is 0.1 m.

6.4.16 ZTRUNCATE

The card:

ZTRUNCATE zlo zhi

allows the user to select the beginning and ending coordinates for the outermost grid in the Z direction. The coordinate system used is the default (with the center at 0 0 0) or the one defined by the latest 'OFFSET' card (6.4.6).

For example

ZTRUNCATE -15 10

defines the outer grid to run from Z = -15 (instead of Z = -16) to Z = 10 (instead of Z = 16). The outer grid must always include outermost but one. For example grid #2 extends from -8 to +8 in grid #3 units, then grid #3 can only be truncated to a minimum of ±8.

ZTRUNCATE -7, 10

for example puts one boundary of grid #3 inside the boundary of grid #2. This is illegal.

ZTRUNCATE is particularly useful for defining the walls of a test tank. Note that it differs from NZ (6.4.8) in that

1. only the outer grid is truncated.
2. the grid may be truncated asymmetrically.

The default is to leave a full NZ length outer grid.

6.5 RUN OPTIONS THAT CONTROL PRINTED OUTPUT

6.5.1 APRT

As part of its printed output NASCAP may tabulate the final potential array (i.e., the potentials at each grid point) after each TRILIN call. The card:

APRT n

gives the number of grids for which potentials are printed out. The default is 1, i.e., potentials are printed for just the inner grid. Potentials may be printed for all the grids requested, or for none, using this command. For example

APRT 3

will cause potential arrays to be printed out for all three grids in a three grid problem, or just the innermost three grids in a 4 or more grid problem.

6.5.2. CONVERGENCE PLOTS

The card:

CONVERGENCE PLOTS ON

causes a printer plot of the square of the residual vector $(\vec{r} \cdot \vec{r})$ for each iteration to be produced after each cycle. The residual vector $\vec{r}$ is explained in Section 3.15.1 dealing with the conjugate gradient potential solver. The default is not to print the plot. This result is also achieved with the card:

CONVERGENCE PLOTS OFF

The convergence plots are only useful as a diagnostic tool, to check the conjugate gradient potential solver as working correctly. Problems in this respect are sometimes solved by increasing the maximum number of iterations using POTCON (6.2.8).

6.5.3 PRINT/NOPRINT

The card:

PRINT <(sub)module>

causes diagnostic information to be printed out during each call to the module or submodule requested. The following four (sub)modules may be printed:

HIDCEL

OBJDEF

LIMCEL (called when LONGTIMESTEP is requested - 6.2.6)

POTENT (potential solver called from CAPACI and TRILIN)

The default mode is not to print messages, except for OBJDEF, which has an intermediate level of print, from a module unless specifically requested with a PRINT card. For example

PRINT LIMCEL

causes diagnostic information to be printed on calls to TRILIN when LONGTIMESTEP has been requested (6.2.6). PRINT's can be explicitly turned off with the card:

NOPRINT <(sub)module>

For example

NOPRINT LIMCEL

cancels a previously requested PRINT LIMCEL. The information printed out is for diagnostic purposes only and is not needed for the usual operation of the code. Warning: The HIDCEL module is capable of producing an extremely large volume of diagnostic information.

6.5.4 SURFACE CELL

In Section 3.10 we discuss how each exposed face of a filled volume element, or surface cell, is assigned a surface cell number n. The card:

SURFACE CELL n

causes a breakdown of the net flux to surface cell number n to be printed after each cycle. Contributions from incident primary fluxes,

secondary emission, backscatter and conductivity, as well as information about the surface cell itself are printed out. The format of the breakdown is shown in Figure 6.4. A card is required for each surface cell to be printed. The default when no surface cell card is included in the options file is to print a breakdown for cell #1 only.

6.5.5 SURFACE CORNER AND SURFACE AT

The same flux breakdown that is printed when a SURFACE CELL card is included in the options file (Figure 6.4) can also be printed using the

SURFACE CORNER x y z <norx nory norz>

card. Instead of referring to the cell according to its NASCAP assigned number (as in the case with SURFACE CELL), SURFACE CORNER refers to the cell by the coordinates of the lowest indexed corner (x y z) of its associated volume cell, and where this still does not uniquely determine it, the direction of its surface normal (norx, nory, norz). The lowest indexed corner is the one with the least positive sum of coordinates X +Y +Z. The associated volume cell is the cell in which it is located, or out of which it points.

For example, consider a cube extending one mesh unit in the positive direction from -1 -1 -1. The bottom face in the X Y plane has vertices:

```
-1  -1  -1
 0  -1  -1
-1   0  -1
 0   0  -1
```

The lowest indexed vertex -1 -1 -1 has a sum = -3. However two other faces in the XZ and YZ planes also share this lowest indexed vertex. To uniquely determine the XY face we must also specify its normal, which points in the -Z direction; i.e.,

norx, nory, norz ≡ 0 0 -1

A flux breakdown for the bottom X Y cell is requested with the card:

SURFACE CORNER -1 -1 -1 0 0 -1

```
SURFACE CELL NO.  28                                    CODE =        004612210403
                                                        LOCATION =     6 10 17
                                                        NORMAL =       0  1  0
                                                        MATERIAL =  KAPT
                        POTENTIAL = -3.071+003 VOLTS
                        STRESS =  1.114+006 VOLTS/METER
                        EXTERNAL FIELD =  2.344+002 VOLTS/METER
                        LIMITING FACTOR =   9.598-002
FLUXES IN A/M**2
      INCIDENT ELECTRONS                    1.23-006
            RESULTING SECONDARIES           5.07-008      [  5.28-007]
            RESULTING BACKSCATTER           3.25-007
      INCIDENT PROTONS                      5.55-008
            RESULTING SECONDARIES           1.16-008      [  1.21-007]
      BULK CONDUCTIVITY                     1.11-010
      PHOTOCURRENT                          1.36-006      [  1.41-005]
                                            ----------
   NET FLUX                                 5.67-007
```

Figure 6.4. Flux breakdown for SURFACE CELL 28.

The coordinate system used by SURFACE CORNER is either the default system (region at mesh center) or the one defined by the most recent OFFSET card (6.4.6). SURFACE CORNER cannot be used until the object has been defined. Since RDOPT always precedes a call to OBJDEF this means that SURFACE CORNER can only be used in subsequent calls to RDOPT (perhaps in a RESTART run).

SURFACE AT is the same as SURFACE CORNER except that it uses the absolute coordinates option (See 5.8.1).

6.5.6 TIMER/NOTIME

The card:

```
TIMER
```

included in the options file causes the computer time left for the NASCAP run to be printed out after each significant step in the calculation. For example, if 400 seconds were requested for the run (using the job control language of the machine running the code) the messages like:

```
TIME LEFT  398
TIME LEFT  372
```

etc., would be printed out periodically as the run progresses. NASCAP (UNIVAC version) will not begin another TRILIN cycle when the time left is less than 300 seconds. The 300 seconds allow NASCAP to finish the cycle it is on and save all files cleanly before run time actually expires completely. Run time checks (for smaller amounts of time) also occur in the HIDCEL module (and the POTENT submodule). NASCAP (UNIVAC version) should always be run with at least ten minutes of time requested.

The default behavior, and the card:

```
NOTIME
```

suppress the printing of the TIME LEFT messages.

6.6 RUN OPTIONS THAT CONTROL GRAPHICAL OUTPUT

6.6.1 3D-VIEW

The card:

```
3D-VIEW x y z
```

adds an additional perspective view to the three views of the object usually plotted by SATPLT (8.7). The coordinates x y z give the point from where object is to be observed. Up to five views may be produced by each call to SATPLT. By default the following sequence of four cards is assumed:

```
3D-VIEW  NONE
3D-VIEW   5   8   -5
3D-VIEW  -5   8    5
3D-VIEW   2  -5    5
```

This establishes the three default views usually produced by SATPLT. The card:

```
3D-VIEW NONE
```

clears all previous view entries. This card can be used in the options file to cancel the three default views. The user may then specify up to five of his own views. If no '3D-VIEW NONE' card precedes declaration of additional views, then a maximum of two may be added to the three already there. The authors recommend directions such as '1 2 3' as tending to produce aesthetically pleasing views of NASCAP object.

6.6.2 CONTOURS

NASCAP can produce potential contour plots after completed cycles using the CONTOURS command. The default behavior is not to plot any potential contours. The card:

```
CONTOURS STANDARD
```

causes six standard contour plots to be produced every cycle. Plots may be made for any plane parallel to an axis plane in any grid. Up

to 14 specific plots may be requested with cards of the form:

$$\text{CONTOURS} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \text{cut \# <GRIDS ng MOD n>}$$

The X Y and Z refer to the direction of the normal to the plane in which the contours are to be plotted, and "cut# " refers to the grid point along this direction, through which the plane passes. For example, the card:

```
CONTOURS Y  6
```

chooses a plot of contours in the X Z plane passing through the point 0 6 0, i.e., a plane cutting the Y axis at point Y = 6. Since 'GRIDS' and 'MOD' are omitted, plotting occurs including all the space to the outermost grid and the plots will be produced every cycle (n = 1).

The optional keyword 'GRIDS' is used to specify the number of grids to include in the plot. The keyword 'MOD' means "produce a plot every n cycles". For example

```
CONTOURS Y  6  GRIDS  1  MOD 5
```

would produce a contour plot for the plane cutting the Y axis at Y = 6 including only the inner grid, every five cycles.

A specifically requested contour plot may be turned off with the card:

$$\text{CONTOURS} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \text{cut\# OFF}$$

For example the above plot can be turned off using

```
CONTOURS Y  6  OFF
```

Note that all coordinates are in inner mesh units, and refer either to the default origin (grid center) or the one defined by the latest OFFSET (6.4.6).

The 'CONTOURS STANDARD' command is equivalent to the following sequence:

```
CONTOURS  X  0  GRIDS 1   MOD 1
CONTOURS  X  0  GRIDS ng  MOD 1
CONTOURS  Y  0  GRIDS 1   MOD 1
CONTOURS  Y  0  GRIDS ng  MOD 1
CONTOURS  Z  0  GRIDS 1   MOD 1
CONTOURS  Z  0  GRIDS ng  MOD 1
```

(where ng ≡ outermost grid).

The MOD number may be controlled by the user independently with the command:

```
CONTOURS STANDARD <MOD n>
```

For example:

```
CONTOURS STANDARD MOD 5
```

will produce the same standard six contours given above every five cycles instead of every cycle.

6.6.3 DESTINATION

The card:

```
DESTINATION dest
```

establishes the destination device for the NASCAP produced plots, such as a graphics terminal, electrostatic printer, microfiche, etc. The options 'dest' are site dependent and should be determined during installation of the code. At S-Cubed the active values for 'dest' are:

```
NONE   - user input at run time requested (default)
COMPRS - written to file 41 (may be processed later)
CALC   - the CALCOMP plotter
TEKT   - the Tektronix graphics terminal
ELEC   - electrostatic plotter
```

The mechanics of NASCAP plotting are discussed in Chapter 9.

6.6.4 MATVIEW

Module SATPLT (8.7) also produces plots showing the pattern of the different surface materials covering the satellite. The card:

$$\text{MATVIEW} \pm \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \text{cuta cutb}$$

can be included in the options file to add different views for material plots to those already selected by default. The 'X Y Z' selects the direction from which the object is to be viewed. Cuta and cutb give the coordinates (inner grid) of the observer and how far he can see along the axis chosen. For example:

```
MATVIEW  -X  -4  10
```

selects a view from the negative X direction with the observer at X = -4 and includes all surfaces between the observer and X = 10. The card:

```
MATVIEW  +X  -4  10
```

selects a view from the positive X direction with the observer at X = 10 and includes surfaces between the observer and X = -4.

The default selection of views is equivalent to the cards:

```
MATVIEW  NONE
MATVIEW  +X   -8    8
MATVIEW  -X   -8    8
MATVIEW  +Y   -8    8
MATVIEW  -Y   -8    8
MATVIEW  +Z   -16   16
MATVIEW  -Z   -16   16
```

The card:

```
MATVIEW NONE
```

cancels all previous view selections, including the six initially specified by default. Up to five views may be chosen for each of the six possible directions.

The coordinate system used is the default grid centered one (in inner grid units) or the most recent one defined by an 'OFFSET' card (6.4.6).

6.6.5 REPEAT

The card:

```
REPEAT n
```

causes any plot to be repeated n times. The default is to make each plot just once. This feature is not general and is hardware dependent. It should be used only on sites where it is known to be implemented (e.g., NASA/Lewis).

6.6.6 SHEATH

The card:

```
SHEATH
```

activates the option that causes plots of particle trajectories and charge densities around the spacecraft to be plotted for space environments (5.4). The default behavior is not to calculate or plot these quantities. The same effect is explicitly brought about with the card:

```
NOSHEATH
```

6.6.7 TANKCUR

The card:

```
TANKCUR ON
```

causes a contour plot of current density to be produced for TEST TANK-1 runs (5.8). The default behavior is not to plot this quantity. The same effect is brought about with the card:

```
TANKCUR OFF
```

6.6.8 TANKTRAJ

TANKTRAJ ON and TANKTRAJ OFF are exactly analogous to the TANKCUR commands explained in 6.6.7. TANKTRAJ refers to particle trajectory plots in a TEST TANK-1 case, rather than current density.

6.6.9 TITLE

The card:

```
TITLE title
```

causes a user specified title to appear in the first frame plotted, along with the date and time of the NASCAP run. The default title is

```
NASCAP
```

The 'title' must begin in column 9. For example the card:

```
TITLE  STAN'S TANK RUN
       ↑ column 9
```

will cause the phrase

```
'STAN'S TANK RUN'
```

to replace 'NASCAP' in the first plot frame.

6.7 OPTIONS DEFINING LOGICAL UNIT NUMBERS

The default values for the logical unit numbers of the NASCAP files are shown in Tables 2.3 and 2.4. These file numbers can be changed to other values by including cards in the run options file of the form

```
filename number
```

For example the logical unit number of file IKEYWD may be changed from the default value of 26 to 46 with the card:

```
IKEYWD  46
```

The other file names shown in Table 6.7 can be used in a similar way. Some examples are:

```
IP      48
ISPCTR  23
IPART   42
```

6.8 OPTION CHECKLIST

The large number of NASCAP options described in this chapter is enough to befuddle even an experienced user. Clearly, some are of more importance than others. For this reason, we have divided them into four categories by frequency of use. These are shown in Table 6.8.

The "most commonly used" options should be familiar even to a beginning user. We suggest that (with the obvious exception of RESTART) they always appear in the options file, even though the defaults may be acceptable.

The "other commonly used options" control output or commonly encountered aspects of charging problems.

The "less commonly used options" are for diagnostic purposes, or require care in use, or are relatively specialized.

The "rarely used options" are those which have acceptable defaults, or serve to restore defaults, or are nearly obsolete.

Options considered totally obsolete, even though still functional, have been omitted from this manual.

TABLE 6.8A. MOST COMMONLY USED OPTIONS

DELTA

END

IOUTER

LONGTIMESTEP/NOLONGTIMESTEP

NCYC

NG

NZ

RESTART

TIMER

TYPE

XMESH

TABLE 6.8B. OTHER COMMONLY USED OPTIONS

3D-VIEW

BFIELD

BIAS

CIJ

CONTOURS

CONVEX

DESTINATION

FIXP

SUNDIR

SUNINT

SURFACE AT

SURFACE CELL

SURFACE CORNER

TANK AXIS

TANKCUR

TANK RADIUS

TANKTRAJ

TITLE

ZTRUNCATE

TABLE 6.8C. LESS COMMONLY USED OPTIONS

APRT

DEADLINE

DEBYE

DELFAC

DIPOLE MOMENT

DISCHARGE

EFFCON

EMITTER

FLASHOVER

FLDCON

IFLUX

MATVIEW

NOPRINT

OFFSET

PRINT

RADCON

RIJ

SECONDARY EMISSION

SHEATH

UPDATE

TABLE 6.8D. RARELY USED OPTIONS

CONVERGENCE PLOTS

FLOAT

IAREA

IAUN

ICNOW

IDIV

IKEYWD

IOBJ

IOBPLT

IP

IPART

IPQCND

IR

IROUS

ISAT

ISPARE

ISPCTR

IU

NOEMITTER

NOSHEATH

NOTIMER

REPEAT

SCALE/NOSCALE/DSCALE

7. NASCAP PARTICLE TRACKING

7.1 INTRODUCTION

NASCAP calculates particle trajectories in order to simulate particle emitters and detectors, electron guns (TYPE 1 Test Tank), and to calculate space charge density (SHEATH option). In the case of particle detectors, particles incident upon a particular surface cell are backtracked to determine their origin. This allows a statistical estimate of the arriving current as a function of parameters such as incident energy and angle of incidence. Unlike particle detectors, emission affects the object potential since a new source of current is introduced. The emitted current is taken into account in this respect. Emitted particle trajectories are calculated by NASCAP, and the trajectory plots produced can be used to estimate the emitted current returning to the spacecraft. NASCAP includes both emitted and return current in its potential calculations.

The detector simulation is activated by executing the module DETECT. The particle emitter simulation is activated by including the keyword 'EMITTER' in the run options file (6.2.4). Examples of the other two uses of particle tracking may be found elsewhere in this volume. Let's begin by discussing the DETECT module.

7.2 DETECT

7.2.1 OVERVIEW

The DETECT module calculates and plots incident energy flux density as a function of incident energy and direction for both ions and electrons. The energy flux density is the quantity actually measured by spacecraft particle detector experiments. It is a measure of the number of particles collected per second, times their energy (i.e., the incident current weighted by the energy of the incident particles).

NASCAP considers a detector to reside on a given surface cell. The range of incident energy and incident solid angle of the incoming particles that the detector is able to measure, is chosen by the user. DETECT then calculates the energy flux density arriving within a cone about the direction chosen, and within the energy range chosen. It takes into account deflection of the particles by electric fields due to charging on the object, deflection by magnetic fields, and "mechanical" deflection. "Mechanical" deflection occurs when a particle that would have reached the detector otherwise, collides with another piece of the spacecraft obstructing the view.

A typical field of view for a detector is shown in Figure 7.1. Particles are assumed to be collected if they arrive within a cone about the incident direction chosen. The width of the cone is given by $\Delta\theta$ (Figure 7.1). ϕ gives the azimuthal angle of the incident direction about the surface normal. The angle θ is the angle between the incident direction and the surface normal of the cell chosen as the position of the detector. The integrated energy flux (i.e., the total collected by the whole cone) is calculated. Plots of differential energy flux as a function of any one of the three variables incident energy, θ and ϕ, may be requested. (One variable becomes the plot abscissa while the other two are held fixed.)

DETECT is used to simulate the operation of particle detector experiments under spaceflight conditions, when the spacecraft is charged. It is also useful in investigating focussing and deflection effects due to charging of the spacecraft in general.

7.2.2. EXECUTION OF DETECT

The module DETECT must be preceded by execution of TRILIN or IPS since they both establish potentials on the surface of the spacecraft. (Exact precedence is summarized in Table 2.2.). DETECT is executed by including the card:

```
DETECT    <n>
```

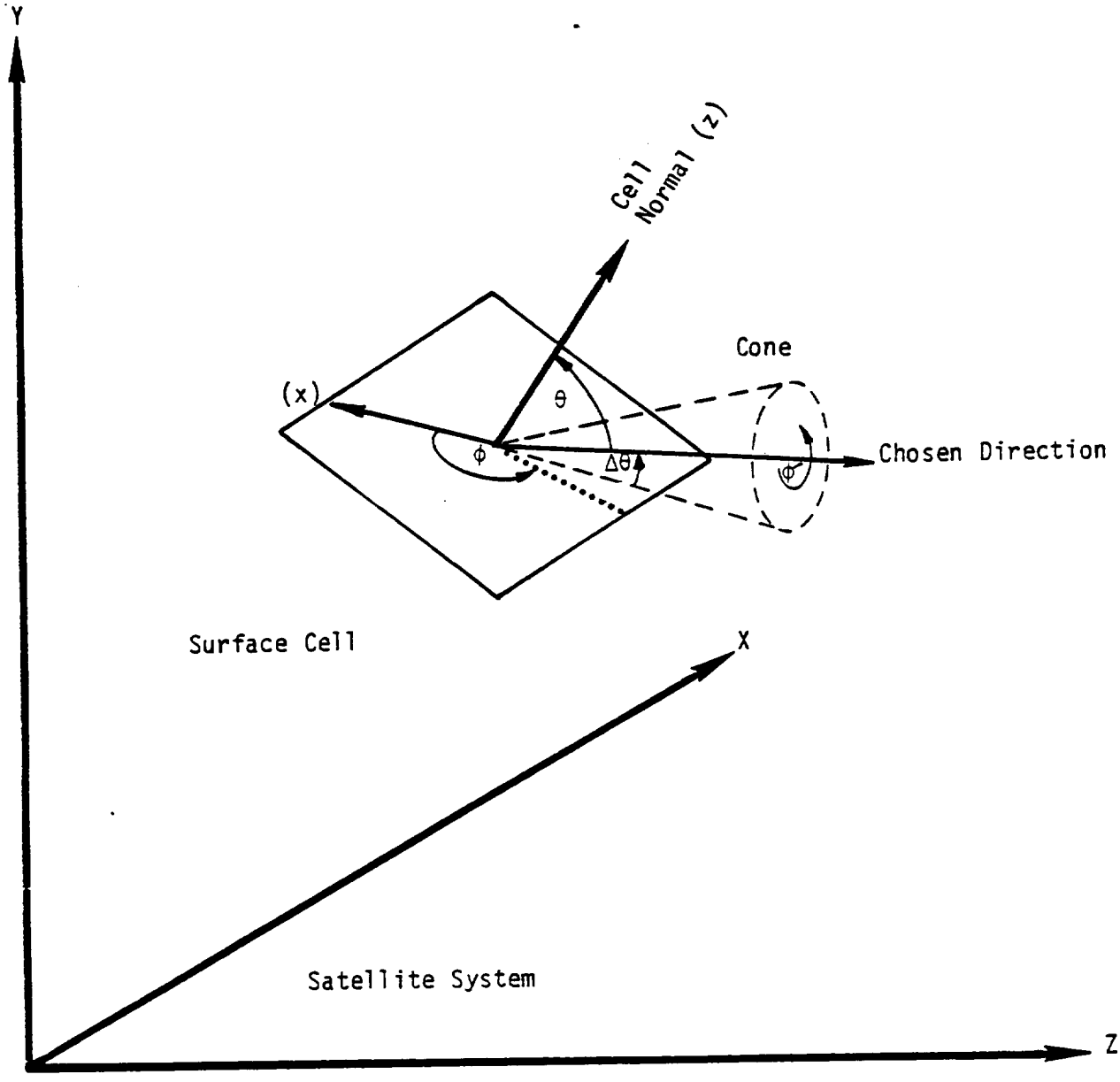


Figure 7.1. Typical field of view for a Detector.

in the NASCAP runstream. The optional parameter n specifies the number of the file where DETECT is to look for input. The default value of n is 5, in which case DETECT expects its input cards to follow immediately in the runstream. DETECT input must be terminated with its own 'END' card, whether it resides in file n or the NASCAP runstream. If DETECT is the last module to be executed in a NASCAP run this means that two 'END' cards are necessary to terminate the runstream: one for the DETECT file and one for the whole runstream (2.4). For example, a runstream might end as follows:

```
                    .
                    .
                    .
                    TRILIN

                    DETECT

DETECT              {    {DETECT
INPUT               {    {INPUT
FILE                {    {CARDS

                    END

                    END
                     .
                     .
                     .
```

The DETECT input cards can be classified into three groups according to their function:

(1) Definition of detector location and orientation.
(2) Control of the particle tracking and current integration.
(3) Control of plots produced.

We examine each of these functions in the following three sections.

7.2.3 DEFINITION OF THE DETECTOR

The detector may lie on the plane of any surface cell. It collects particles arriving within a cone about a chosen direction.

(This is shown in Figure 7.1). The choice of surface cell, incident direction and the width of the cone are all specified using keywords in a DETECT input file. The energy range of the incoming particles that are detected may also be chosen in this way.

Direction is specified using a cell-based polar coordinate system. In this system the surface normal defines the +Z axis. The X and Y axes lie in the surface plane. The X axis is chosen to lie on top of the projection of the surface normal in the XY plane of the computational grid, i.e., the projection of the surface X axis and the surface normal on the grid XY plane are coincident. Direction in this surface cell system is determined by the polar coordinates θ and ϕ. θ is the angle between the normal (the Z axis) and the direction vector. ϕ is the angle between the X axis and projection of the direction vector on the surface plane in a counterclockwise sense. For example, a 1 1 1 vector in this system would point between the positive axes and have coordinates $\theta = 45^\circ$ and $\phi = 45^\circ$. The Y axis has coordinate $\theta = 90^\circ$ and $\phi = 90^\circ$.

The cone about the direction vector is defined by the half-angle, or width, $\Delta\theta$.

The keywords that determine these quantities have the following syntax.

7.2.3.1 DETECT

The detector input file must begin with the card

DETECT

This tells the DETECT module that a new detector definition is to follow.

More than one detector can be defined within a DETECT input file. A new detector is specified by including another DETECT card.

All input cards following one DETECT are assumed to refer to that detector until another DETECT card is encountered. For example, a DETECT input file defining multiple detectors might have the form:

```
      .
      .
      .
DETECT

    { PARAMETERS FOR
    { FIRST DETECTOR

DETECT

    { PARAMETERS FOR
    { SECOND DETECTOR

DETECT

    { PARAMETERS FOR
    { THIRD DETECTOR

END
.
.
.
```

Note that more than one detector may be defined for the same surface cell (pointing in perpendicular directions for example).

7.2.3.2 ICELL

The location of the detector is set with the card:

ICELL n

The parameter n gives the surface cell number where the detector is to reside. If no ICELL card is included before the other input cards it is assumed to reside on surface cell number one by default.

Detectors on boom cells are allowed but require special treatment. This is explained in Section 7.2.4 Note that boom cells follow surface cells, i.e., an object with 158 surface cells and 13 boom cells will have boom cells numbered 159-171.

7.2.2.3 ENERGY

The detector collects particles with energy in the range from E to E + ΔE. The energy E is defined with the card

ENERGY E

where E is in eV. For example,

ENERGY 2000

will set E to 2 keV. The default value assumed if no ENERGY card is included is 10 eV.

7.2.3.4 DEK

The energy accepting "width" of the detector ΔE is determined by the value of DEK.

$$\Delta E = E \times \left(\frac{DEK}{100}\right)$$

DEK is the percentage of E equal to ΔE. It is set with the card

DEK d

The default value is 0. For example, if E were set at 2 eV and DEK at 10:

ENERGY 2000
DEK 10

then the detector would collect particles with energies in the range 2000-2200 eV.

7.2.3.5 THETA

The detector collects particles that fall within a cone around a chosen direction. This direction is determined by its polar coordinates ϕ and θ, in the surface cell system described in 7.2.3. THETA (θ) is the angle between the chosen direction and the surface normal. It is set with the card:

THETA θ

θ must be in degrees and lie between $\pm$ 90. The default value is 0 (i.e., along the surface normal).

7.2.3.6 DTH

The aperture, or width of the cone about the chosen direction of the detector is determined by its half angle $\Delta\theta$. This is set with the card

DTH $\Delta\theta$

$\Delta\theta$ may range from 0 to 90°. The default value is 0. For example:

DTH 8

sets $\Delta\theta$ to 8°.

7.2.3.7 PHI

The angle θ does not uniquely define the chosen direction. One more angle is required. The angle ϕ is the angle between the projection of the chosen direction in the surface cell plane and the X axis of the surface coordinate system (in the counterclockwise sense). (See 7.2.3). This is set with the card

PHI ϕ

where ϕ is in degrees and may take values from 0 to 360°. The default is 0 (i.e., the chosen direction lies in the XZ plane of the surface system).

7.2.4 BOOM DETECTORS (ZETA)

Detectors are placed on booms in just the same way as other cells. They are assumed to lie at the center of the boom segment or cell specified. Since the surface of the boom is cylindrical there is no unique direction for the surface normal, and hence no unique surface cell coordinate system. This problem is overcome by defining the angle between the projection of the chosen boom surface normal and a grid axis, in the grid plane perpendicular to the boom. For example, if the boom lies along the grid Z axis the projection of the boom-normal

is in the grid XY plane, and the angle ζ(Zeta) is measured from the grid X axis. This is shown in Figure 7.2. For booms along the other axis, the labels are cyclicly permuted.

The angle zeta is set using the card

ZETA ζ

The default value of zeta is 0. For example:

ZETA 25

sets ζ to 25°. If the detector is not on a boom cell, ZETA is ignored.

7.2.5 CONTROL OF PARTICLE TRACKING AND CURRENT INTEGRATION

The particle tracking algorithm moves the particles in steps. The number of steps included in the trajectory calculation is chosen by the user as 'NSTP'. Each step is designed to move each particle the same distance. Thus faster moving (higher energy) particles have shorter times associated with each step. The distance associated with the steps is determined by the "code velocity" VCODE. The greater VCODE the greater the distance associated with each step.

It is important that the particles tracked from the detector move far enough to be able to reach at least the boundary of the inner grid. The choice of NSTP and VCODE should be made with this in mind. In general, the larger VCODE, the smaller NSTP may be while still allowing the particles to reach the boundary, (since the distance associated with each step is greater). However, as the step distance increases the accuracy of the calculation is decreased. Hence, there is a trade off between the number of steps (computation time) and accuracy. A good compromise can usually be made by choosing VCODE and NSTP so that particles reach the boundary in a few hundred steps.

To calculate the integrated current arriving at the detector in the range of energy and direction selected during its definition, particles must be tracked for a sample of values of E, θ and ϕ. The number of samples taken over the energy range and the range of θ

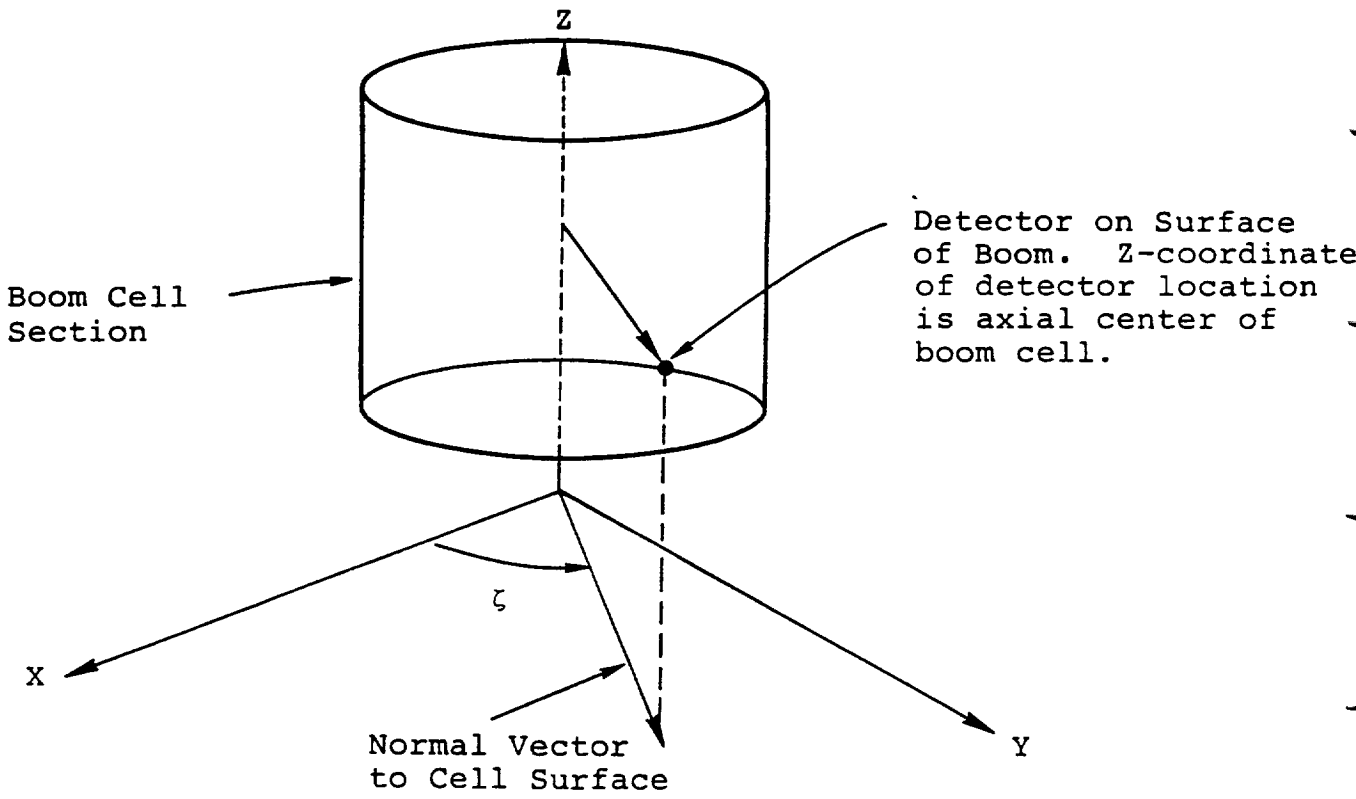


Figure 7.2. Boom cell coordinate system.

and ϕ are specified by the user. Each new combination causes another particle to be tracked. If the number of samples to be taken in all three variables is chosen to be 10, then all 10 x 10 x 10 = 1000 combinations must be tracked. The larger the number of samples chosen the more accurate are the integrated currents calculated, but the computational effort is greatly increased.

To understand these principles more clearly, let's examine the ways the variables we have discussed are controlled.

7.2.5.1 NSTP

The number of steps to be taken for each particle in reverse trajectory calculations is set with the card:

NSTP n

n can take values from 1 to 30,000. The default value of 500 is a reasonable choice for tracking inside the inner grid. If particles are to be tracked out to further grids at least 400 more steps should be added for each extra grid. For example, if tracking is to occur out to the third grid NSTP might be set to 1300.

NSTP 1300

These values assume a value of VCODE of around 0.3 (the default).

7.2.5.2 VCODE

The particle code velocity or distance moved in inner grid units per step is set with the card

VCODE v

The default value is 0.3 (i.e., 3 steps move a particle approximately 1 grid unit). This is a safe value to use in most applications.

For a detector on a boom in grid number IG this is automatically scaled by the mesh size $2^{(IG-1)}$.

7.2.5.3 NE

The number of points sampled over the energy range $E \rightarrow E + \Delta E$ (7.2.3) is set with the card:

NE n

n may take the value 1 or any even value up to 12. The default value is 1. For example the following cards

ENERGY 2000
DEK 10
NE 4

set the energy range to 2000-2200 eV. Four representative energies are sampled within this range. If NE is 1, the (single) sample energy is chosen equal to E.

7.2.5.4 NMU2

NMU2 sets the number of points sampled over the width of the detector cone (over $\Delta\theta$).

NMU2 n

n may take any positive value. The default is 1. For example:

NMU2 10

sets the number of samples over $\Delta\theta$ to 10.

7.2.5.5 NP

The number of points taken around the perimeter of the cone is set with the card

NP n

This breaks up the interval of the azimuthal angle ϕ' in the detector coordinate system from 360° to 360°/n. The default value of n is 1, in which case ϕ' is chosen to be 0. (See Figure 7.1 for definition of ϕ'.)

7.2.6 CONTROL OF PLOTS

Two types of DETECT plots are produced: plots of energy flux density against one of the variables E, θ and ϕ, and particle trajectories.

The variable E, θ, or ϕ, chosen for the plot of energy flux density is called the Independent Variable. The range of the independent variable and the number of points plotted are also selected by the user.

Plots are made for both ions and electrons on the same graph. The scales and pen-type can all be set by the user independently, or chosen automatically using the AUTOS option.

Particle trajectory plots show a silhouette of the spacecraft and lines representing the path of each of the particles tracked. For each request, views in each of the three grid axis planes are plotted for both electrons and ions (i.e,, a total of six plots). Trajectory plots may be made in more than one grid, and in more grids than were actually included in the potential calculation in the first place (NG). This is to allow for the effect of large radius curved trajectories induced by magnetic fields. The potential v in the grids outside the outer computational grid is assumed to be derived from a monopole at the object center with charge q (equal to the total charge on the object) i.e.,

$$v = \frac{q}{4\pi\varepsilon_0 r}$$

where r is the distance from the object center.

Examples of both types of plot are given in Figures 7.3 and 7.4.

Let's examine the remaining DETECT input cards that control the plots.

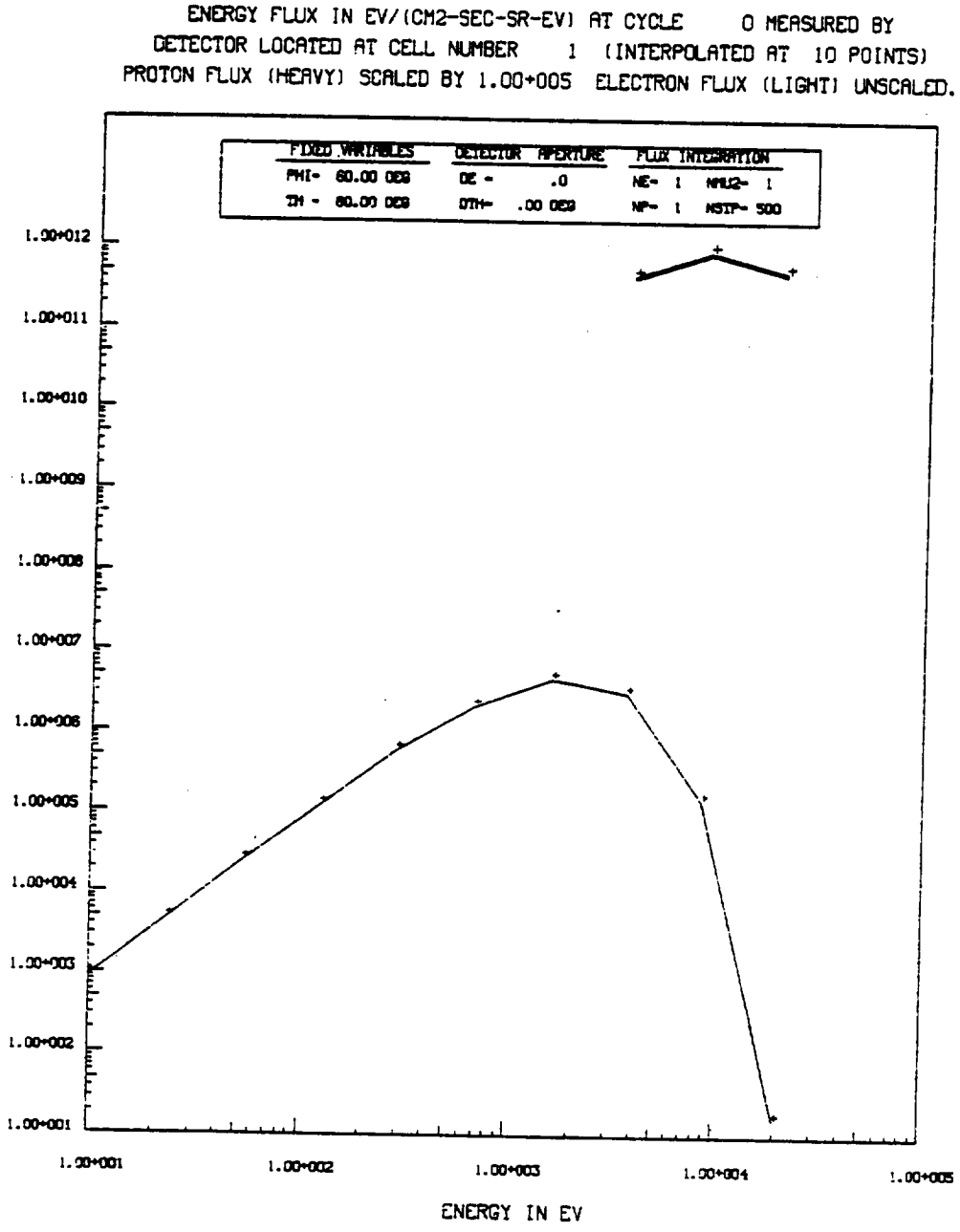


Figure 7.3. Detector energy flux vs energy plot.

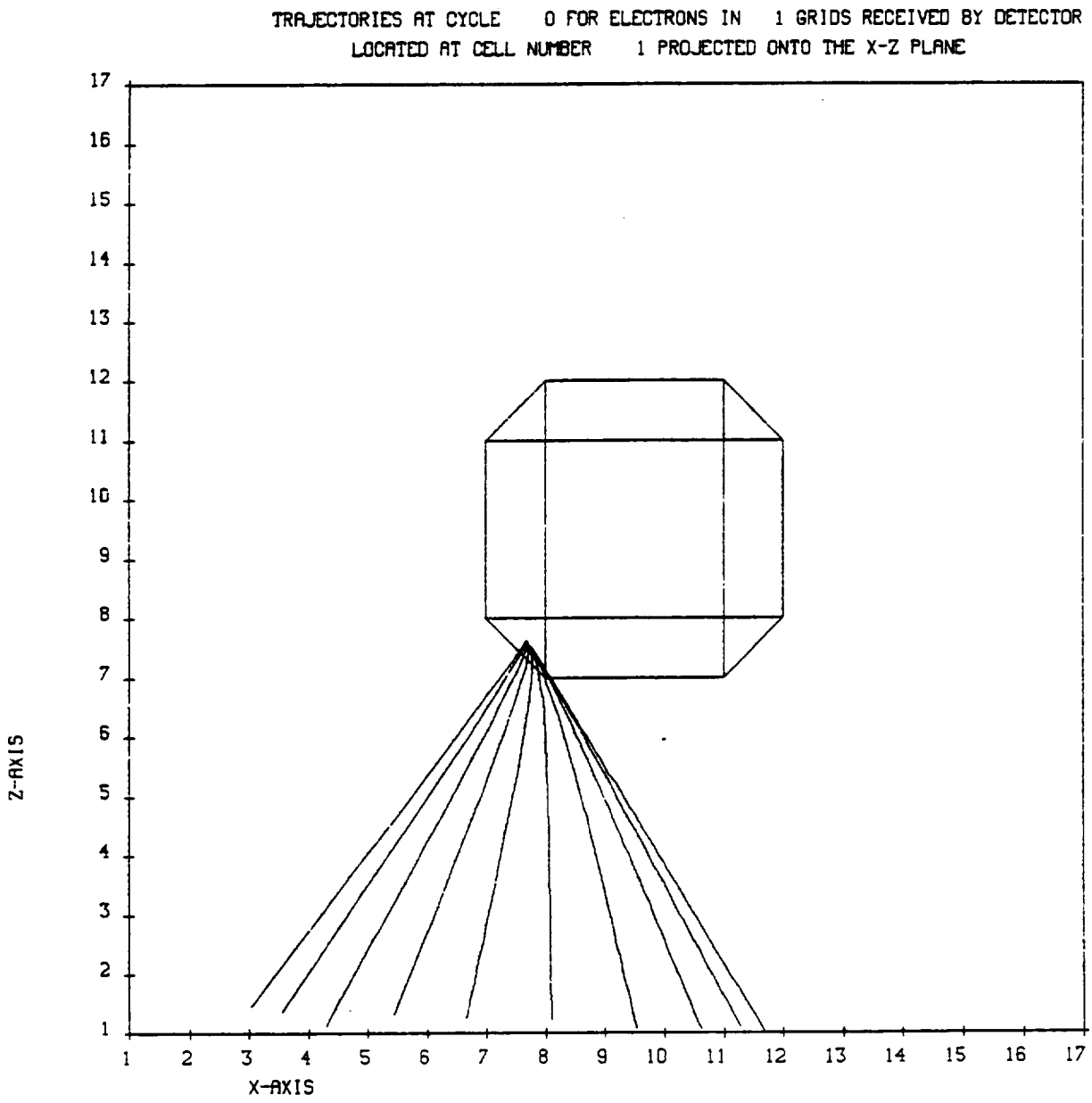


Figure 7.4. Detector particle trajectory plot.

7.2.6.1 INDVAR

The independent variable is set with the card:

INDVAR = var

var may be the words ENERGY, THETA and PHI, corresponding to the choice of E, θ or ϕ as the variable which energy flux density is plotted against. The default selection is ENERGY. The scale of the axis in the plot depends on the choice of variable as follows:

Independent Variable	Independent Variable Axis Scale
ENERGY (E)	LOG
THETA (θ)	LINEAR
PHI (ϕ)	LINEAR

The dependent variable, energy flux density, is always plotted on a LOG scale.

7.2.6.2 FINALV

The range of the independent variable in the plot begins at the value chosen in the definition of the detector and ends at the value set with the card

FINALV f

For example, the cards:

```
THETA      45
PHI        10
ENERGY     10,000
DEK        10
INDVAR =  ENERGY
FINALV     20,000
```

define a detector direction with $\theta = 45^\circ$ and $\phi = 10^\circ$ (in the surface system) which remains fixed, in a plot of energy flux density against initial energy where the energy range is swept from (10keV, 11 keV) to (20 keV, 22 keV).

The default value of f is 49999 eV, since the default independent variable is ENERGY. If θ and ϕ are chosen as independent variables FINALV must be changed explicitly from this default value to an acceptable limit for the variables. For θ acceptable limits are within $\pm$ $(90-\Delta\theta)^\circ$. For ϕ FINALV may range from 0 to 720°.

7.2.6.3 N

The number of points included in the energy flux density plot is set with the card

N n

N has a default value of 20, and must be between 3 and 500. For example, the same plot discussed in 7.2.6.2 can be made with 50 points using the cards:

```
THETA     45
PHI       10
ENERGY    10,000
DEK       10
INDVAR =  ENERGY
FINALV    20,000
N         50
```

7.2.6.4 AUTOS

The card

AUTOS

included in the detector definition causes automatic scaling of the calculated energy flux density in the plot against the independent

variable. The default behavior is to require manual selection of scale using the FLXMAX and FLXMIN options discussed below. The use of AUTOS is highly recommended.

7.2.6.5 FLXMIN AND FLXMAX

The minimum and maximum values on the energy flux density axis of the plot against the independent variable may be set using FLXMIN and FLXMAX. For example, the cards

```
FLXMIN   1.E6
FLXMAX   1.E14
```

will set the minumum value to 10^6 eV/(cm^2 s sr eV) and the maximum to 10^{14} eV/(cm^2 s sr eV). The scale is logarithmic. Default values are 10^4 and 10^{12} respectively. These cards are ignored when the AUTOS option (7.2.6.4) is in force.

7.2.6.6 PSCALE

Since the ion fluxes are an order of magnitude or two less than the electron fluxes, and both curves are overlaid on the same set of axes, it is often convenient to scale the ion fluxes by a factor p. This is set using the card

```
PSCALE   p
```

For example, the card

```
PSCALE   1.E2
```

will scale a proton flux of 6 x 10^8 eV/(cm^2 s sr eV) to 6 x 10^{10} for the purpose of a plot. The default value is p = 10^5.

7.2.6.7 LWPEN

To distinguish the ion and electron curves on the same graph, the ion energy fluxes are plotted with a broader penstroke. The number of vector points covered by the penstroke for the ion curve may be set with the card

```
LWPEN    n
```

n may take a value between 1 and 10. The default is 3. Electron curves are always drawn with a width of 1.

7.2.6.8 LABABV

If the card

LABABV

is included in the detector definition the headings on the plot will be omitted. This saves time when plotting on interactive graphics terminals but is apt to lead to confusion.

7.2.6.9 PRFLUX

If the card

PRFLUX

is included in the detector definition values of energy flux density included in the plot will be tabulated as printed output also.

7.2.6.10 PLPART

The particle trajectory plots are not automatically produced by default. Including the card

PLPART

in the detector definition causes a minimum of 6 plots to be produced, giving views in each of the grid axis planes for both ions and electrons. The plots extend to the highest grid reached by any of the particles. The grids plotted can also be controlled with the following options.

7.2.6.11 NGBND

The number of grids included in the plot may be set with the card

NGBND n

n may take integer values greater than 0. If n = 0 the highest grid reached by particles is automatically included. n is zero by default.

For example

NGBND 5

will include only the first five grids in the trajectory plots, even if some particles actually reached into grid 6 and higher.

7.2.6.12 NGPLOT AND NGINC

It is possible to make up to 4 different sets of plots of the same trajectories including the same or different grids. The card

NGPLOT n

sets the number of sets to n. n can take integer values from 1 to 4. The default is 1. The card

NGINC m

sets the increment for the outer boundary for successive plots. For example, the cards

NGBND 1
NGPLOT 3
NGINC 2

will produce three sets of plots of the same trajectories with the outermost grid number IG given by

$$IG = NGBND + (I-1) \times NGINC \quad (\text{for } I = 1, 2, 3)$$

i.e. with IG = 1, 3, and 5.

The default value of NGINC is 0. NGBND, NGINC and NGPLOT must all be chosen so that IG does not exceed LIMGRD.

7.2.6.13 LIMGRD

The highest grid in which particles may be tracked is set with the card

LIMGRD n

n may take any positive value above zero. The default value is NG, the number of grids included in the computational space. LIMGRD may exceed NG, in which case a monopole potential is used beyond the computational space.

7.2.6.14 MODPAR

To save plotting time not all the line segments making up a particle trajectory need be plotted. The card

MODPAR n

causes only every nth line segment to be plotted. For example

MODPAR 2

causes every other line segment to be plotted. The choice of

MODPAR 0

causes n to be set to $2^{IR}-1$, where IR is the grid number on which the plot is taking place. Then in the inner grid, all the line segments are plotted. In the 2nd grid, every other one is plotted, in the 3rd, every 4th one and so on. The default value of n is 0.

7.2.7 THE DETECT INPUT FILE: EXAMPLE

Figure 7.5 shows a sample detector input file with comments explaining each card. Figure 7.6 shows the printed output generated by the DETECT module associated with this input. A second example illustrating the use of DETECT is given in Chapter 11.

7.3 EMITTER

7.3.1 OVERVIEW

Particle emitters are defined in essentially the same way as particle detectors. The emitter is positioned on a particular surface cell, and the particles emitted from a cone about a chosen direction are tracked over a range of energies defined by the user. Those that reach the outer boundary of the computational space are considered lost to the spacecraft.

```
1.   DETECT
2.   COMMENT  ****** DEFINE DETECTOR NUMBER 1 ******
3.   COMMEN
4.   ICELL                    225 INDEX OF DETECTOR SURFACE CELL
5.   N                         25 NUMBER OF INDEPENDENT VARIABLE POINTS
6.   NSTP                     350 MAXIMUM NUMBER OF TRAJECTORY STEPS
7.   INDVAR=ENERGY
8.   ENERGY                 10.0 EV   (LOW END OF DETECTOR ENERGY RANGE)
9.   FINALV              49000.0 EV   (HIGH END OF DETECTOR ENERGY RANGE)
10.  PHI                     0.0 DEG  (FIXED AZIMUTHAL ANGLE)
11.  THETA                  50.0 DEG  (FIXED POLAR ANGLE)
12.  AUTOS                            ACTIVATE PLOT AUTO-SCALING OPTION
13.  PLPART                           REQUEST PARTICLE TRAJECTORY PLOTS
14.  END
```

Figure 7.5. NASCAP detector keyword file to perform an energy scan over 25 points logarithmically spaced from 10 eV to 50 keV. Detector looking in the direction of the normal to surface cell 225.

```
DETECTOR NUMBER 1:

    CELL LOCATION =  225


ENERGY FLUX INTEGRAL

   DE    = 0.00     EV        NE    =    1
   NSTP  = 350                NP    =    1
   DTH   =      .00 DEG       NMU2  =    1

      INDEPENDENT VARIABLE FOR PLOT = ENERGY
      INDEPENDENT VARIABLE RANGE =  1.00+01 EV     TO    4.90+04 EV
      IS DIVIDED INTO  25 POINTS


 FIXED VARIABLES

                PHI =      .00 DEG
              THETA =    50.00 DEG

      PROTON ENERGY FLUX PLOT SEPARATION SCALE FACTOR = 1.00+05
      PROTON ENERGY FLUX PLOT PEN LINE WIDTH = 3 RASTER INCREMENTS
      PARTICLE VELOCITY =    .300 MESH UNITS PER STEP
      ENERGY FLUX SCALE RANGE IS DETERMINED AT EXECUTION TIME


 **** PARTICLE TRAJECTORY PLOTS WILL BE PRODUCED FOR THIS DETECTOR ****
```

Figure 7.6. Example of printed output from Detector routines.

The total emitted current is considered a loss of charge (either positive or negative depending on whether ions or electrons are emitted) to the underlying conductor associated with the emitter surface cell. Particles that return to the spacecraft (i.e., collide with its surface) are considered to be a source of charge for the cells collecting them. Hence both the emission of the particles and their subsequent collection are taken into account by TRILIN in calculating currents to the object and object potential.

The emitter option should be considered a realistic model only for particle emitters operating at low current density. This is because NASCAP does not take into account the formation of space-charge barriers in front of the emitter. Space-charge effects become significant for electron emission, at currents greater than a few milliamperes and for proton emission at currents greater than about 0.1 milliamperes.

Plots of particle tracks can be produced in any number of computational grids (as selected by the user).

7.3.2 EXECUTING EMITTER

Unlike DETECT the emitter option is <u>not</u> a separate module. An emitter is defined and included in a TRILIN calculation by including the card

EMITTER <n>

in the <u>run options</u> file (6.2.4). The parameter n gives the file number where the emitter input cards are to be found. The default value of n is 5. If n = 5 is chosen the input cards must follow TRILIN in the NASCAP runstream. If the flux definition file is also file 5 (the NASCAP runstream) then the emitter input cards should follow the flux definition cards.

The emitter input file, like the DETECT input file should be terminated with an 'END' card (7.2.2). The emitter input cards fall into the same three groups as for DETECT and in many cases fulfill the same functions. These are:

(1) Definition of the emitter
(2) Control of the particle tracking
(3) Control of the plots produced.

We examine these in turn.

7.3.3. DEFINITION OF THE EMITTER

An emitter is defined in almost exactly the same way as a detector (Figure 7.1). One difference is that the beam of emitted particles must have an energy distribution rather than range. The choice is restricted to a Gaussian or Lorentzian distribution. The beam is assumed to be emitted within a cone defined around the chosen direction. The angular distribution of the beam within this cone must also be selected. The two possible choices are a uniform distribution and one biased towards the center axis of the cone by the factor $\cos \theta'$ (where θ' is the angle between any direction and the center axis of the cone). This is discussed in greater detail in Section 7.4.

The direction of the emitter is defined by specifying the polar angles θ and ϕ of the central axis of the cone, in the same cell coordinate system described for the detector (7.2.3). The first step, however, is to announce a new emitter with the EMITTER keyword. All parameters defined following EMITTER are assumed to refer to the same emitter until a further EMITTER card is encountered. In this way, more than one emitter may be defined. No two emitters may occupy surface cells associated with the same underlying conductor.

7.3.3.1 EMITTER

Just like the detector card DETECT (7.2.3.1), EMITTER must be the first card in the Emitter input file. All cards following EMITTER refer to the same emitter until a new EMITTER card is encountered. Hence more than one emitter may be defined in any one emitter input file. No two emitters may be on surface cells associated with the same conductor.

For example, an emitter file defining two emitters has the form

```
EMITTER

    { parameters for
    { first emitter

EMITTER

    { parameters for
    { second emitter

END
```

where each emitter is associated with a different conductor.

The cards used to define the emitter are described below.

7.3.3.2 ICELL

The card

```
ICELL  n
```

locates the emitter on surface cell number n. The cell may be a boom cell (but see 7.3.3.11). The default value of n (if no ICELL card is included) is n = 1.

7.3.3.3 ENERGY

The card

```
ENERGY  E
```

sets the peak value in eV of the energy distribution of the emitted particle beam. The default value is 1000 eV. For example,

```
ENERGY  2000
```

sets the peak value to 2000 eV.

7.3.3.4 JTYPE

The card

```
JTYPE  n
```

determines the energy and angular distribution function types, discussed in 7.3.3 and 7.4. n may take integer values from 1 to 4. The default is JTYPE = 1. The significance of each value is summarized in the table below.

JTYPE	Distribution Chosen
1	Uniform Angular, Gaussian energy
2	Cosine θ Angular, Gaussian energy
3	Uniform Angular, Lorentzian energy
4	Cosine θ Angular, Lorentzian energy

7.3.3.5 SIGMA

The width s in eV of the energy distribution is set with the card

```
SIGMA  s
```

The default value is 0.1 eV. For example, the cards

```
ENERGY  2000
JTYPE   2
SIGMA   10
```

define a beam with a Gaussian energy distribution centered at 2000 eV, with a width of 10 eV (7.4) and an angular distribution weighted towards the chosen direction by cos θ (7.4).

7.3.3.6 PHI

The card

PHI ϕ

sets the azimuthal angle in degrees of the emitter orientation in the surface cell system. The default is $\phi = 0^{\circ}$. This is exactly analogous to the detector card PHI (7.2.3.7).

7.3.3.7 THETA

The card

THETA θ

sets the polar angle θ (in degrees) of the emitter orientation in the surface cell system. The default is $\theta = 0$. This is exactly analogous to the detector card THETA (7.2.3.5).

7.3.3.8 DTHETA

The card

DTHETA $\Delta\theta$

sets the half-angle width of the cone about the emitter direction, in degrees. The default is $\Delta\theta = 0$. This is exactly analogous to the detector card DTH (7.2.3.6).

7.3.3.9 BEAMI

The card

BEAMI i

sets the total emitter beam current to i amps. The default is $i = 1 \times 10^{-6}$ amps. For example

BEAM 2.E-5

sets the current to 2×10^{-5} amps.

7.3.3.10 ISPEC

Whether the emitter emits protons or electrons is determined with the card

ISPEC n

where n may take the value 1 for an electron emitter and 2 for a proton emitter. The default is a proton emitter ISPEC = 2.

7.3.3.11 ZETA

If an emitter is to be defined for a boom cell, the angle zeta ζ, fixing the surface plane, must be specified. This is explained in 7.2.4.

7.3.4 CONTROL OF PARTICLE TRACKING

The particle tracking for emitters is carried out in just the same way as for detectors. Again there is a trade-off between the number of particle tracking steps taken to reach the boundary and the accuracy of the calculation. This is explained in Section 7.2.5.

The duration of the first tracking step for each particle is chosen so that the distance it moves is equal to the code velocity set by VEDOWN (rather than VCODE used for a detector). This duration is retained for further steps unless the distance moved exceeds VEDOWN or falls below VEUP when it is adjusted to fall within these limits.

The number of particles tracked by each emitter is given by the product

NPHIS x NTHETS x NENGS

where NPHIS, NTHETS AND NENGS are the number of samples in ϕ, θ and energy. These correspond exactly to NP, NMU2, AND NE in the detector case. (7.2.5.5, 7.2.5.4, 7.2.5.3).

Let's examine these input cards more carefully.

7.3.4.1 NSTEPS

The card

NSTEPS n

sets the number of particle tracking steps to n. n may range from 1 to 2500. The default is 500. Only the first 800 steps are plotted. In all other respects NSTEPS is identical to the DETECT parameter NSTP (see 7.2.5.1).

7.3.4.2 VEDOWN

The card

VEDOWN d

sets the maximum number of mesh units that any particle may move in a single particle tracking step. Hence the particle tracking steps associated with particles having different velocities (energies) have different durations. The step duration is initially set for each particle so that it moves a distance equal to VEDOWN in the first step. If the particle is subsequently accelerated so that it would move a distance greater than VEDOWN in a step, the duration of the step is automatically cut back.

The default value is 0.3 inner mesh units. This is a reasonable value to use in most cases.

When particles enter higher grids, VEDOWN is automatically scaled by the factor 2^{IG-1}, where IG is the number of the grid. For example, if the particle reaches the third grid IG = 3, and VEDOWN is scaled by $2^2 = 4$.

7.3.4.3 VEUP

Particles can be decelerated as well as accelerated and the card

VEUP u

sets the minimum distance that each particle must move in a particle tracking step before the step duration is automatically increased. The minimum distance in inner mesh units is defined by

$$\text{min distance} = \frac{\text{VEDOWN}}{\text{VEUP}}$$

The default value of VEUP is 5. Then if VEDOWN is set at 5, then the minimum distance moved by each particle is 0.3/5 = 0.06 inner mesh units.

Like VEDOWN (7.3.4.2) VEUP is scaled by the factor 2^{IG-1} in grid number IG.

7.3.4.4 SCALEV

The scaling of VEDOWN and VEUP for higher grids can be changed from the factor 2^{IG-1} to an arbitrary factor f with the card

SCALEV f

The default value is 1.0. SCALEV is only effective for grids higher than 2.

For example, with the card

SCALEV 5

VEDOWN and VEUP would be scaled by a factor $2^{IG-1} = 2$ for the second grid but by the factor 5 for the third and higher grids.

SCALEV is a <u>global</u> command and affects <u>all</u> of the emitters in the input file.

7.3.4.5 NENGS

The card

NENGS n

sets the number of energies to be sampled over the range of the energy distribution function chosen. The range is divided up into n - 1 pieces so that each corresponds to an equal weight (or number of particles). The default value is 1.

NENGS is analogous to the DETECT keyword NE (7.2.5.3).

7.3.4.6 NTHETS

The card

NTHETS n

sets the number of samples to be taken in the angle θ across the range of the cone $\Delta\theta$. The default is 1. NTHETS is analogous to the DETECT keyword NMU2 (7.2.5.4).

7.3.4.7 NPHIS

The card

NPHIS n

sets the number of samples to be taken in the angle ϕ', (the azimuthal angle around the cone axis). The default value is 1. This is analogous to the DETECT keyword NP (7.2.5.5).

7.3.4.8 CYMULT

Particles are considered lost when they pass out of the highest grid specified by LIMGRD (7.2.6.13). LIMGRD may be higher than the highest computational grid (NG). (For tracking in grids outside NG a monopole potential (7.2.6) is assumed.)

Particles are also considered lost when moving in grids higher than NG for a time longer than a limit set by the card

CYMULT n

For an environment with a non-zero magnetic field B, n corresponds to the number of "cyclotron" revolutions for the particle.

$$\text{Time limit} = n \times \left(\frac{2\pi \cdot \text{mass}}{E \cdot B} \right)$$

When the magnetic field is zero the time limit is given by $n \times T_{NG}$, where T_{NG} is the time spent escaping from the first NG grids (the computational space). The default is 1. For zero magnetic field CYMULT should be set to around 5.0.

7.3.5 CONTROL OF PLOTS AND PRINTED OUTPUT

Emitter produces only one type of plot. This shows the trajectories of the emitted particles. Views are plotted in the three grid axis planes. The trajectories may be plotted in more than one grid, and even out to grids beyond the computational space. If trajectories extend beyond the computational space the potential is assumed to be monopole (7.2.6).

Extra printed output can be requested showing the cells affected by capture of emitted particles, and the histories of each particle emitted.

The following input cards control these features.

7.3.5.1 NGBND, NGPLOT, NGINC

The keywords NGBND, NGPLOT and NGINC control the number of grids included in the trajectory plots. These are explained in Sections 7.2.6.11 and 7.2.6.12.

7.3.5.2 LIMGRD

The card

LIMGRD n

sets the number of the highest grid in which particle tracking to to take place. The default value is 6. If n exceeds 2 or NG (see 6.4.7) then a monopole potential is assumed in higher grids (7.2.6). LIMGRD is a global command (7.3.4.4).

7.3.5.3 IPLTYP

The card

IPLTYP n

sets the type of particle trajectory plots produced. n may take the values 0 or 1. If n = 0 three separate projection views for each emitter are produced. If n = 1 the plots for each emitter are combined on a single set of three projection views. IPLTYP only has an effect when more than one emitter is defined. The default value is 1 (i.e., combined emitter plots).

This is a global command (7.3.4.4).

7.3.5.4 JCYCEM

The card

JCYCEM n

causes trajectory plots to be produced for every n computational cycle. If n = 0 no plots are produced. The default value is 0 (no plots). For example the card

JCYCEM 2

will produce plots every other NASCAP code cycle.

This is a global command (7.3.4.4).

7.3.5.5. PRFLUX

If the card

PRFLUX

is included in the emitter input file a list of all surface cells that capture a particle will be printed for each particle emitter. This card should usually be included in the input file. Again this is a global command (7.3.4.4).

7.3.5.6 IPRNT

If the card

IPRNT

is included in the input file a summary of each particle tracked is produced. This has the following form.

IPHI	index number of discrete azimuthal angle at which the particle was emitted.
ITH	index number of discrete polar angle at which the particle was emitted.
IEK	index number of discrete energy at which the particle was emitted.
VINIT	initial code velocity with which particle was emitted (in inner grid units/timestep).
VIN	initial velocity with which particle was emitted (in meters/second).
JCLAST	index number of volume cell which particle was in at step just before hitting the satellite. If the trajectory was incomplete this will be 0. (Note the volume index is not necessarily the same as the surface cell index!)
PXYZ	potential (in volts) at the particle position at the last timestep completed prior to hitting the satellite or abandoning tracking.

IR — index number of grid in which the particle was in at the last timestep completed prior to hitting the satellite or abandoning tracking.

ISTP — number of discrete steps which this particle was tracked for before it hit the satellite or tracking was abandoned.

7.3.6 EXAMPLE OF AN EMITTER INPUT FILE

Figure 7.7 shows a sample emitter input file. Figure 7.8 shows the printed output from a completed run, and Figures 7.9 and 7.10 show two views of the particle trajectories.

7.4 TECHNICAL DISCUSSION

7.4.1 PARTICLE DETECTORS

(a) Calculation of Energy Flux at a Cell Surface

In order to obtain an expression for the energy flux density measured by a detector located at a given surface cell of the satellite model it is helpful to first consider the general problem of calculating the total energy flux which is incident at the surface of the cell due to the ambient plasma environment. Let k be the unit normal vector for the surface cell. Using the cell's rectangular coordinate system (obtained by appropriate rotation of the satellite coordinate system) with the +Z axis in the direction of k, the energy flux at the cell surface center is calculated as follows:

$$\vec{E}_o = -k\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\left(\frac{m|\vec{V}_o|^2}{2e}\right)\frac{1}{e}\left\{(e\vec{V}_o\cdot\hat{k})\, f_o(\vec{V}_o)\right\} d^3V_o$$

where $\vec{E}_o$ = energy flux vector (eV/(M^2-sec))at cell surface.

```
      1:EMITTER
      2:ICELL 3
      3:ENERGY 1000
      4:SIGMA 10
      5:DTHETA 5
      6:BEAMI 2.E-5
      7:NENGS 10
      8:JCYCEM 1
      9:PRFLUX
     10:END
EOF:10
0:>
```

Figure 7.7. Sample Emitter input file.

```
******TRILIN
FLUX DEFINITION SINGLE
                ELECTPON TEMPERATURE =    5.00+003 ELECTRON VOLTS
                ELECTRON DENSITY =        1.00+006 METER**(-3)
                ION TEMPERATURE =         5.00+003 ELECTRON VOLTS
                ION DENSITY =             1.00+006 METER**(-3)
*** RESTART AT NEW CYCLE =   1

  QSUMER FOUND QSUM= -1.30+005 CODE UNITS.
         AFTER SCREENING CORRECTION (SCREENING LENGTH=  2.00+003 M.) QSUM= -1.30+005
               QSCALE= -1.30+005          CORRECTED TO  -1.30+005
*** QSUMO FROM LAST CYCLE =  -1.2969+005

 *** THE SYSTEM IS NOW AT TIME     .000     SECONDS.     1 CYCLES HAVE BEEN REQUESTED.
                           DELTA=  5.00+000 SECONDS.     DELFAC=  1.00+000.
```

Figure 7.8. TRILIN output with EMITTER option selected.

```
        BEGIN CYCLE NO.     1          TIME =     .000      SECONDS.

 QSUMER FOUND QSUM= -1.30+005 CODE UNITS.
        AFTER SCREENING CORRECTION (SCREENING LENGTH=  2.00+003 M.) QSUM= -1.30+005
                QSCALE= -1.30+005          CORRECTED TO  -1.30+005
                QSUM  = -1.2969+005
                PCOND =  -1.000+003  -2.000+003
                QCOND =   1.521+009  -5.929+005
-------------------------------------------------------------------------------

 EXPLICITLY CALCULATED FLUXES FOR CYCLE    1     TIME =    .000     SECONDS.
 DURING THIS TIMESTEP, NASCAP WILL TAKE INTO ACCOUNT SUCH
 ADDITIONAL EFFECTS AS SURFACE CONDUCTIVITY, DISCHARGES, EMITTER OPERATION,
 AND VARIATION OF LIMITING FACTORS FOR LOW-ENERGY EMITTED ELECTRONS.
-------------------------------------------------------------------------------

 SURFACE CELL NO.  167                                        CODE =       011111120302
                                                              LOCATION =     9  9 10
                                                              NORMAL =       0  0 -1
                                                              MATERIAL =   SOLA

                          POTENTIAL = -2.000+003 VOLTS
                          STRESS =    .000     VOLTS/METER
                          EXTERNAL FIELD = -2.609+003 VOLTS/METER
                          LIMITING FACTOR =  1.000+000

   FLUXES IN A/M**2
          INCIDENT ELECTRONS                          1.27-006
               RESULTING SECONDARIES                  1.02-006
               RESULTING BACKSCATTER                  4.34-007
          INCIDENT PROTONS                            6.20-008
               RESULTING SECONDARIES                  8.57-008
          BULK CONDUCTIVITY                            .00
          PHOTOCURRENT                                 .00
                                                     ----------
       NET FLUX                                       3.30-007

          INITIAL NET CHARGING CURRENT (WITHOUT LIMITING) =  3.98-007 AMPERES.
          INITIAL NET CHARGING CURRENT (WITH    LIMITING) = -6.58-007 AMPERES.
ICELL 3                ICELL SET TO          3
ENERGY 1000            ENERGY SET TO    1.000000+003
SIGMA 10               SIGMA SET TO     1.000000+001
DTHETA 5               DTHETA SET TO    5.000000+000
BEAMI 2.E-5            BEAMI SET TO     2.000000-005
NENGS 10               NENGS SET TO          10
JCYCEM 1               JCYCEM SET TO          1
PRFLUX                 NON-ZERO EMITTER SURFACE CELL CURRENT PRINT FLAG SET
END
```

Figure 7.8. (Continued).

```
          PARAMETER DEFINITION SUMMARY FOR LOW-DENSITY PARTICLE EMITTERS

                        NUMBER OF PARTICLE EMITTERS = 1
                        PLOTS ARE PRODUCED EVERY     1 CYCLES
                        TRAJECTORY PLOT TYPE =     OVERLAY
-------------------------------------------------------------------------------

EMITTER NUMBER 1:
    CELL LOCATION=     3
    EMITTER TYPE =     PROTON
    BEAM CURRENT =2.00-005 AMPS

BEAM CURRENT INTEGRAL

    ENERGY=1.00+003 EV      SIGMA=1.00+001          NENGS=  10
       PHI=      .00 DEG                            NPHIS=   1
     THETA=      .00 DEG    DTHETA=    5.00 DEG     NTHETS=   1

    MAXIMUM INITIAL PARTICLE VELOCITY=    .300 INNER GRID UNITS PER TIME-STEP
    TIME STEP INCREASE TOLERANCE FACTOR=  5.000
    MAXIMUM NUMBER OF PARTICLE STEPS= 500
    CYCLOTRON PERIOD LIMIT=  1.000
    HIGHEST GRID TRACKING ALLOWED IN =   6
    SCALE FACTOR FOR VELOCITY IN GRIDS ABOVE 2 =  1.000

GUN TYPE= 1

-------------------------------------------------------------------------------
  NEXTRA=     0

 EFPREP --    2 GRIDS OUT OF   2 READ IN.
****** EMITTER ROUTINE EXECUTION INITIATED BY EMTRUN *** ***

PARTICLE EMITTER ENERGIES (EV):
                          9.8355+002      9.8964+002      9.9326+002      9.9615+002      9.9875+002      1.0013+003
1.0038+003      1.0067+003      1.0104+003      1.0165+003

PARTICLE EMITTER ENERGY WEIGHTS:
                          9.7017-003      4.2889-003      3.1462-003      2.6993-003      2.5264-003      2.5264-003
2.6993-003      3.1462-003      4.2889-003      9.7017-003

  CURRENT TO CELL  167 ORIGINATING FROM EMITTER  1 =    .0000     AMPS.  VOLUME CELL INDEX=  167 SHARED WITH  0 OTHER CELLS

 NON-ZERO SURFACE CELL CURRENT CONTRIBUTIONS FROM EMITTER NUMBER  1    SUM OF CELL CURRENTS=    .000000     AMPS


***** SUMMARY OF PARTICLE TRACKING FOR EMITTER 1 AT CYCLE     1 *****

NUMBER OF TIMES PARTICLE TRACKING TIME-STEP WAS INCREASED =       10
NUMBER OF TIMES PARTICLE TRACKING TIME-STEP WAS DECREASED =        0
NUMBER OF PARTICLES WHICH PASSED OUT OF SECOND MESH =     10
NUMBER OF TIMES CYCLOTRON LIMIT WAS EXCEEDED =    10
TOTAL NUMBER OF PARTICLES WHICH ESCAPED =     10
NUMBER OF PARTICLE EMISSIONS SUPPRESSED BY LOCAL CELL FIELD =      0
NUMBER OF PARTICLE EMISSIONS SUPPRESSED BY BARRIER AT ANODE =      0
HIGHEST GRID TRACKED IN =  3


MINIMUM POTENTIAL SEEN = -3.0000+003 VOLTS  (DISTANCE FROM MESH CENTER =  7.3485-001 METERS)
MAXIMUM POTENTIAL SEEN = -4.1257+002 VOLTS  (DISTANCE FROM MESH CENTER =  5.0031+000 METERS)
AVERAGE EMITTER CELL POTENTIAL = -3.0000+003 VOLTS

ANALYTIC MAGNITUDE OF EMISSION CURRENT =   2.00000-005 AMPS
NUMERICAL CURRENT WHICH ESCAPED TO ENVIRONMENT =   2.00000-005 AMPS
NUMERICAL CURRENT WHICH RETURNED TO  SATELLITE  =     .00000     AMPS
TOTAL NUMBER OF PARTICLES TRACKED =     10
```

Figure 7.8. (Continued).

```
EMITTER CONDUCTOR POTENTIAL = -1.0000+003 VOLTS

CALLED EMITER NECELS= 1 ICYC= 1 XMESH=  2.0000-001 NMAT= 4 NSURF=  180 QTOT= -1.2969+005 NX=17 NY=17 NZ=33 IER=  0
IN PLEMIT IEMIT=    1 IG=    3 IGS=           4 GSCALE=  2.5000000-001 IVIEW=   1
CALLED PLEMIT IXYZ= 1
IN PLEMIT IEMIT=    1 IG=    3 IGS=           4 GSCALE=  2.5000000-001 IVIEW=   1
CALLED PLEMIT IXYZ= 2
IN PLEMIT ILMIT=    1 IG=    3 IGS=           4 GSCALE=  2.5000000-001 IVIEW=   1
CALLED PLEMIT IXYZ= 3
***IN ADEMIT***  IEMIT=  1 CUREMT=   2.000-005 FRAC=   5.000-001 EMBEAM=   2.000-005 VC=   1.000+003
 IN ADEMIT CURRENT TO CELL  167 CHANGED BY FLUX FROM EMITTER   IFROM   7.4672+003 TO   7.4672+003 CODE UNITS
```

Figure 7.8. (Continued).

```
                                        1 EMITTERS FOUND BY ADEMIT ON FILE   11
    NO.      CONDUCTOR      EMT-INF (AMPS)      BARRIER (VOLTS)      SPECIES      WIDTH (EV)    ENERGY (EV)      NDIST
     1            1          2.0000-005             .0000              2          1.0000+001    1.0000+003          1
  TOTAL CAPACITANCE TO INFINITY =    49.9 CODE UNITS;    8.83-011 FARADS.
  BADEMT SET CONDUCTOR   1 TO  -2.010+003 VOLTS DUE TO CURRENT FROM EMITTER  1
    ICCG --- RDOTR/RDOTR1 =   9.61-021/  1.60+011
  LEAVING ICCG1 -- VCTRI =  -2.010+003 -2.088+003
  BADEMT SET CONDUCTOR   1 TO  -2.010+003 VOLTS DUE TO CURRENT FROM EMITTER  1
    ICCG --- RDOTR/RDOTR1 =   1.30-020/  1.60+011
  LEAVING ICCG1 -- VCTRI =  -2.010+003 -2.074+003
    ICCG --- RDOTR/RDOTR1 =   1.97-020/  1.57+011
  LEAVING ICCG1 -- VCTRI =  -2.000+003 -2.058+003
  UNEMIT: IRET= 1     DQC= -5.91+005     DQCO= -1.05+006     DFDVC= -5.65+003
CONDUCTOR  1 UNFIXED
    ICCG --- RDOTR/RDOTR1 =   1.80-017/  5.46+007
  LEAVING ICCG1 -- VCTRI =  -1.070+003 -2.057+003
  HIGHQ --- NUNH=   2
    ICCG --- RDOTR/RDOTR1 =   2.56-017/  6.02+007
  LEAVING ICCG1 -- VCTRI =  -1.070+003 -2.074+003
  LOWQ --- NUNL=   3
    ICCG --- RDOTR/RDOTR1 =   3.23-019/  3.56+007
  LEAVING ICCG1 -- VCTRI =  -1.070+003 -2.037+003
  LOWQ --- NUNL=   2
    ICCG --- RDOTR/RDOTR1 =   3.65-016/  6.20+007
  LEAVING ICCG1 -- VCTRI =  -1.070+003 -1.413+003
   VFIX ---    0 OUT OF  164 NODES FIXED.
    ICCG --- RDOTR/RDOTR1 =   3.65-016/  6.20+007
  LEAVING ICCG1 -- VCTRI =  -1.070+003 -1.413+003
  NO DISCHARGE ANALYSIS
  NO DISCHARGE ANALYSIS
    ICCG --- RDOTR/RDOTR1 =   7.04-023/  3.66+007
  LEAVING ICCG2 -- VCTRI =  -1.070+003 -1.413+003
 AVERAGE FLUXES (ONLY AVAILABLE FOR INSULATING CELLS)
AVERAGE FLUX TO CELL  167 IS    2.651-007 A/M**2
NEW CONDUCTOR POTENTIALS
        VNEW              DQ              VOLD        CONDUCTOR
   -1.0696+003     9.1690+005     -1.0000+003                1
   -1.4126+003    -1.4554+000     -2.0000+003                2
```

Figure 7.8. (Continued).

```
   TOTAL CHANGE IN CHARGE =     3.537+003 CODE UNITS
                                6.264-009 COULOMBS

   AVERAGE NET CHARGING CURRENT =     1.253-009 AMPERES
                                      7.075+002 CODE UNITS/SEC.

CONDUCTOR CURRENTS (AMPS; POSITIVE INTO CONDUCTORS):

                                        1           2
NET CURRENT(AVG DQ/DT):              3.25-007   -5.15-013
CONDUCTIVITY CURRENT (NEW)
  (FROM INSULATING CELLS):          -8.95-009    9.60-015
PLASMA CURRENT (INITIAL)
  (TO BARE CELLS):                  -3.63-007     .00
REMAINDER CURRENT:                   6.97-007   -5.25-013
```

Figure 7.8. (Continued).

```
          CONTINUE CYCLE NO.     1 AT UPDATED TIME =   5.000+000 SECONDS.
                        QSUM = -1.2616+005

SURFACE POTENTIALS - ALL  184 CELLS
CELL NO.                                                                                                                    CELL NO.
   1    -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003      10
  11    -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003      20
  21    -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003      30
  31    -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003      40
  41    -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003      50
  51    -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003      60
  61    -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003      70
  71    -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003      80
  81    -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003      90
  91    -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003     100
 101    -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003     110
 111    -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003 -3.071+003     120
 121    -3.071+003 -3.071+003 -3.071+003 -3.071+003 -1.070+003 -3.071+003 -1.070+003 -3.071+003 -1.070+003 -3.071+003     130
 131    -3.071+003 -1.070+003 -3.071+003 -1.070+003 -1.070+003 -1.070+003 -3.071+003 -1.070+003 -3.071+003 -1.070+003     140
 141    -1.070+003 -1.070+003 -3.071+003 -1.070+003 -3.071+003 -3.071+003 -1.070+003 -3.071+003 -1.070+003 -3.071+003     150
 151    -1.070+003 -3.071+003 -3.071+003 -1.070+003 -1.406+003 -1.406+003 -1.435+003 -1.406+003 -1.406+003 -1.435+003     160
 161    -1.406+003 -1.406+003 -1.435+003 -1.406+003 -1.406+003 -1.435+003 -1.406+003 -1.435+003 -1.406+003 -1.406+003     170
 171    -1.435+003 -1.406+003 -1.406+003 -1.406+003 -1.406+003 -1.406+003 -1.406+003 -1.406+003 -1.406+003 -1.406+003     180
 181    -1.070+003 -1.070+003 -1.070+003 -1.070+003

            26 POTENTIAL ITERATIONS COMPLETED.
               RDOTR/RDRMAX=  2.42+001/  2.46+007
PCOND =    -1.0696+003  -1.4126+003
QCOND =     1.5218+009  -2.3481+005
  NEXTRA=      0

 EFPREP --     1 GRIDS OUT OF   1 READ IN.

IP = 13  IR = 12  IU = 10  ISPARE = 14  IPSAVE = 10

LAST CYCLE COMPLETED IS   1.

IP = 10  IR = 12  IU = 13  ISPARE = 14  IPSAVE = 10
```

Figure 7.8. (Concluded).

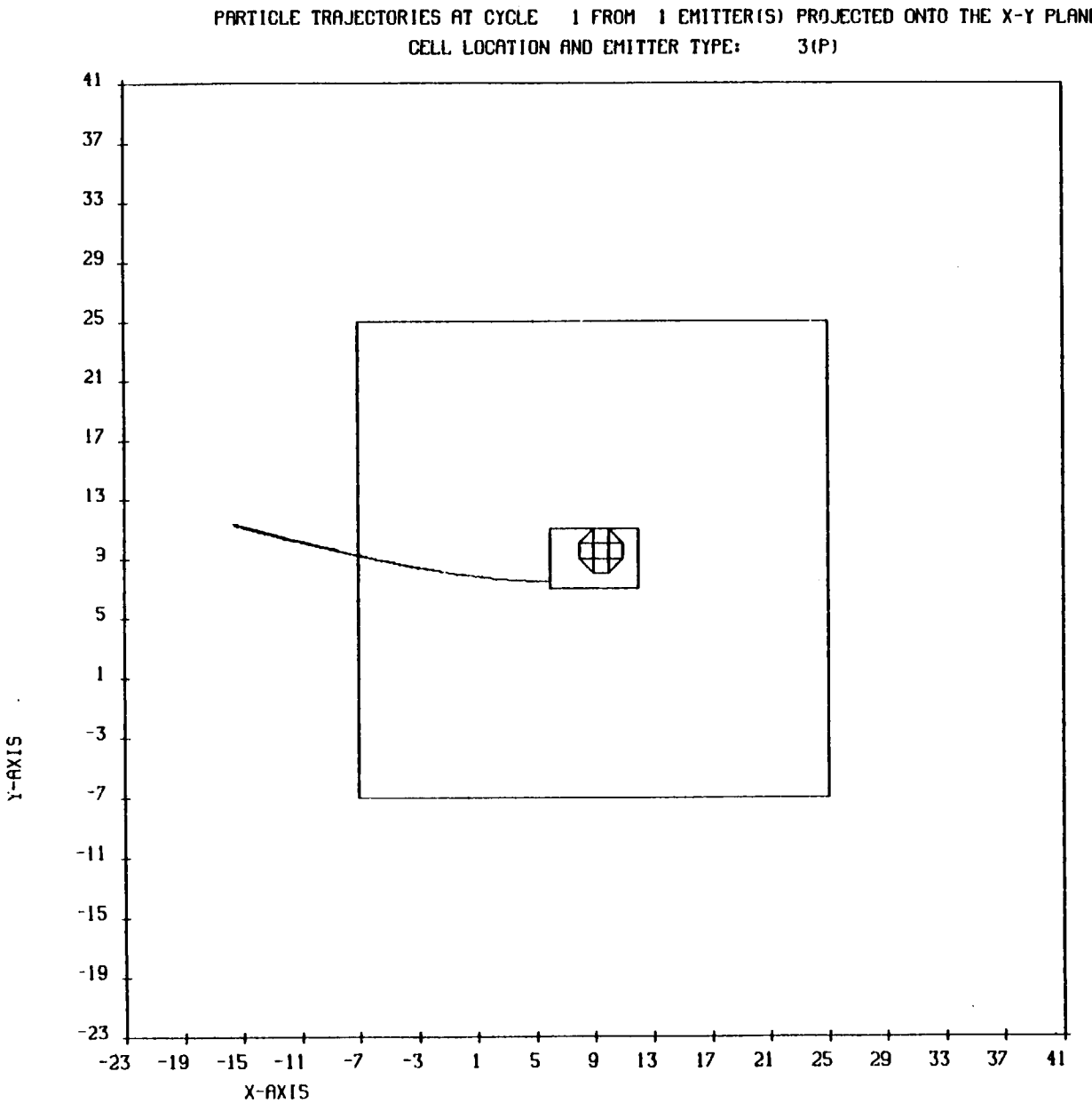


Figure 7.9. Sample particle emitter trajectory plot.

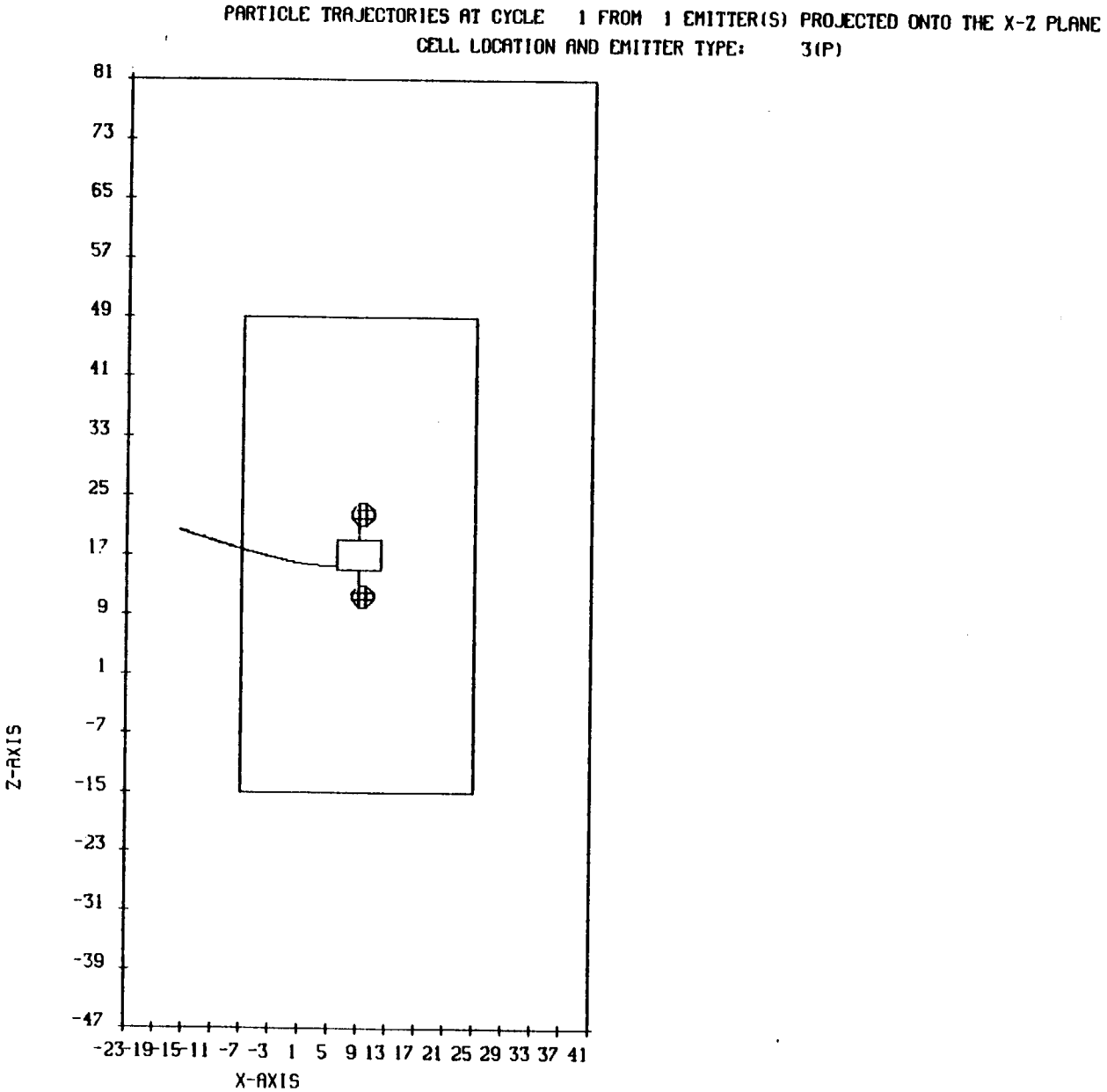


Figure 7.10. Sample particle emitter trajectory plot.

$\vec{V}_o = v_x \hat{i} + v_y \hat{j} + v_z \hat{k}$ (velocity at surface)

$d^3V_o = dv_x\, dv_y\, dv_z$

$f_o(\vec{V}_o)$ = phase space density function evaluated at the surface for particles with velocity $\vec{V}_o$.

m = mass of incident particles.

e = charge of incident particles (electrons or protons).

To evaluate the integral it is expedient to change from rectangular to spherical coordinates. The necessary substitutions are:

$V_o = |\vec{V}_o|$

$d^3V_o = V_o^2 \sin\theta\, d\theta\, d\phi\, dv_o$

$(e\vec{V}_o \cdot \hat{k}) = ev_o \cos\theta$

With these the energy flux integral transforms into

$$\vec{E}_o = -\hat{k} \int_0^{\infty} \int_0^{2\pi} \int_0^{\pi/2} \left(\frac{mv_o^2}{2e^2}\right) \left\{ev_o \cos\theta\, f_o(\theta,\phi,v_o)\right\} v_o^2 \sin\theta\, d\theta\, d\phi\, dv_o$$

$$= -\hat{k} \int_0^{\infty} \int_0^{2\pi} \int_0^{\pi/2} \left(\frac{m}{2e}\right) v_o^5\, f_o(\mu,\phi,v_o)\, \frac{d\mu^2}{2}\, d\phi\, dv_o$$

where $\mu = \cos\theta$.

Next we change variables from v_o (the magnitude of the velocity at the surface) to E_o (the kinetic energy at the surface of the cell).

Let

$$\frac{1}{2} m v_o^2 = e E_o \quad \text{(factor e because } E_o \text{ is in eV)}$$

$$dv_o = \frac{e dE_o}{m v_o}$$

Then the energy flux integral becomes

$$\vec{E}_o = -\hat{k} \int_0^{\infty} \int_0^{2\pi} \int_0^{1} 2\left(\frac{e}{m}\right)^2 E_o^2 f_o(\mu, \phi, E_o) \frac{d\mu^2}{2} d\phi \, dE_o$$

$$= -\hat{k} \int_0^{\infty} \int_0^{2\pi} 2\left(\frac{e}{m}\right)^2 E_o^2 f_o(E_o, \vec{\Omega}_o) \, \mu \, d\Omega \, dE_o$$

where we have introduced the solid angle as an integration variable for notational convenience.

Finally we introduce the energy flux density function $G(E,\Omega)$. From the definition we know that

$$\vec{E}_o = -\hat{k} \int_0^{\infty} \int_0^{2\pi} G_o(E_o, \vec{\Omega}_o) \, \mu \, d\Omega \, dE_o$$

Comparison of the integrands yields the identity

$$2\left(\frac{e}{m}\right)^2 f_o(E_o, \vec{\Omega}_o) = \frac{G_o(E_o, \vec{\Omega}_o)}{E_o^2}$$

This equation provides the key to correct evaluation of G at the cell surface by reverse trajectory particle tracking. Since f is a constant along a particle trajectory we have for particles emitted at the cell surface with initial energy E_0 and velocity vector in the direction of $\vec{\Omega}_0$:

$$f_0(E_0, \vec{\Omega}_0) = f_\infty (E_\infty, \vec{\Omega}_\infty)$$

$$\frac{G_0(E_0, \vec{\Omega}_0)}{E_0^2} \quad \frac{G_\infty (E_\infty, \Omega_\infty)}{E_\infty^2}$$

where

f_0 = phase space density function evaluated at cell surface.

f_∞ = phase space density function evaluated at infinity.

G_0 = energy flux density function evaluated at cell surface.

G_∞ = energy flux density function evaluated at infinity.

E_0 = initial kinetic energy of particle to be tracked.

E_∞ = kinetic energy of particle after reverse trajectory tracking to infinity.

$\vec{\Omega}_0$ = initial velocity direction vector of particle at cell surface.

$\vec{\Omega}_\infty$ = velocity direction vector for particle after reverse trajectory tracking to infinity.

Therefore, if the energy flux density function G is known at infinity then using reverse trajectory particle tracking the energy flux at the surface of the cell may be computed from

$$\vec{E}_o = -\hat{k} \int_0^{\infty} \int_0^{2\pi} E_o^2 \left\{ \frac{G_\infty (E_\infty, \vec{\Omega}_\infty)}{E^2} \right\} \mu \, d\Omega \, dE_o$$

This equation is used (with slight modification) in the following section to arrive at an expression for the energy flux density which is measured by a particle detector located on the surface cell.

(b) Detector Energy Flux Density Measurement

Consider an ideal particle detector located at the center of a surface cell and oriented such that the +Z axis of the detector's rectangular coordinate system points in the direction in which the energy flux density is to be measured. Assume that the detector's rectangular coordinate system is transformed into a spherical coordinate system and that n is the unit normal pointing in the direction in which the particle detector is pointing. If the detector responds to particles having energy E_o then the measured value for the energy flux will be

$$\frac{\partial^2 \vec{E}_o}{E_o} = -\vec{n} E_o^2 \left\{ 2 \left(\frac{e}{m} \right)^2 f_o(E_o, \vec{n}) \right\} \mu$$

$$= -\vec{n} E_o^2 \left\{ \frac{G_\infty (E_\infty, \vec{\Omega}_\infty)}{E_\infty^2} \right\} \mu$$

where

$\vec{E}_o$ = energy flux vector at cell surface.

f_o = phase space density function evaluated at cell surface.

E_o = kinetic energy (in eV) of particles at cell surface.

ϕ = azimuthal angle in detector coordinate system.

θ = polar angle in detector coordinate system.

E_∞ = kinetic energy (in eV) of particles after reverse trajectory tracking to infinity.

$\vec{\Omega}_\infty$ = velocity direction vector for particles after reverse trajectory tracking to infinity.

m = mass of particles.

$G_\infty(E,\vec{\Omega})$ = energy flux density function (i.e., tabulated Deforest data, for example. Units are $eV/(sec\text{-}cm^2\text{-}sr\text{-}eV)$.)

In practice, a real detector responds to a finite range of particle energies and velocity vectors so that the energy flux density observed by the detector is really $\partial^2\vec{E}_0/\partial E_0 \partial\Omega$ averaged over the energy and angular apertures of the detector. Thus, in general, the value which the detector yields is of the form

$$\frac{\partial^2\vec{E}_0}{\partial E_0 \partial\Omega} = \frac{-\vec{n}\int_0^{\infty}\int_0^{2\pi} W(E_0,\vec{\Omega})\, E_0^2 \left\{\frac{G_\infty(E_\infty,\vec{\Omega}_\infty)}{E^2}\right\} \cos\theta \, d\Omega \, dE_0}{\int_0^{\infty}\int_0^{2\pi} W(E_0,\vec{\Omega})\, d\Omega \, dE_0}$$

where $W(E_0,\vec{\Omega})$ is a weight function which describes the characteristics of the detector's energy and angular apertures.

In the current version of NASCAP it has been assumed that the energy aperture of a detector is a rectangular weight function which has a value of 1 from E to E + ΔE and 0 elsewhere. The angular aperture is assumed to be a hemispherical cap of "width" $\Delta\theta$ in the polar angle. (The vector $\vec{n}$ passes through the center of this cap.) The weight has a value of 1 anywhere on the cap and 0 elsewhere. Therefore, NASCAP detectors compute the energy flux density from

$$\frac{\overline{\partial^2 \vec{F}_o}}{\partial E_o \, \partial \Omega} = \frac{-\vec{n} \int_E^{E+\Delta E} \int_0^{2\phi} \int_{\cos^2\Delta\theta}^{1} E_o^2 \left\{ \frac{G_\infty(E_\infty, \vec{\Omega}_\infty)}{E^2} \right\} \frac{d\mu^2}{2} \, d\phi \, dE_o}{\int_E^{E+\Delta E} \int_0^{2\pi} \int_0^{\Delta\theta} \sin\theta \, d\theta \, d\phi \, dE_o}$$

$$= \frac{-\vec{n} \int_E^{E+\Delta E} \int_0^{2\pi} \int_{\cos^2\Delta\theta}^{1} E_o^2 \left\{ \frac{G_\infty(E_\infty, \vec{\Omega}_\infty)}{E_\infty^2} \right\} \frac{d\mu^2}{2} \, d\phi \, dE_o}{(1 - \cos\Delta\theta)\, 2\pi \, \Delta E}$$

where $\mu = \cos\theta$.

This integral is evaluated by a three-dimensional approximation formula which uses the mid-point rule with n_ϕ points to compute the integral over ϕ, the mid-point rule with n points to compute the integral over μ^2, and the even-order Gauss-Legendre formula with n_ε points to compute the integral over E_o. The composite formula used is:

$$\frac{\overline{\partial^2 \vec{F}_o}}{\partial E_o \, \partial \Omega} \approx -\vec{n} \left\{ \left(\frac{2\pi}{n_\phi} \right) \sum_{i=1}^{n_\phi} \frac{(1-\cos^2\Delta\theta}{2m} \sum_{j=1}^{n_\psi} \left(\frac{\Delta E}{2} \right) \sum_{k=1}^{n_\varepsilon/2} W_k \varepsilon_k^2 \left\{ (\phi_i, \mu_j^2, \varepsilon_k) \right.\right.$$

$$+ W_{-k}\varepsilon_{-k}^2 \; F(\phi_j, \mu_j^2, \varepsilon_{-k})\Big\}\Big\} \frac{1}{(1-\cos\Delta\theta)\; 2\pi\; \Delta E}$$

$$= -\vec{n}\gamma \sum_{i=1}^{n_\phi} \sum_{j=1}^{n_\psi} \sum_{k=1}^{n_\varepsilon/2} \left\{ W_k \varepsilon_k^2 \; F(\phi_j, \mu_j^2, \varepsilon_k) + W_{-k}\varepsilon_{-k}^2 \; F(\phi_j, \mu_j^2, \varepsilon_{-k}) \right\}$$

where

$$\varepsilon_k = \frac{\Delta E}{2} (\chi_k + 1) + E$$

$$\phi_i = \frac{2\pi}{n_\phi} (i - 1/2)$$

$$\mu_j^2 = \Delta\mu^2 \; (j - 1/2) + (1 - n_\psi \Delta\mu^2) \quad \{\psi \text{ denotes } \mu^2\}$$

and

$$\Delta\mu^2 = (1 - \cos^2\delta\theta)/n_\psi$$

$$\gamma = \frac{(1 + \cos\Delta\theta)}{4\; n_\psi \; n_\phi} \quad \text{(multiply by } 10^{-4} \text{ to put units in cm}^{-2}\text{)}$$

$$F(\phi_i, \mu_j^2, \varepsilon_k) = \frac{G_\infty (E_\infty, \vec{\Omega}_\infty)}{E_\infty^2} \Bigg|_{ijk} \quad \text{(returned by FSPACE)}$$

E_∞ and $\vec{\Omega}_\infty$ are the final energy and velocity vector respectively of a particle after reverse trajectory tracking from the center of the surface cell (beginning with initial velocity specified by ϕ_i, μ_j^2, and ε_k) to infinity.

The χ_k and W_k are the Gauss-Legendre integration coefficients for n_ε an even integer. (Note the $\chi_k = -\chi_{-k}$ and $W_k = W_{-k}$.) A slightly modified formula is used to permit $n_e = 1$. (Also note that $-1 \leq \chi_k \leq 1$ for all k.)

It should be noted that although the detector energy flux integral includes only contributions from the ambient plasma environment it is possible that some particle trajectories will yield $E < 0$. This could occur if the particle originates from another part of the satellite, for example.

For detector particle trajectory plotting purposes all particles must be tracked regardless of origin. Therefore, a test is made within the innermost integral summation loop to determine if $E_\infty \geq 0$. If it is not then no attempt is made to evaluate G and G is assumed to be 0.

7.4.2 PARTICLE EMITTERS

7.4.2.1 DISCRETE PARTICLE EMISSION ANGLES AND ENERGIES

The present version of NASCAP offers the user two choices for emission angle selection. One choice is the uniform distribution, a special case of which results in each particle representing the same solid angle fraction of the current. The other choice is a cosine θ distribution in which a disproportionate number of particles are emitted at angles "close" to the axis of the hemispherical cap (Z-axis of the emitter coordinate system). Two choices for the energy spectrum of the beam are also provided. Either choice results in an approximate representation of a mono-energetic peak in the energy spectrum - the difference between the two choices being the mathematical form of the approximation function. The emission angles and energy distribution functions available are listed below. (Any angular dependence may be combined with any energy dependence.)

(a) Uniform Angular Current Density Dependence

For each of n_ε discrete energies, n_ϕ n_θ particles are emitted. The initial emission velocity direction vector of each particle (measured in the emitter coordinate system) is

$$\vec{V}_{ij} = (\sin\theta_j \cos\phi_i)\hat{i} + (\sin\theta_j \sin\phi_i)\hat{j} + (\cos\theta_j)\hat{k}$$

where

$$\phi_i = \frac{2\pi}{n_\phi}(i - 1/2) \qquad i = 1, 2, \ldots, n_\phi$$

$$\theta_j = \frac{\Delta\theta}{n_\theta}(j - 1/2) \qquad j = 1, 2, \ldots, n_\theta$$

For the special choice of $n_\phi = n_\theta$ each particle represents the same solid angle fraction of the emitted current.

(b) Cosine θ Angular Current Density Dependence

For each of n_ε discrete energies, n_ϕ n_θ particles are emitted. The initial velocity direction vector of each particle (measured in the emitter coordinate system) is

$$\vec{V}_{ij} = (\sin\theta_j \cos\phi_i)\hat{i} + (\sin\theta_j \sin\phi_i)\hat{j} + (\cos\theta_j)\hat{k}$$

where

$$\phi_i = \frac{2\pi}{n_\phi}(i - 1/2) \qquad i = 1, 2, \ldots, n_\phi$$

$$\theta_j = \sin^{-1}\left(\frac{(j-1/2)\sin\Delta\theta)}{n_\theta}\right) \qquad k = 1, 2, \ldots, n_\theta$$

(c) Gaussian Energy Current Density Dependence

A Gaussian function may be used as an approximation to a mono-energetic spectrum. The current density function for the Gaussian approximation is

$$J(\varepsilon) = \frac{I_B}{\sqrt{2\pi}\,\sigma} \exp\left(-\frac{1}{2}\left(\frac{\varepsilon-\varepsilon_0}{\sigma}\right)^2\right)$$

where I_B is the total beam emission current.

It is easy to show that

$$\int_{-\infty}^{\infty} J(\varepsilon)\, d\varepsilon = I_B \ .$$

Since a real current distribution is not defined for negative energies the Gaussian function is only an approximate representation. However, one can show that

$$\lim_{\sigma \to 0} J(\varepsilon) = I_B\, \delta(\varepsilon - \varepsilon_0) \ ,$$

and

$$\int_0^{\infty} J(\varepsilon)\, d\varepsilon \to I_B \quad \text{for} \quad \varepsilon_0 > 0 \text{ and } \frac{\sigma}{\varepsilon_0} << 1.$$

Thus the mono-energetic energy peak can be represented to any degree of accuracy desired simply by choosing σ/ε_0 small enough. It is worth noting that $\sim$68 percent of the current falls in the range $\varepsilon = \varepsilon_0 \pm \sigma$ and $\sim$92 percent of the current falls in the range $\varepsilon = \varepsilon_0 \pm 2\sigma$.

NASCAP chooses the discrete energy representation of the Gaussian energy distribution as follows:

$$\varepsilon_i = F^{-1}\left(1 + \frac{(1/2 - i)}{n_\varepsilon}\right) \qquad i = 1, 2, \ldots, n_\gamma$$

where

$$F(X) = \int_X^{\infty} \frac{1}{\sqrt{2\pi}\,\sigma} \exp\left\{-\frac{1}{2}\left(\frac{\varepsilon - \varepsilon_0}{\sigma}\right)^2\right\} d\varepsilon \qquad (7.1)$$

This choice results in the following equality being satisfied:

$$\int_{\varepsilon_i}^{\varepsilon_{i+1}} J(\varepsilon)\, d\varepsilon = \frac{I_B}{n_\varepsilon} \qquad (7.2)$$

where we define $\varepsilon_0 = 0$ and $\varepsilon_{n_\varepsilon+1} = \infty$.

Thus each discrete energy ε_i represents the same fraction $(1/n_\varepsilon)$ of the total emitted current. Furthermore, half of this fraction is a result of energy in the range $\varepsilon_{i-1} < \varepsilon \leq \varepsilon_i$ and half is a result of energy in the range $\varepsilon_i \leq \varepsilon < \varepsilon_{i+1}$.

(d) Lorentzian Energy Current Density Dependence

A Lorentzian function may be used as an approximation to the mono-energetic spectrum. The current density function used by NASCAP for the Lorentzian approximation is

$$J(\varepsilon) = \frac{\mu \ I_B}{\left(\pi/2 + \tan^{-1} \mu\right)} \left\{ \frac{\alpha^2 \ \varepsilon_0 \varepsilon}{\left(\varepsilon^2 - \varepsilon_0^2\right)^2 + \left(\varepsilon_0 \varepsilon \alpha\right)^2} \right\}$$

where I_B = total emitter beam current.

$$\mu = \sqrt{2 - \alpha^2/\alpha} \quad \text{and} \quad \alpha = \sigma/\varepsilon_0$$

This density function has the property that

$$\lim_{\sigma \to 0} J(\varepsilon) \quad I_B \ \delta(\varepsilon - \varepsilon_0)$$

and

$$\int_0^\infty J(\varepsilon) \ d\varepsilon = I_B \quad \text{for all } \sigma/\varepsilon_0 < \sqrt{2} \ .$$

NASCAP chooses the discrete energy representation of the Lorentzian energy distribution according to Eq. (7.1) with the integrand for F(X) replaced by the Lorentzian density function divided by I_B. This choice of energies also results in the satisfaction of the equality given by Eq. (7.2).

8. OTHER MODULES

There are seven other NASCAP modules still left to discuss. In this chapter we tie up these loose ends. Three of the remaining modules, HIDCEL, SPIN and ROTATE all concern the illumination of the object with sunlight. NEWMAT allows you to change material properties without redefining your whole object. SATPLT lets you examine how your object looks from a number of points of view. IPS allows you to set the initial potentials of insulators and conductors to some value other than zero. CAPACI calculates the capacitances of the object. Finally STRESS searches out cells that have the greatest internal electric fields and so are most likely to "punchthrough".

Let us begin by looking at the shadowing modules.

8.1 HIDCEL

The fraction of the full sun intensity that effectively illuminates each surface cell of an object depends on its orientation, i.e., on the angle θ between the surface normal and the negative of the imagined velocity vector of the photons (i.e., the sun direction vector):

$$I = I_0 \cos \theta$$

For surfaces pointing away from the sun I is zero, and they are completely in shadow.

Surfaces that point towards the sun may also be completely or partially in shadow, due to other parts of the object lying between them and the sun. This "geometrical" shadowing also contributes to the overall illumination of each cell.

The module HIDCEL calculates the fraction of each surface cell that is actually illuminated by the sun as a result of geometrical shadowing. The values it calculates form the 'shadowing table'. This is written out to file 21 (2.8) under the keywords 'AREAS' (for non-boom cells) and 'BSHAD' (for boom cells). [Table 2.6.] TRILIN then calculates the effective sun intensity (and hence photocurrent) for each cell by multiplying the shadowing table entry by the appropriate cos θ factor (and SUNINT (6.4.11)).

HIDCEL is executed by including the primary keyword

HIDCEL

in the NASCAP runstream. HIDCEL is usually executed immediately before TRILIN. (Precedence of keywords is summarized in Table 2.2.) It requires no user input itself, but must be used in conjunction with the run options (Chapter 6) 'SUNINT' and 'SUNDIR'. Including the card

SUNINT s

in the options file changes the sun intensity from the default value of zero (no sun at all) to s. (This is explained in Section 6.4.11.) Once SUNINT is set to a non-zero value, photoemission will be included in TRILIN's current calculations, and TRILIN will look for a shadowing table in file 21. If no shadowing table has been created by a previous execution of HIDCEL an error will occur. This can be avoided either by making sure HIDCEL has been executed, or by including the card

CONVEX

(see 6.4.2) in the options file. CONVEX tells TRILIN that a shadowing table is not needed because all entries in it would be one. In other words, the object has no surfaces shielded from the sun by the rest of the object (a sphere, for example). Obviously most complex objects are not convex and for these HIDCEL should be executed. The shadowing table calculated depends on the orientation of the object with respect to the sun. This is determined by the user with the run option SUNDIR. The card

SUNDIR x' y' z'

included in the options file changes the orientation vector defining

the direction from the spacecraft toward the sun from its default value of X = 1, Y = 1, Z = 1 to X = x', Y = y', Z = z'. (See Section 6.4.10.) Each new choice of direction must be accompanied by a new shadowing table. In other words if SUNDIR is changed a new call to HIDCEL must be made. Failure to do this will cause TRILIN to use the old shadowing table and calculate erroneous results with no obvious error messages. Any calls to HIDCEL for the purposes of calculating photoemission must follow calls to TANK but precede calls to TRILIN. This is discussed in Section 5.9.1.

For multiple runs using the same object and the same sun position, the same shadowing table can be used and so HIDCEL need only be executed once (in the first run). Similarly RESTARTed runs remember the shadowing table from the previous run. HIDCEL plots a 3D-VIEW (6.6.1) of the object from the sun position each time it is called, either explicitly by the user, or by other modules (TANK, SPIN, ROTATE).

A summary of HIDCEL operations is given in Figure 8.1.

8.2 ROTATE

The module ROTATE is a utility designed to simulate the rotation of a spacecraft in sunlight. It is used with multiple calls to TRILIN. ROTATE is executed between calls to TRILIN by including the card

ROTATE <n>

in the NASCAP runstream. ROTATE expects to find two cards in the user input file n. There is no default value for n and n = 5 is most commonly used. The two cards following ROTATE in the NASCAP runstream are then read as ROTATE input. A segment of a NASCAP runstream using ROTATE has the general form:

1. HIDCEL calculates geometrical shadowing factors for each surface cell (shadowing table).

2. Shadowing table stored as 'AREAS' and 'BSHAD' in File 21.

3. Precedence: HIDCEL must be preceeded by OBJDEF and logically preceeds TRILIN.

4. If SUNINT / 0, then either HIDCEL must be called or CONVEX be specified as a run option.

5. Each new choice for SUNDIR must be followed (for non-CONVEX objects) by a new call to HIDCEL.

6. HIDCEL plots the view of the object from the "sun" position.

7. HIDCEL uses no input file.

Figure 8.1. HIDCEL summary.

```
.
.
TRILIN
ROTATE 5
ωx  ωy  ωz
x   y   z
TRILIN
ROTATE 5
ωx  ωy  ωz
x   y   z
TRILIN
.
.
.
```

The first card that ROTATE expects to find contains the angular velocity vector (in rad s^{-1}) ω_x ω_y ω_z. The second contains the initial sun direction <u>for cycle 1</u>! Obviously this remains the same for all further TRILIN cycles. For example, the sequence:

```
.
.
.
TRILIN
ROTATE 5
0.2  0.0  0.0
0.0  1.0  0.0
TRILIN
ROTATE 5
0.2  0.0  0.0
0.0  1.0  0.0
.
.
.
```

simulates an object rotating about the X axis at 0.2 radians per second (1.9 rpm), beginning with the sun direction lying along the Y axis (in the positive sense). An initial call to TRILIN (before any call to ROTATE) is required to establish the elapsed time (usually equal to DELTA (6.2.2) - but see (6.2.6)). The subsequent call to ROTATE changes the sun direction vector and the magnetic field vector to simulate the rotation of the object by the elapsed time times the

magnitude of its angular velocity. In our example above, if the first call to TRILIN increased the elapsed time to 5 seconds, then the sun direction vector will be rotated from 0 1 0, about the X axis by 5 x 0.2 = 1.0 radian. The next call to TRILIN will then take place with the rotated sun direction vector (0 -0.54 -0.84) and so on.

Of course, changing the sun direction vector must always be accompanied by a new call to HIDCEL. ROTATE automatically calls HIDCEL to establish a new shadowing table (8.1) unless the option

CONVEX

has been included in the run options file. Further calls to TRILIN without any more calls to HIDCEL, SPIN or ROTATE will use the last shadowing table created by ROTATE.

If the number of cycles chosen for each call to TRILIN (NCYC 6.2.7) is greater than one, the same shadowing table will be used for each cycle, until ROTATE is called again. This will lead to significant errors unless the timestep is much shorter than the rotation period. When simulating rotation NCYC should usually be one.

ROTATE should always be called after any call to TANK (See Section 8.1).

ROTATE can be used to simulate rotation in an anisotropic plasma environment (whether there is sunlight present or not), since the direction of the aligned flux component (the magnetic field direction) is also rotated.

The calls ROTATE makes to HIDCEL generate the appropriate plots (see 8.1).

Finally, omission of any file number in the call to ROTATE causes ω_x ω_y ω_z and x y z to be set at the default values, i.e.,

angular velocity = ω_x ω_y ω_z 0 0 $2\pi/60$
(1 rpm about the Z axis)

x y z 1 0 0
(Initial sun direction along the X axis)

For example

```
TRILIN          TRILIN
ROTATE     ≡    ROTATE 5
TRILIN          0  0  2π/60
                1  0  0
                TRILIN
```

A summary of ROTATE is given in Figure 8.2.

8.3 SPIN

The module SPIN creates a shadowing table (8.1) based on the <u>average</u> illumination of each surface cell over one rotation period. The card:

```
SPIN <n>
```

included in the NASCAP runstream will execute module SPIN. SPIN should preceed a call to TRILIN intended to simulate charging of an object averaged over a rotation. (Exact precedence is summarized in Table 2.2.)

Like ROTATE (8.2) SPIN expects to find two input cards in file n. n has no default and n = 5 is most commonly used. In this case, SPIN looks for the next two cards in the NASCAP runstream as input. A segment of the runstream calling SPIN has the general form:

1. ROTATE simulates rotation of an object in sunlight and/or an anistropic flux.

2. Unless CONVEX is specified in the options file ROTATE calls HIDCEL and creates a new shadowing table.

3. Precedence: ROTATE must be preceeded by TRILIN and logically preceeds a second call to TRILIN.

4. ROTATE reads two cards from file n, e.g. for n = 5
ROTATE 5

   ω_x ω_y ω_z angular velocity vector (rad/5)

   x y z initial sun direction at the beginning of cycle 1.

5. NCYC should usually be 1.

6. Calls to ROTATE should follow calls to TANK.

Figure 8.2. ROTATE summary.

```
.
.
.
SPIN 5
num
x  y  z
TRILIN
.
.
.
```

The first card read by SPIN:

```
'num'
```

defines the number of views of the object to be included in the rotational average. The second card:

```
x  y  z
```

defines the orientation of the spin axis. For example

```
SPIN 5
4
0  1  0
```

calls for 4 views to be included in the average for rotation about the Y axis. The initial direction of the sun with respect to the satellite, or the first view, is defined by the 'SUNDIR' option, included in the options file (Section 6.4.10). For example, including the card

```
SUNDIR  1  0  1
```

in the option file (IKEYWD) defines the initial view to be in the XZ plane at an angle of 45° from the positive X axis (i.e., between the positive X and Z axes). The remaining three views in our example are generated by rotating the sun direction vector by $2\pi/num$ ($= 2\pi/4 = \pi/2$) and making a fresh call to HIDCEL for each time. The final average will therefore be over the shadowing factors for the four orientations 45°, 135°, 225°, 315° in the XZ plane. If num had been chosen to be 3 then the three views would have been from angles 45°, 165°, 285°, and so on. The shadowing table generated by SPIN differs from that generated by HIDCEL and ROTATE since the contribution made by the angle θ between the surface normal and the sun direction is

included. Recall from 8.1, this contribution is added later by TRILIN for HIDCEL and ROTATE, and the shadowing table contains only geometrical shadowing factors. Hence, if the object is defined as

CONVEX

in the options file (6.4.2) a shadowing table is still compiled by SPIN, containing the average of cos θ over the "num" views for each call.

The maximum number of views possible is 25. The greater the number specified, the more accurate the average. For typical objects, eight views is usually sufficient.

If no file number is included in the call to SPIN, the default values of the input parameters are used. For example, the cards

```
.
.
.
SPIN
TRILIN
.
.
.
```

in the NASCAP runstream will lead to a potential calculation, using a shadowing table that is an average of eight views (the default value of "num") about the Z axis (the default rotation axis).

SPIN and ROTATE (8.2) differ in the way they model charging of an object rotating in sunlight. Often the part of the object in shadow charges negatively, while the sunlit part remains close to neutral, or is charged less, because of photoemission. Thus the potential of a particular surface cell will tend to oscillate up and down with the rotation frequency, as it moves in and out of the sun. This oscillatory potential can only be modeled with ROTATE, i.e., ROTATE is able to resolve charging behavior on a timescale less than a rotation period. SPIN, on the other hand, models the average behavior, i.e., behavior on a timescale longer than a rotation period. Its results are valid therefore only if charging occurs on a

timescale larger than a rotation. For spacecraft spinning slower than they charge, ROTATE should be used.

Like ROTATE and HIDCEL, calls to SPIN should follow calls to TANK (see Section 5.9.1). Following a call to SPIN, the CONVEX keyword should be omitted from the runstream input.

A summary of SPIN use is given in Figure 8.3.

8.4 IPS

Module IPS (Initial Potential Specification) allows you to set the initial potentials of both conductors and insulators (dielectrics) to any value. Without the use of IPS all initial potential are assumed to be zero. IPS should always be used when FIXP and/or BIAS determine non-zero initial potentials. IPS should precede a call to TRILIN and/or DETECT. Calls to TRILIN following IPS in the same run are automatically RESTARTed (6.2.9) at cycle 1. If TRILIN is to be executed in a subsequent and separate run, a RESTART card must be explicitly placed in the options file by the user. (Exact precedence is summarized in Table 2.2). The card

```
IPS <n>
```

in the NASCAP runstream executes module IPS. The file number n is optional and defines the file in which IPS expects to find its input cards. The default is 5, in which case IPS looks for input following immediately in the NASCAP runstream. IPS is able to interpret eight types of potential specification cards as input. These are:

```
ALL matl v
BOOM i v
BOOM CELL v
DARK matl v
END
PCOND i v
POTENTIAL v
SUNLIT matl v
SURFACE CELL v
```

We examine each of these in turn.

1. SPIN simulates the average behavior of an object rotating in sunlight.

2. Unless CONVEX is specified as a run option SPIN calls HIDCEL for each view requested. Following SPIN, CONVEX should be deleted from the runstream input.

3. Precedence: SPIN must be preceeded by OBJDEF and logically preceeds TRILIN.

4. SPIN reads two cards from file n (e.g., n = 5)

```
SPIN 5
num       number of views about spin axis included
          in the average.
x  y  z   spin axis direction.
```

5. SPIN creates a shadowing table by averaging the tables created for each of num views defined by equally spaced rotations from the initial sun direction (SUNDIR) about the axis x y z. Angle effects are included. (8.3)

6. Calls to SPIN should follow calls to TANK.

Figure 8.3. SPIN summary.

8.4.1 PCOND

The card:

PCOND i v

sets the potential of conductor number i to v volts. All of the overlying surface cells are also set to potential v, and any differential charging is eliminated. For example

PCOND 2 -1000

sets the conductor number 2, and all surface cells associated with conductor 2 to -1000 volts.

8.4.2 SURFACE CELL

The card

SURFACE CELL i v

sets the potential of insulating surface cell number i to v volts. The surface cell number is the same as that previously assigned by OBJDEF (3.10). For example:

SURFACE CELL 32 -800

sets the potential of insulating cell 32 to -800 volts.

If the surface cell chosen is not an insulator IPS prints a reminder of this fact and ignores the request.

8.4.3 BOOM CELL

The card

BOOM CELL i v

sets the potential for insulating BOOM cell i to v volts. It works in exactly the same as SURFACE CELL (8.4.2) Indeed it is formally equivalent to:

SURFACE CELL nsurf+i v

where nsurf is the number of non-boom surface cells. For example, suppose there are 300 non-boom cells on an object, and you wish to set

the fifth boom cell to -200 V. This can be achieved with the card

```
BOOM CELL  5   -200
```

or equivalently with

```
SURFACE CELL  305  -200
```

8.4.4 BOOM

The card:

```
BOOM  i  v
```

sets all insulating cells on BOOM i to potential v volts. The underlying conductor is unaffected. For example, the card

```
BOOM  4   -4000
```

sets all insulating cells, on the 4th BOOM to appear in the object definition file (3.5), to -4000 volts.

8.4.5 ALL, DARK, SUNLIT

The card

```
ALL  matl  v
```

sets all the surface cells of insulating material 'matl' to v volts. Attempts to set the potentials of conducting materials (those with property 3 equal to -1 (4.3.3)) with this command are ignored and a warning message is printed. For example, the card

```
ALL KAPTON  -1000
```

sets all cells with surface material Kapton to -1000 volts. The card

```
ALL GOLD  -1000
```

is ignored since gold is a metallic conductor (if its properties are properly defined!). The two subsets of those cells in shadow and those cells in sunlight can be set independently using the cards

```
DARK  matl  v
```

and

```
SUNLIT matl v
```

For example, the card

```
DARK  KAPTON  -1000
```

will set only the KAPTON cells that are in shadow to -1000 volts. Partially shadowed cells (i.e., those with illumination greater than zero) are considered sunlit.

8.4.6 POTENTIAL

The card

```
POTENTIAL v
```

can be used to set any string of cells to a potential v. Immediately following this card, a second card gives the cell numbers to be set. Further cards may also follow. Up to 15 cell numbers may be written on each card. IPS will continue to read cards until an 'END' is found in place of a cell number. For example

```
POTENTIAL  -500
1  3  6  25  7  8
101  512  613  26  27
17  21  END
```

sets the potential of cells 1, 3, 6, 25, 7, 8, 101, 512, 613, 26, 24, 17, and 21 to -500 volts. (This is a particularly useful feature to use with the TERMTALK subset capability.[20]

8.4.7 END

The 'END' card terminates input to the IPS module.

8.4.8 'FIXP' AND 'BIAS' CARDS

The run options FIXP and BIAS (see 6.3.5 and 6.3.1) fix the potential of a conductor and bias it relative to conductor 1 respectively.

These potentials are initially implemented in the IPS module, and will be re-implemented by any subsequent TRILIN call. However, it is possible to conflict with these specifications using the PCOND command. The following rules should be observed:

- Potentials of fixed conductors, or mutually biased systems of fixed conductors, should be specified only in the options file.
- Potentials of floating conductors should be specified only in the IPS file.
- If conductor 1 is at zero potential, potentials of conductors biased to it should not be specified in the IPS file.
- If conductor 1 is floating at non-zero potential, potentials of conductors biased to it should be individually specified in the IPS file.

8.4.9 IPS Files

A typical file read by IPS might have the form

```
BOOM 2  -1000
ALL KAPTON  -2000
DARK TEFLON  -2500
DARK KAPTON  -1638
POTENTIAL  -1770
1  180  223  6  END
END
```

This file sets all the insulating cells on the second boom defined to -1000 volts. All Kapton cells are set to -2000 volts. If some of the boom cells are Kapton, the previous assignment of -1000 V will be overridden by the latest assignment of -2000 V.

Dark Teflon and Kapton cells are set to -2500 and -1638 V respectively. Again, any duplicate assignments are overridden with the latest assigned value. Thus all dark Kapton cell potentials are assigned -1638 V rather than -2000 V.

Finally, cells 1, 180, 223, and 6 are set to -1770 volts. Note that the cell number list is terminated with an 'END', as is the entire file (with a second 'END').

Potential assignments made using IPS are <u>not</u> remembered by subsequent IPS calls. IPS zeroes potentials not specified by FIXP or BIAS before beginning with its own assignments.

The IPS input commands are summarized in Figure 8-4.

8.5 CAPACI

Module CAPACI calculates the capacitance of the whole object, the individual conductors, and surface cells to infinity. In addition it calculates the capacitances between the different parts of the spacecraft. This information is all stored in file ICNOW(21) (Table 2.6).

CAPACI is usually executed after OBJDEF. It <u>must</u> be executed before TRILIN or IPS, since TRILIN uses the capacitance information stored in file 21.

No user input is normally required for CAPACI. However, if DEBYE (6.4.3) is specified as a run option, CAPACI reads the plasma environment information from the IFLUX file. The IFLUX file is then read again later by TRILIN in the normal way.

PCOND i v

Set conductor i and all overlying surfacea cells to potential v.

SURFACE CELL i v

Set insulating surface cell i to potential v.

BOOM CELL i v

Set the i^{th} boom cell to potential v. (Equivalent to SURFACE CELL [NSURF + i] v).

BOOM i v

Set all insulating cells on BOOM i to potential v. (Does not set underlying conductor.)

ALL matl v

DARK matl v

SUNLIT matl v

Sets all cells of material matl to potential v. Variants allow only dark or only sunlit cells to be set.

POTENTIAL v

S_1 S_2 ... END

Set a list of surface cells to potential v. The list appears on subsequent cards, with up to fifteen numbers per card. Processing continuers until END is encountered in place of a cell number. (The TERMTLK SUBSET capabilities might be used to generate such a list.)[20]

END (or @EOF)

Conclude keyword processing

Figure 8.4. IPS input commands.

8.6 NEWMAT

The module NEWMAT allows the properties of a material (Chapter 4) to be changed, without re-defining the whole object using OBJDEF (Chapter 3) again. The 19 properties that characterize each material are initially defined during the execution of OBJDEF. NEWMAT is most often used to change some of the properties in a subsequent run, prior to a new call to TRILIN. (The exact precedence of NEWMAT is summarized in Table 2.2.) NEWMAT is executed by including the card

```
NEWMAT  n
```

in the NASCAP runstream. The parameter n specifies the number of the file where NEWMAT expects to find its input parameters. Usually n = 5 is chosen so that NEWMAT reads the next four cards in the NASCAP runstream as input.

For example, the cards:

```
.
.
.
NEWMAT 5
KAPTON
3.5  0.000127  1.E-16  5.  2.1  0.15  71.48  0.60
312.1  1.77  0.455  140.  0.00002  1.E+16  15.  16.
1.E-13  1.  1.E+3  20.
END
```

included in the NASCAP runstream redefine the KAPTON material properties to the values given on the cards. The format for input of material properties for NEWMAT is exactly the same as in OBJDEF (4.4). The completed list of materials and properties must be terminated by an 'END' card. (Otherwise NEWMAT will assume that all further cards in the runstream are new material names.) For example, if two materials are to be re-defined, the relevant part of the runstream might have the form:

```
            NEWMAT 5
           ⎧KAPTON
           ⎪{3 parameter cards (4.4)
NEWMAT     ⎨GOLD
INPUT      ⎪{3 parameter cards (4.4)
           ⎩END
            TRILIN
            END
```

There are two restrictions in the use of NEWMAT:

1. The names of materials cannot be changed, or new material names introduced.

2. The values of the bulk conductivity and surface conductivity (properties 3 and 14) may not be changed so that the material changes from an insulator to a metallic conductor or visa versa, or from a surface non-conductor to a surface conductor. In other words, the values of properties 3 and 24 may not be changed from positive values to negative values or vice versa.

Changing the sign of properties 3 and 14 cause changes in the structure of conductivity matrices rather than their value, and OBJDEF must be re-executed in these cases.

Note that the capacitances of the object brought about by changes in material properties are automatically accounted for by NEWMAT, and no subsequent re-execution of CAPACI is necessary.

8.7 SATPLT

Module SATPLT requires no direct user input, and causes three-dimensional views of the object to be plotted, along with two-dimensional maps of the pattern of surface materials.

The nature of the views and maps are determined using the run options 3D-VIEW (6.6.1) and MATVIEW (6.6.4) respectively. If no views are specifically requested using this option, the default views discussed in 6.6.1 and 6.6.4 are produced. SATPLT is usually called after OBJDEF as an aid, to see if the object we had in mind is actually the object we defined (or to see if they at least look the same). The exact precedence is summarized in Table 2.2. The card:

SATPLT

included in the runstream executes SATPLT. Examples of the plots produced are given in Chapter 9.

8.8 STRESS

The module STRESS is used to determine the surface cells with internal electric fields of greatest magnitude. The internal electric field, or stress, E_{stress} is defined as

$$E_{stress} = \frac{V_c - V_s}{d}$$

where V_c is the potential of the underlying conductor, V_s is the potential of the dielectric surface and d is the thickness of the dielectric surface layer. The greater this stress field, the more likely a dielectric breakdown or "punchthrough" will occur. (See 6.3.3 discussing the NASCAP DISCHARGE analysis.)

STRESS is executed by including the card

STRESS <m>

in the NASCAP runstream, usually after a call to TRILIN. (Exact precedence is summarized in Table 2.2.) The only input parameter is the optional quantity m. m is the number of cells to be reported by STRESS. For example, the card

STRESS 10

will cause the 10 cells with the greatest stress to be identified in descending order of stress field. Omission of <m> causes all cells to be listed in descending order of stress.

For each cell included in the list generated by STRESS, the value of its stress field and its cell number, along with its surface material, normal, vertex, and other identifying information, is printed out.

9. GRAPHICAL OUTPUT

Graphical output is a key component in the presentation and interpretation of NASCAP results. The plotting protocol is designed to be easily interfaced to any system's graphics library. The plots appear in four colors (black, red, green, blue) when plotted on color hardware. The types of plots produced are (1) object illustration and shadowing plots; (2) contour plots; (3) particle trajectory plots; and (4) detector plots.

9.1 OBJECT ILLUSTRATION AND SHADOWING PLOTS

Object illustration plots are produced by the SATPLT module (or the interactive OBJCHECK object definition program).[20] Three types of plots are produced: material plots, 3-D plots without hidden line elimination, and 3-D plots with hidden line elimination (shadowing plots).

9.1.1. MATERIAL PLOTS

Material plots (Figures 9.1-9.2) are designed to show the placement of materials on the object. Each of the fifteen materials is shown with different shading and (on appropriate hardware) different colors. (Materials 1, 5, 9, 13 are in black; 2, 6, 10, 14 in red; 3, 7, 11, 15 in green; and 4, 8, 12 in blue.) By default, six plots are generated showing the view from each coordinate direction. The MATVIEW keyword (6.6.4) may be used to expose surfaces which would otherwise be hidden (Figure 9.3).

9.1.2. 3-D PLOTS

Two types of 3-D object plots are available. The first type (Figure 9.4), plotted only by SATPLT (or OBJCHECK), plots the outline of the large blocks (RECTAN, OCTAGON, etc.) projected on a plane normal to the view direction without hidden line elimination. Booms

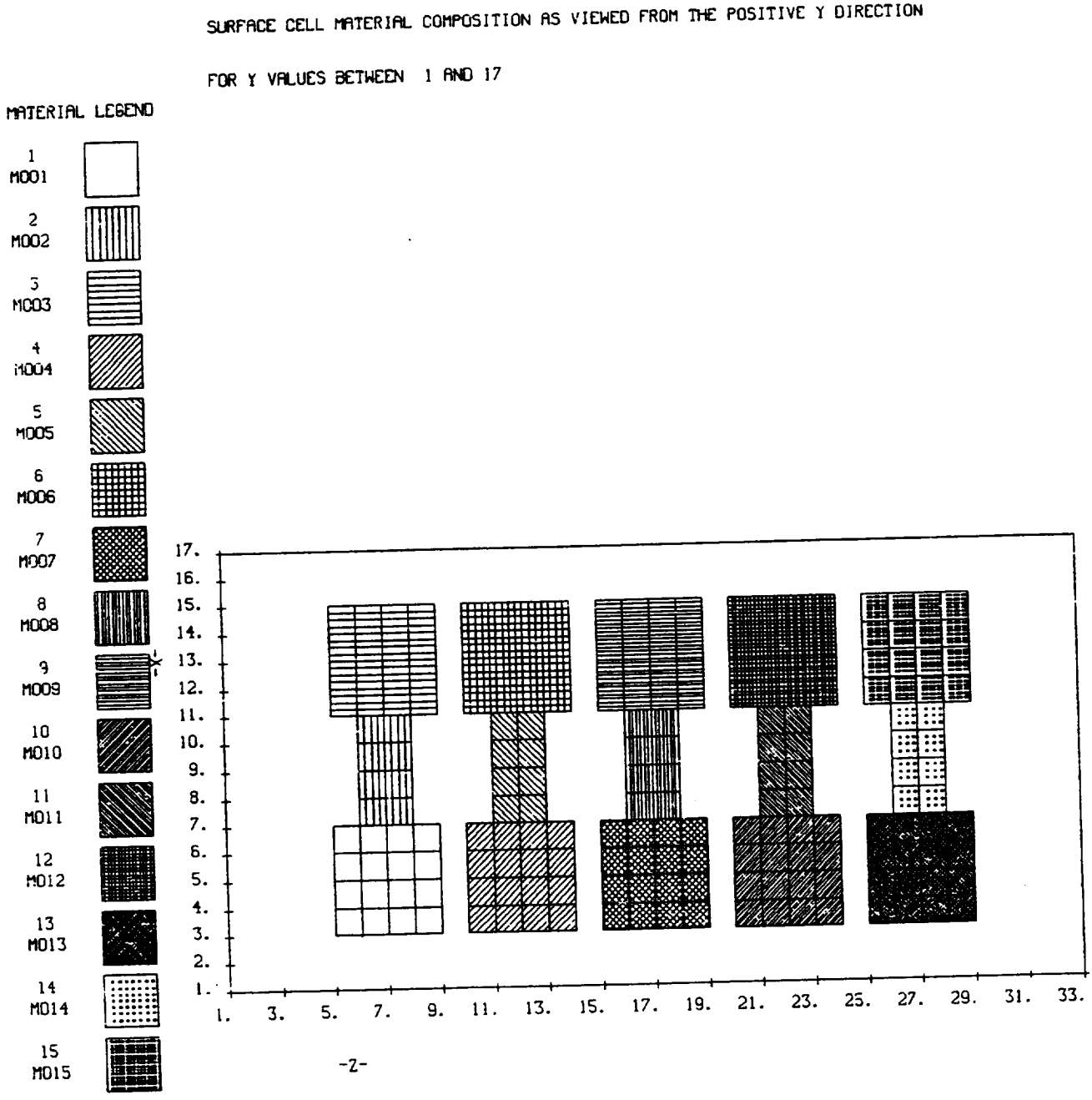


Figure 9.1. Material plot of an object consisting of five dumbbells. All fifteen shading patterns are illustrated.

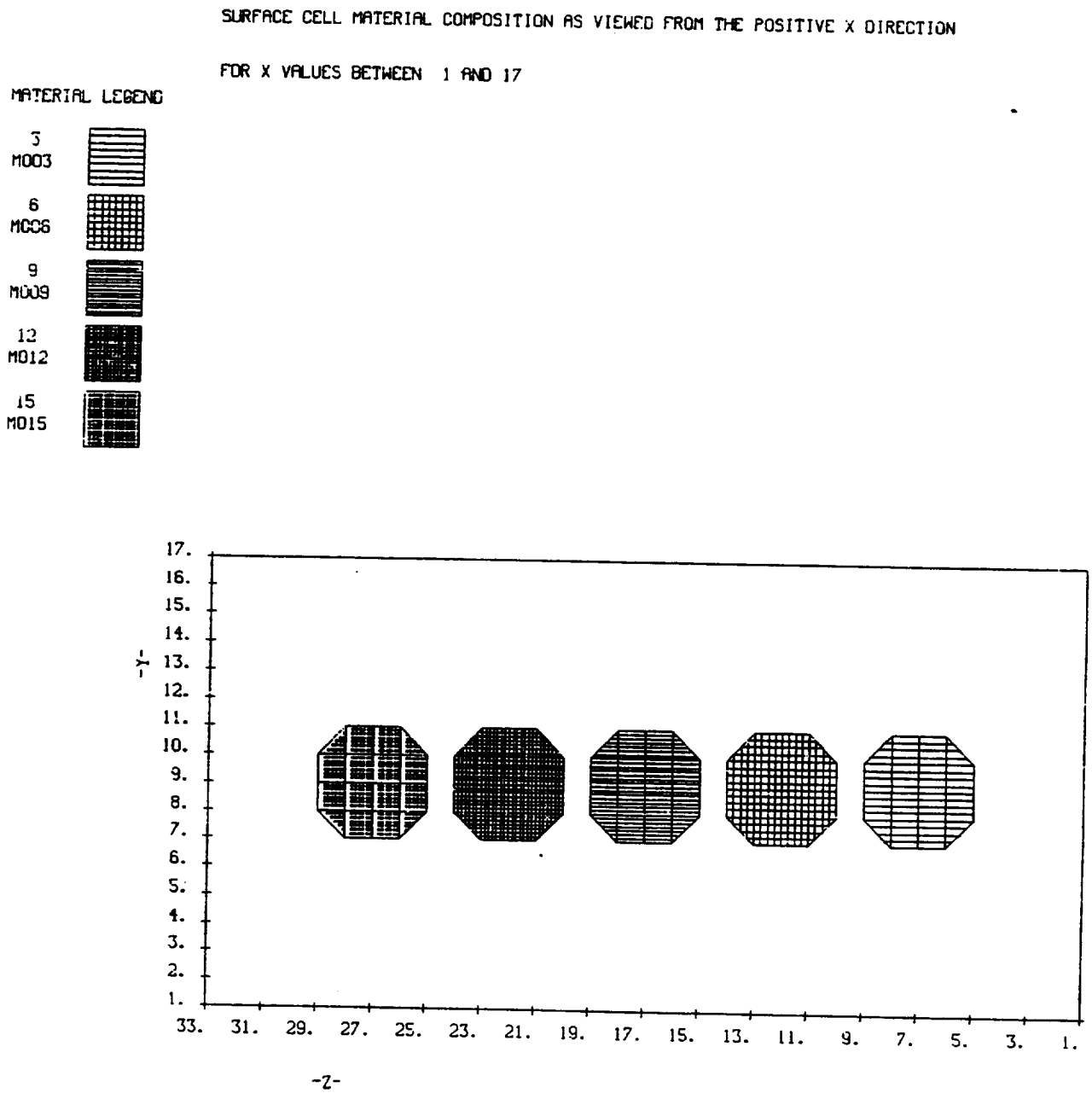


Figure 9.2. Another material plot view of the object in Figure 9.1.

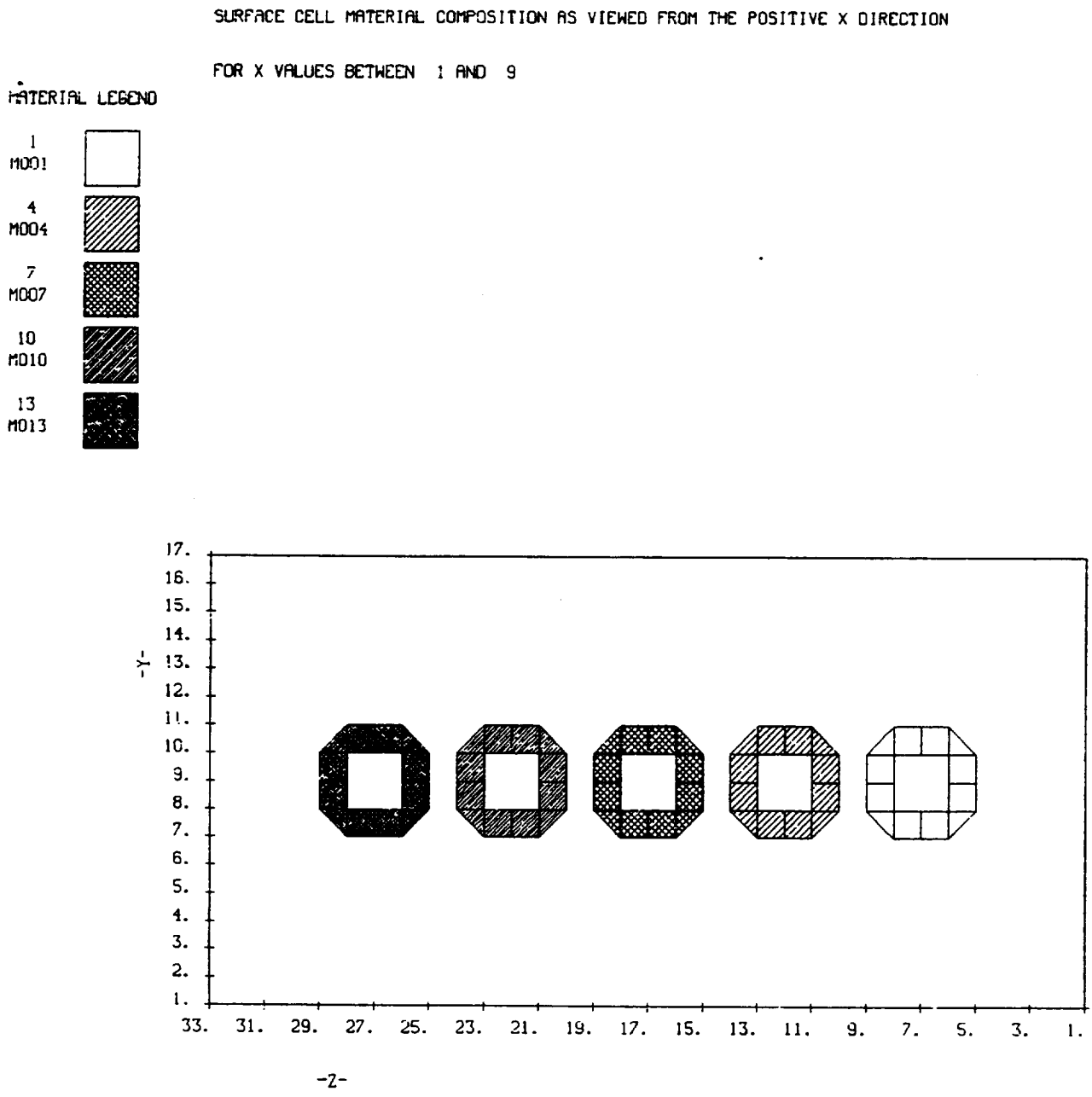


Figure 9.3. Material plot view of surfaces which were hidden in Figure 9.2.

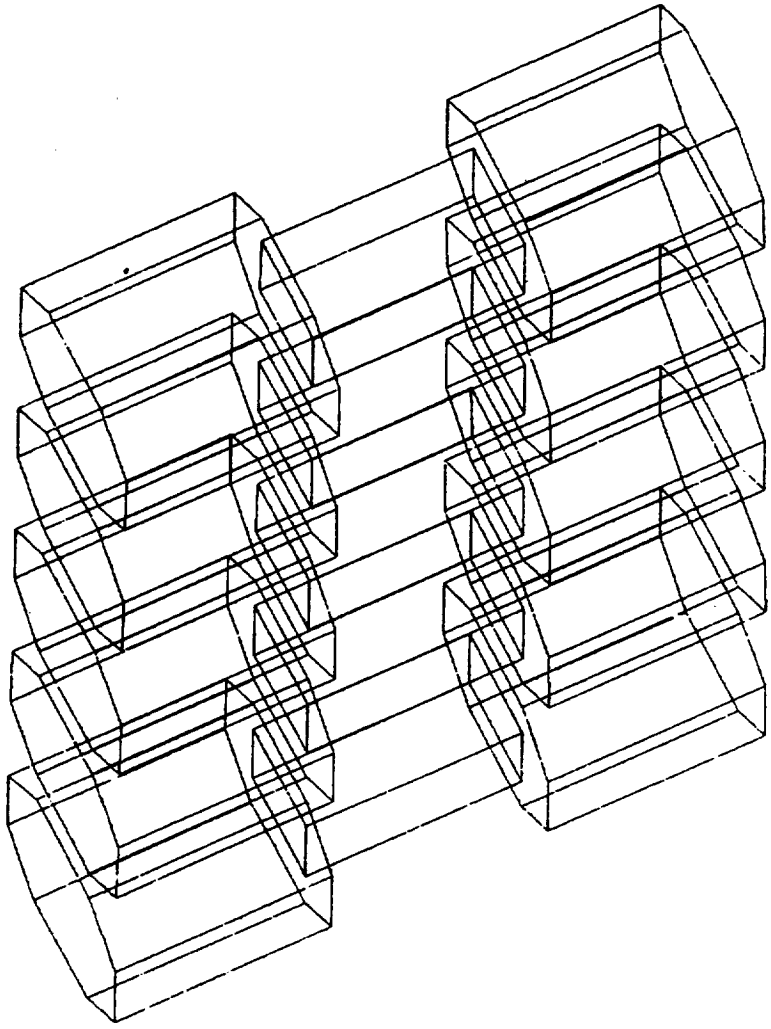


Figure 9.4. Perspective view of the object in Figures 9.1-9.3, without hidden line elimination.

are omitted from this plot. The second type (Figure 9.5) plots individual surface cells and boom surfaces with hidden lines eliminated. This type of plot is also produced by calls to the HIDCEL, SPIN, ROTATE and TANK modules. The plots are from the perspective of a viewer 1000 mesh units distant, except that the TANK module places the viewer at the gun positions. On appropriate hardware, the shadowing plots are color-coded by material (as on the material plots).

9.2 CONTOUR PLOTS

Contour plots are produced by various portions of the TRILIN module. The quantity whose contours are most commonly plotted is the electrostatic potential. (This may also by plotted by the interactive POTPLT program.[20]) In addition, contours of space charge (calculated by the SHEATH option), and of current density (calculated by the TYPE 1 test tank) may be plotted. Contour plots include a "silhouette" of the test object.

9.2.1 ELECTROSTATIC POTENTIAL CONTOURS

Contours of electrostatic potential in a plane normal to one of the coordinate axes will be plotted on request. Frequency and location of plots may be controlled through the CONTOURS keyword (6.6.2). Each plot is captioned as to cycle number, time, location, and contour levels (volts). (The interactive POTPLT program also allows control over number of contours.) A potential contour plot example is shown in Figure 9.6.

It should be noted that "exact zeros" in the interior of the potential array are assumed interior to the object and are set at conductor 1 potential. This has proved a good procedure in the vast majority of cases. The user must be aware that the contour lines inside the object do not exist and should be expunged before presentation.

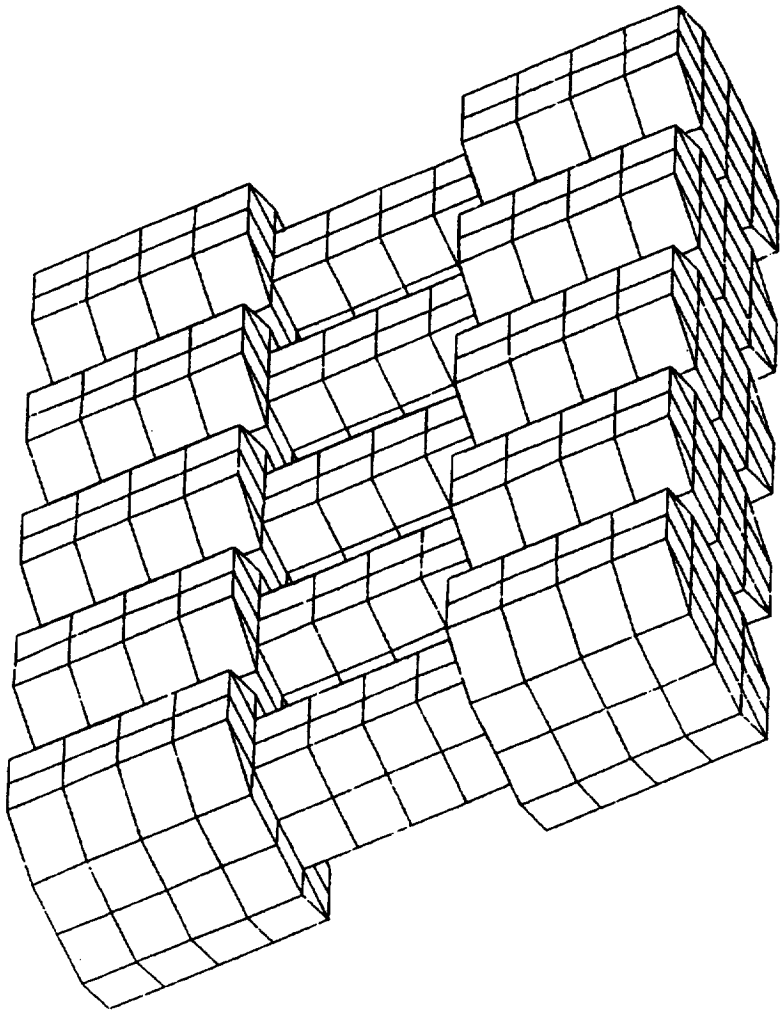
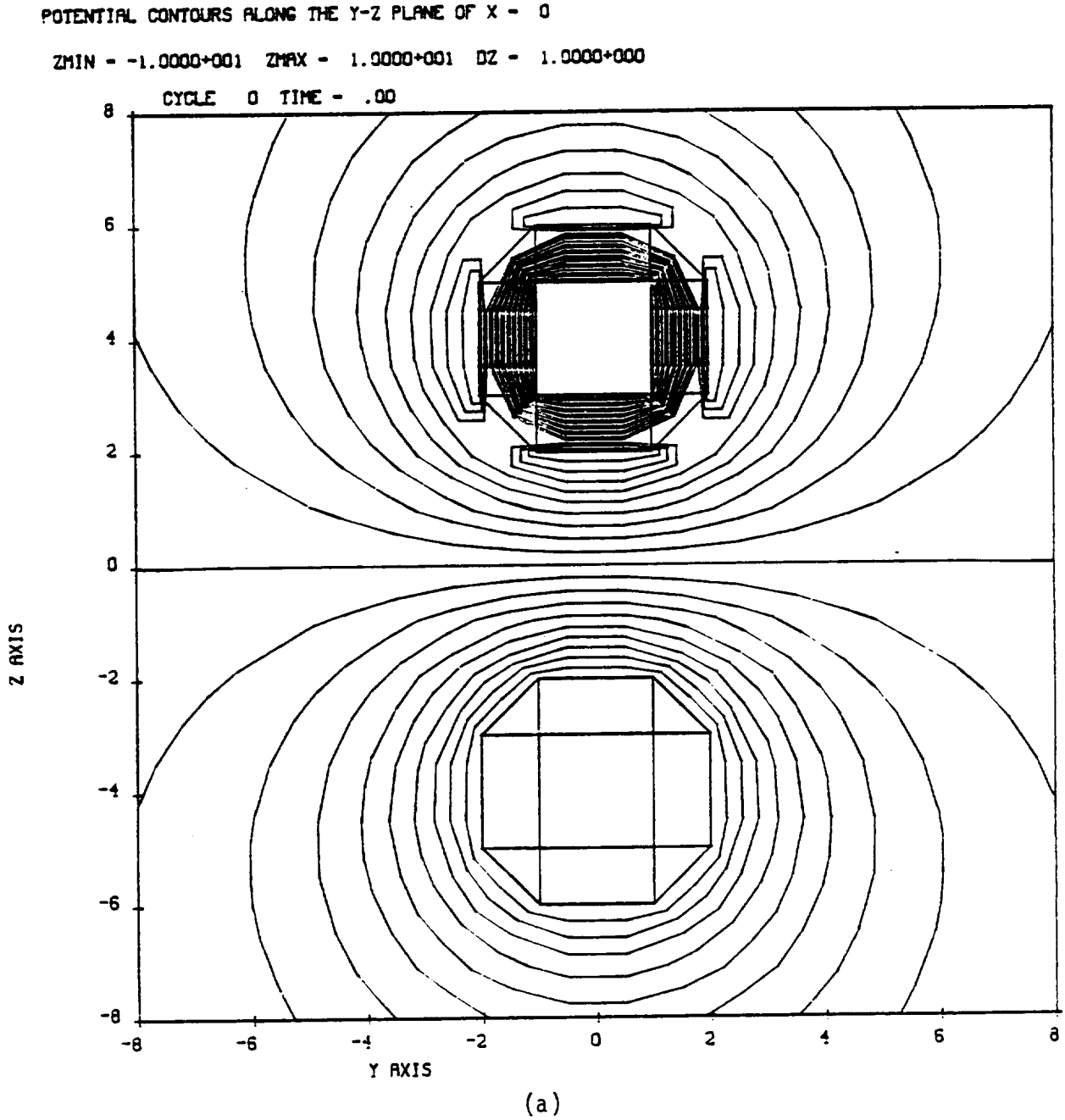
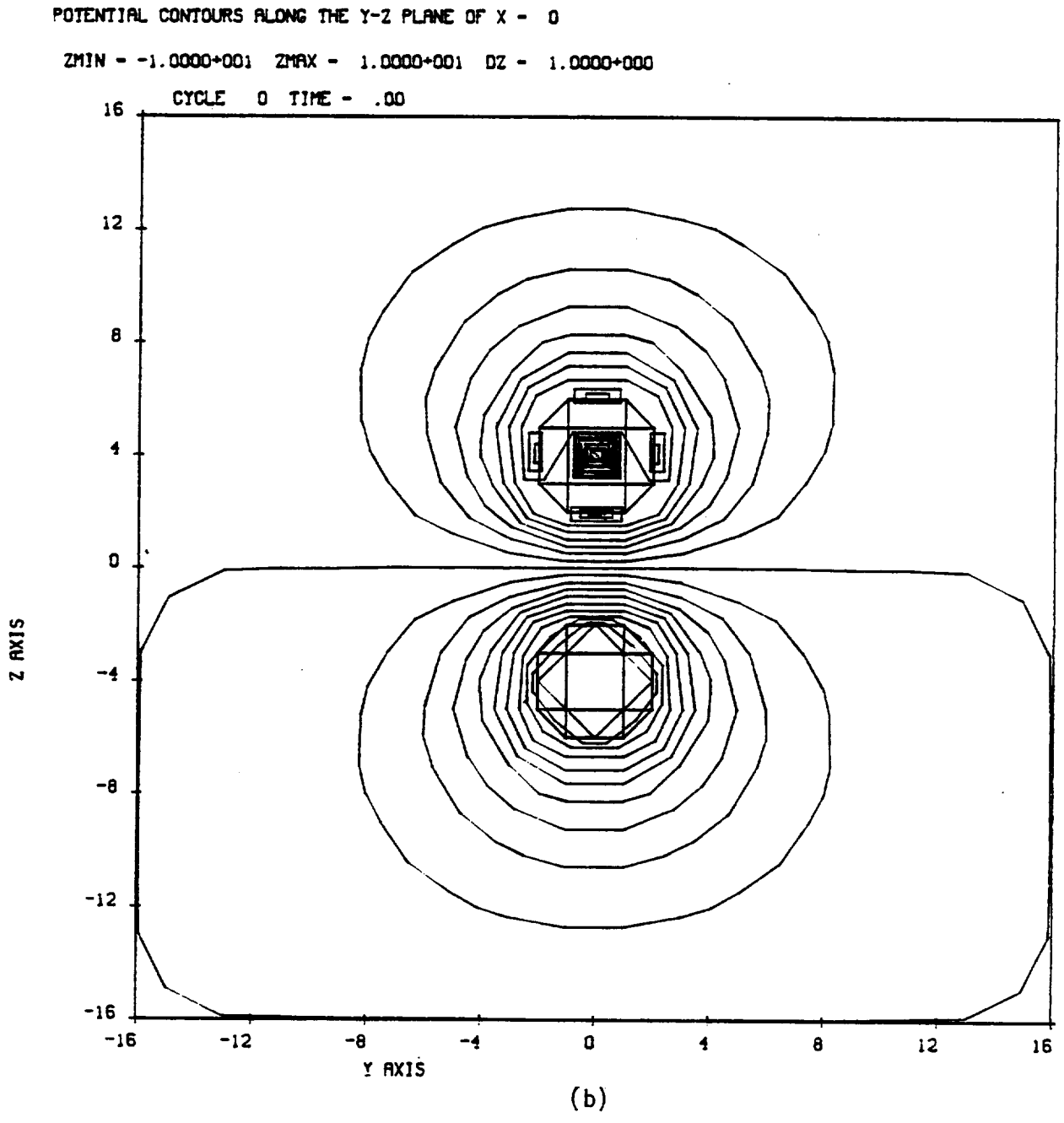


Figure 9.5. The view of Figure 9.4 after hidden line elimination.



(a)

Figure 9.6. Electrostatic potential contours about an object composed of two spheres. The lower sphere is at +10 V and the upper at -10 V. (a) One-grid plot; (b) Two-grid plot.



(b)

Figure 9.6. Electrostatic potential contours about an object composed of two spheres. The lower sphere is at +10 V and the upper at -10 V. (a) One-grid plot; (b) Two-grid plot.

9.2.2. CHARGE DENSITY CONTOUR PLOTS

Space charge density associated with low energy emitted electrons (i.e,, secondary electrons and photo-electrons), is plotted by the TRILIN module when the keyword SHEATH is included in the options file (6.6.6). The contour levels are in coul/m^3. An example is shown in Figure 9.7a. The example is for the same case as Figure 9.6; most of the low-energy electrons result from sunlight incident from the +Y direction. Note that the charge density near the positive (lower) sphere is about double that near the negative (upper) sphere. The reason is seen in the accompanying particle trajectory plot, which shows electrons repelled from the negative sphere, but forming a cloud around the positive sphere.

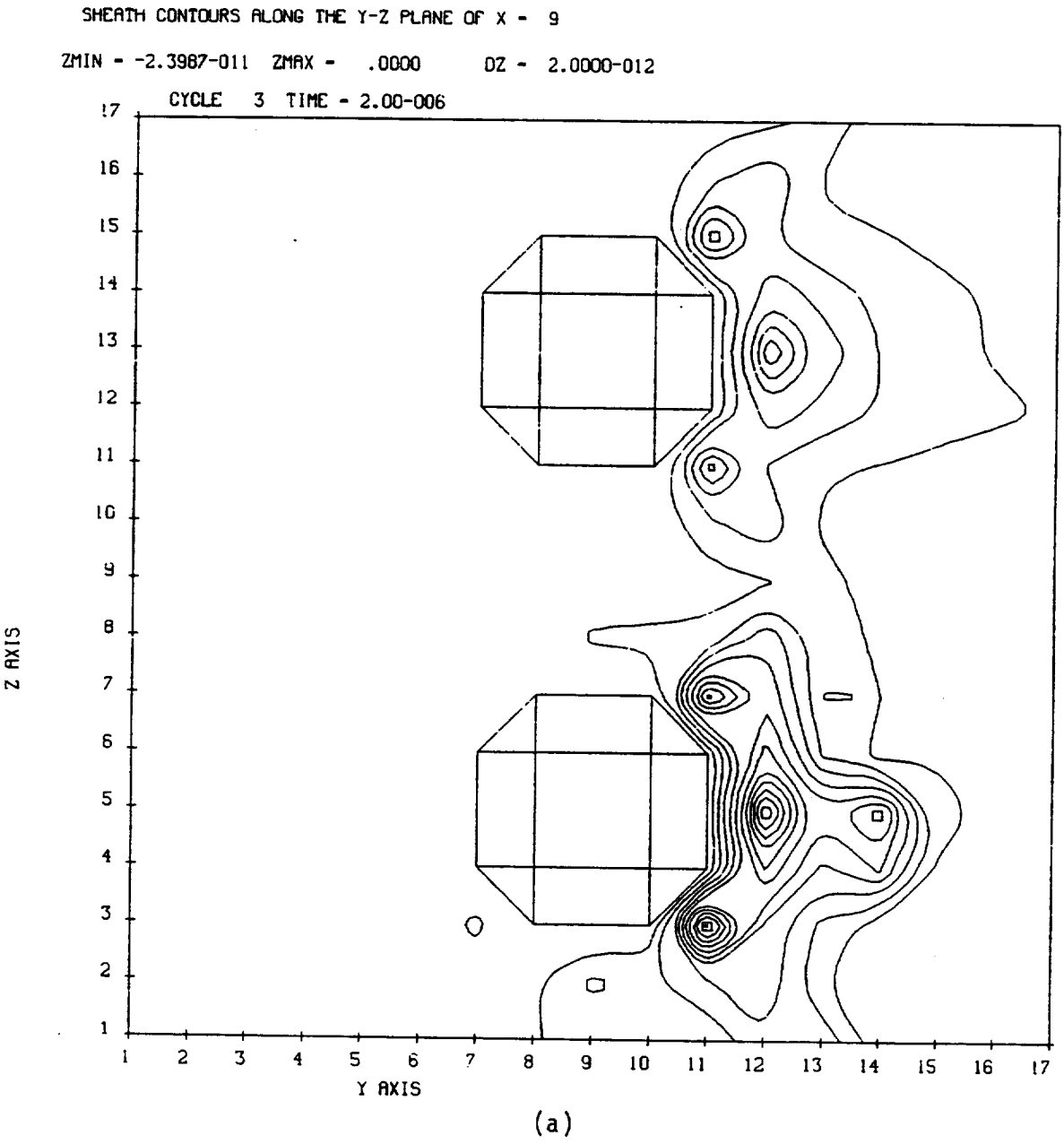
9.2.3 CURRENT DENSITY CONTOUR PLOTS

Current density contour plots from the TYPE 1 test tank may be requested using the TANKCUR keyword. The plots give the Z-component of current (A/m^2) projected onto the "sample plane". Examples are shown in Figures 9.8d-f.

9.2.4. CONTOUR PLOT RESOLUTION ERRORS

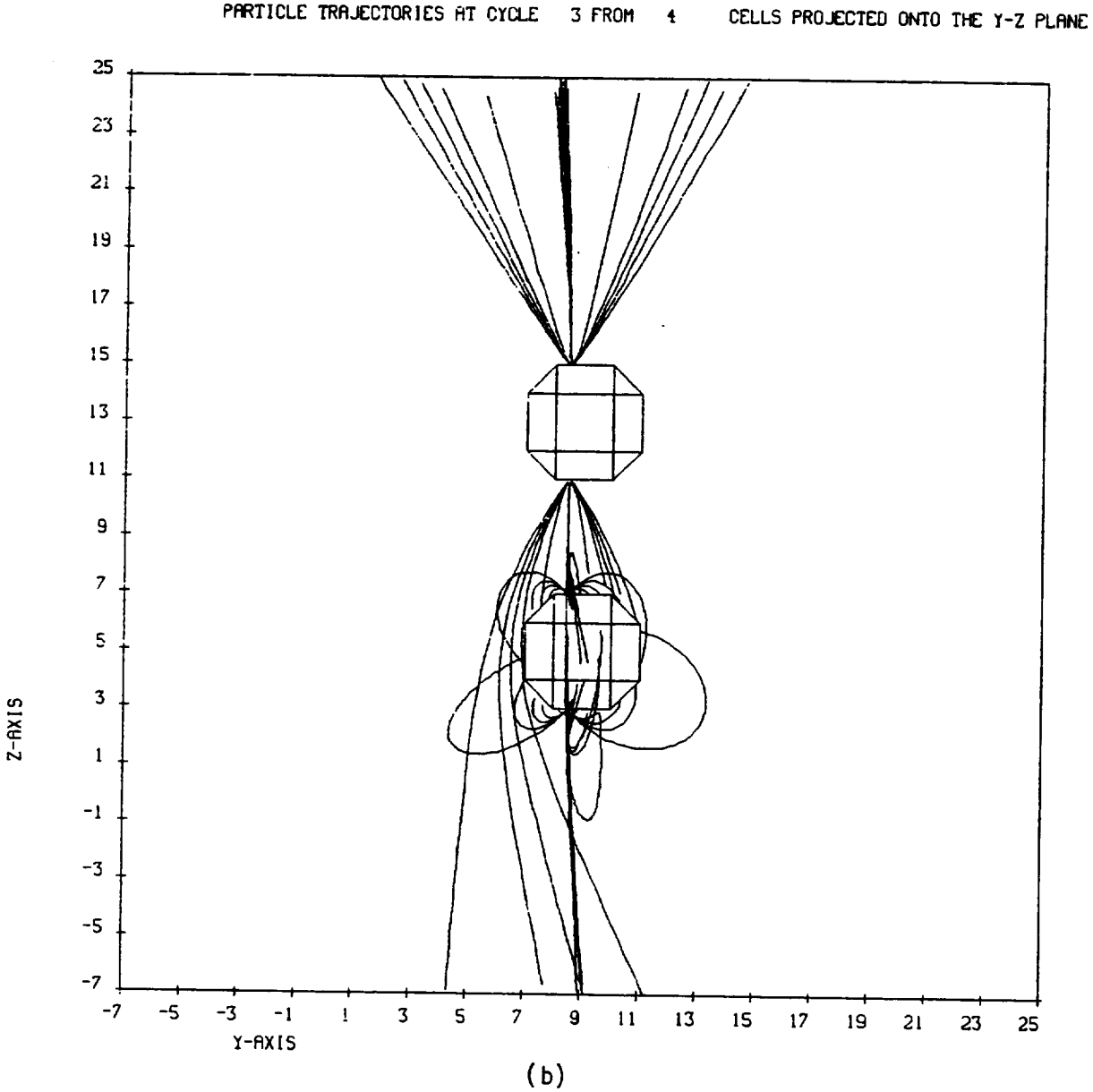
Contour plots are performed using straightforward bilinear interpolation. Near object surfaces, this is a far cruder model than is used internally in NASCAP (for potential calculations, particle tracking, and electrostatic field calculation). In interpreting contour plots the user should be aware of these shortcomings.

Some of these errors are shown in Figure 9.6. We have previously mentioned that the conductor 1 potential (+10V in this case) is inserted for potentials interior to the object. This results in contour lines interior to the upper (-10V) sphere. Also, the contours exterior to the upper sphere are in error near the slanted surfaces. NASCAP understands the potential at the midpoint of the



(a)

Figure 9.7. Low energy electron sheath structure for two spheres (upper at -10 V; lower at +10 V) with sunlight from +Y direction. (a) Charge density contours; (b) Electron trajectories.



(b)

Figure 9.7. Low energy electron sheath structure for two spheres (upper at -10 V; lower at +10 V) with sunlight from +Y direction. (a) Charge density contours; (b) Electron trajectories.

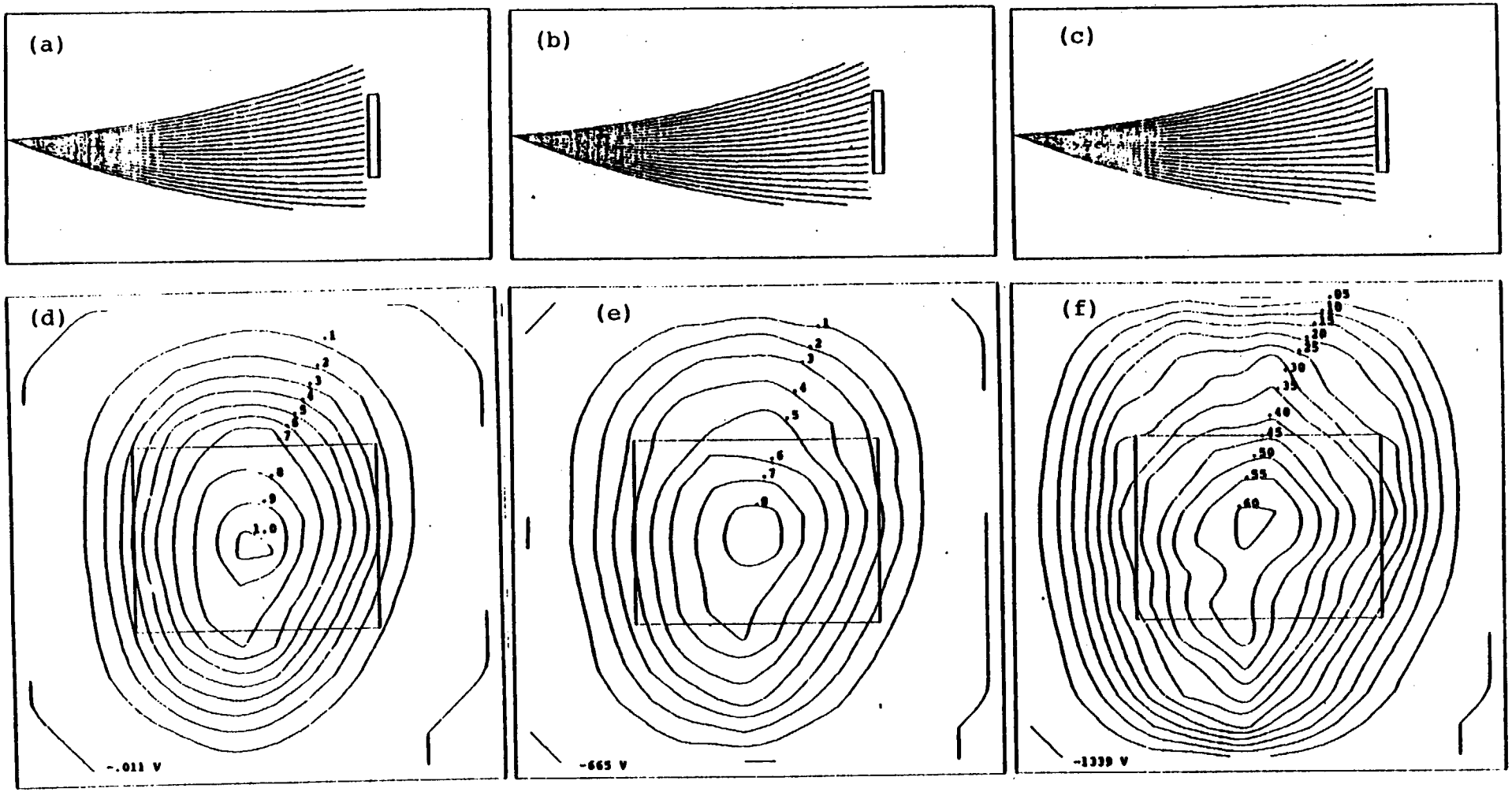


Figure 9.8. Particle trajectory plots (a-c) and current density contour plots (d-f) for uncharged (a,d), partially charged (b,e), and fully charged (c,f) aluminum plate subject to 2 keV electron beam. The numbers indicate current densities in nA/cm^2.

slanted line to be -10 V; however its bilinearly interpolated value is about -4V. (This error is not apparent for the lower sphere because the interpolation error is less than the contour interval.) In the case of the two-grid plot (Figure 9.6b), the mesh point density is insufficient to resolve the object, so that conclusions may be drawn only about potentials distant from the object surface.

The contour routines do not recognize the existence of double points. Thus the potential beneath a thin plate will appear to vary linearly from its "top" value to the correct value one grid unit below.

The contour routines do not recognize the existence of thin booms. Thus the potential near a boom appears to vary linearly from the boom center to its correct value one grid unit away, rather than logarithmically from the boom surface.

9.3 PARTICLE TRAJECTORY PLOTS

Particle trajectory plots are produced by the DETECT module, and within the TRILIN module by the TYPE 1 test tank (keyword TANKTRAJ), SHEATH, and EMITTER facilities. The DETECT module plots one trajectory for each value of the independent variable for each species (Figures 9.9-9.10). The TYPE 1 test tank plots trajectories for all particles emitted with $\phi = 0$ or π (Figure 9.8a-c). The SHEATH routines plot trajectories for all particles emitted from surface cells requested for output (keyword SURFACE CELL n) (Figure 9.7b). The EMITTER routines plot the trajectory of the emitted beam (absent space charge effects) (Figure 9.11).

9.4 DETECTOR PLOTS

The detector plots give the energy flux of electrons and ions measured by a detector as a function of a specified independent variable (energy or angle). Electrostatic, magnetic field, and particle shadowing effects are taken into account. Examples are shown in Figure 9.12. The DETECT module is more fully discussed in Chapter 7.

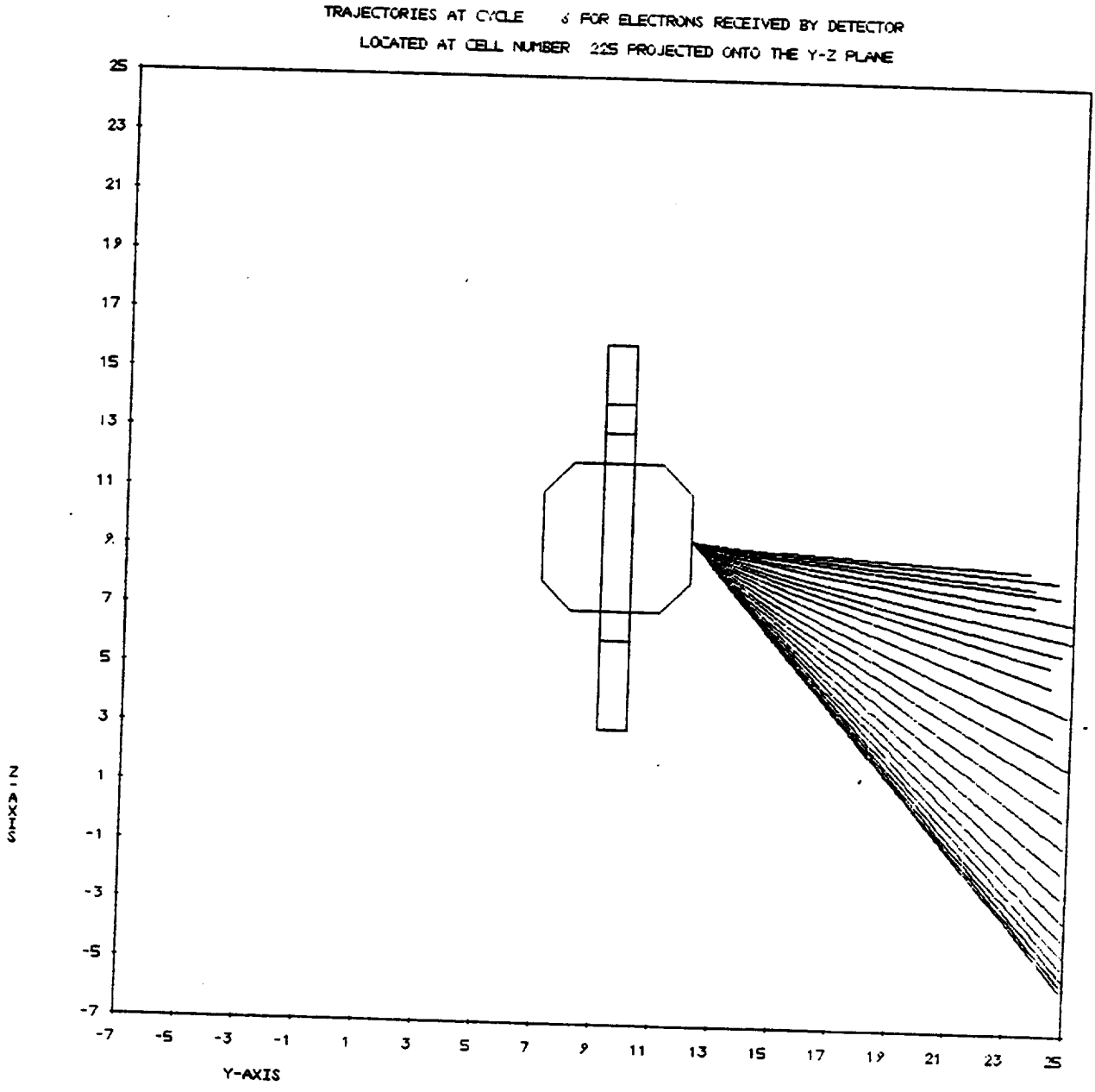


Figure 9.9. Trajectories for electrons received at 25 different detector energies logarithmically spaced from 10 eV to 50 keV. (Conducting object charged to -4.5 keV and no magnetic field.)

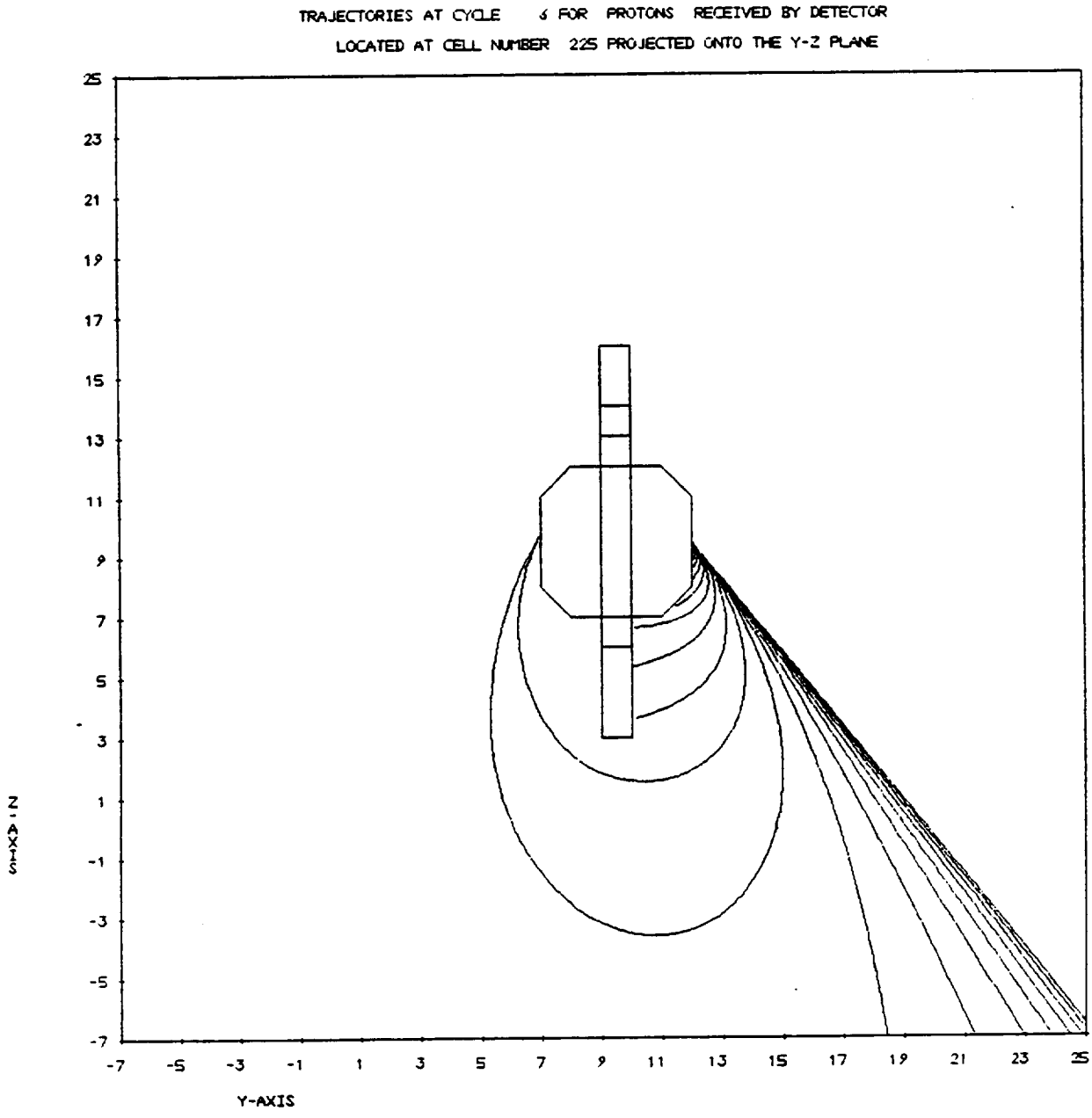


Figure 9.10. Trajectories for protons received at 25 different detector energies logarithmically spaced from 10 eV to 50 keV. (Conducting object charged to -4.5 keV and no magnetic field.)

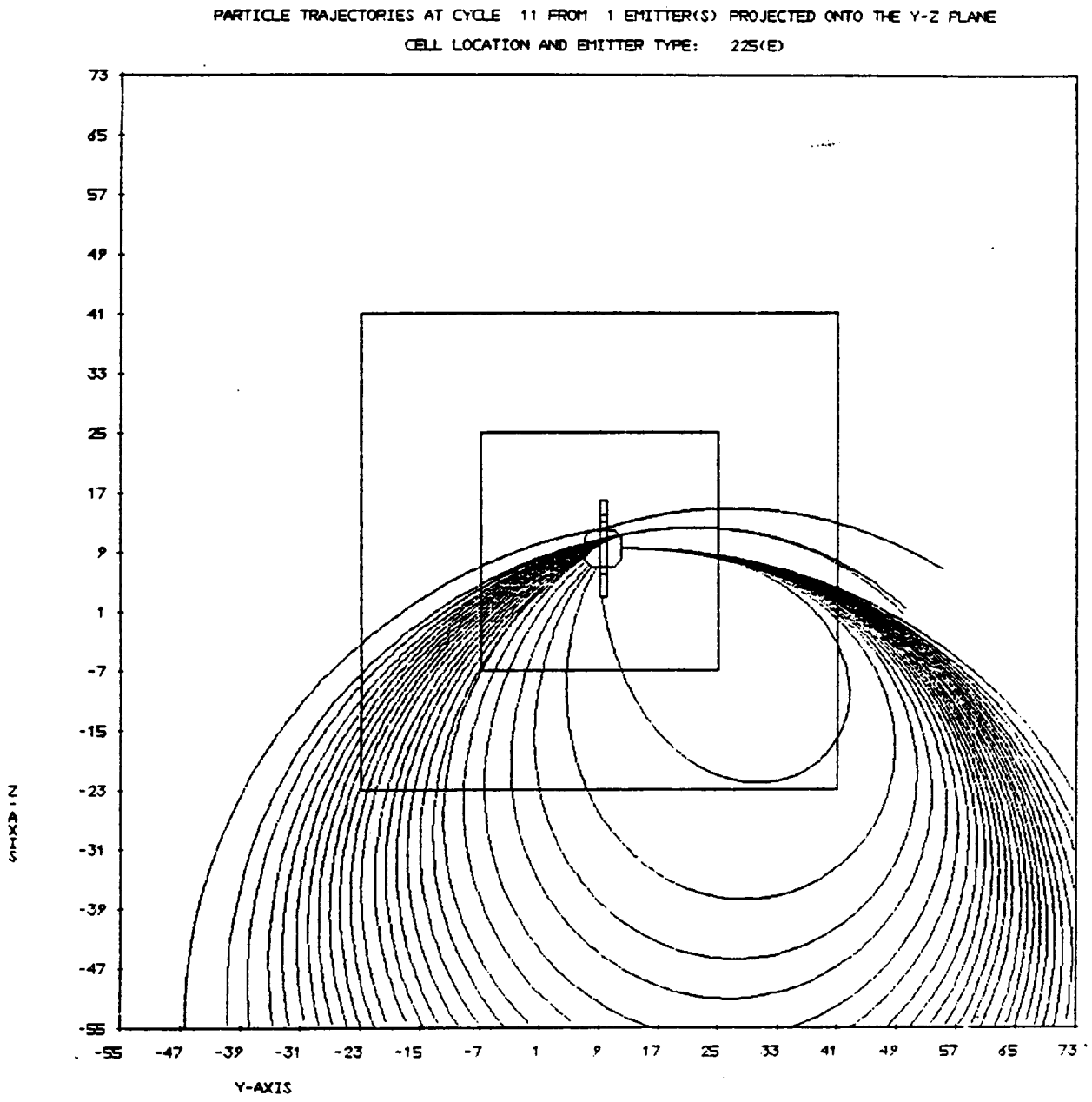


Figure 9.11. Conducting object potential = +0.98 keV.
Uniform magnetic field = 0.1 gauss along -X axis.
Plot boundary = grid 4.
Mean beam energy = 1.1 keV.
Beam energy spread = 0.1 keV (25 energies).
Beam angular spread = 0°.
Electron emission current = 1 MA.
Highest grid which particles entered = 6.

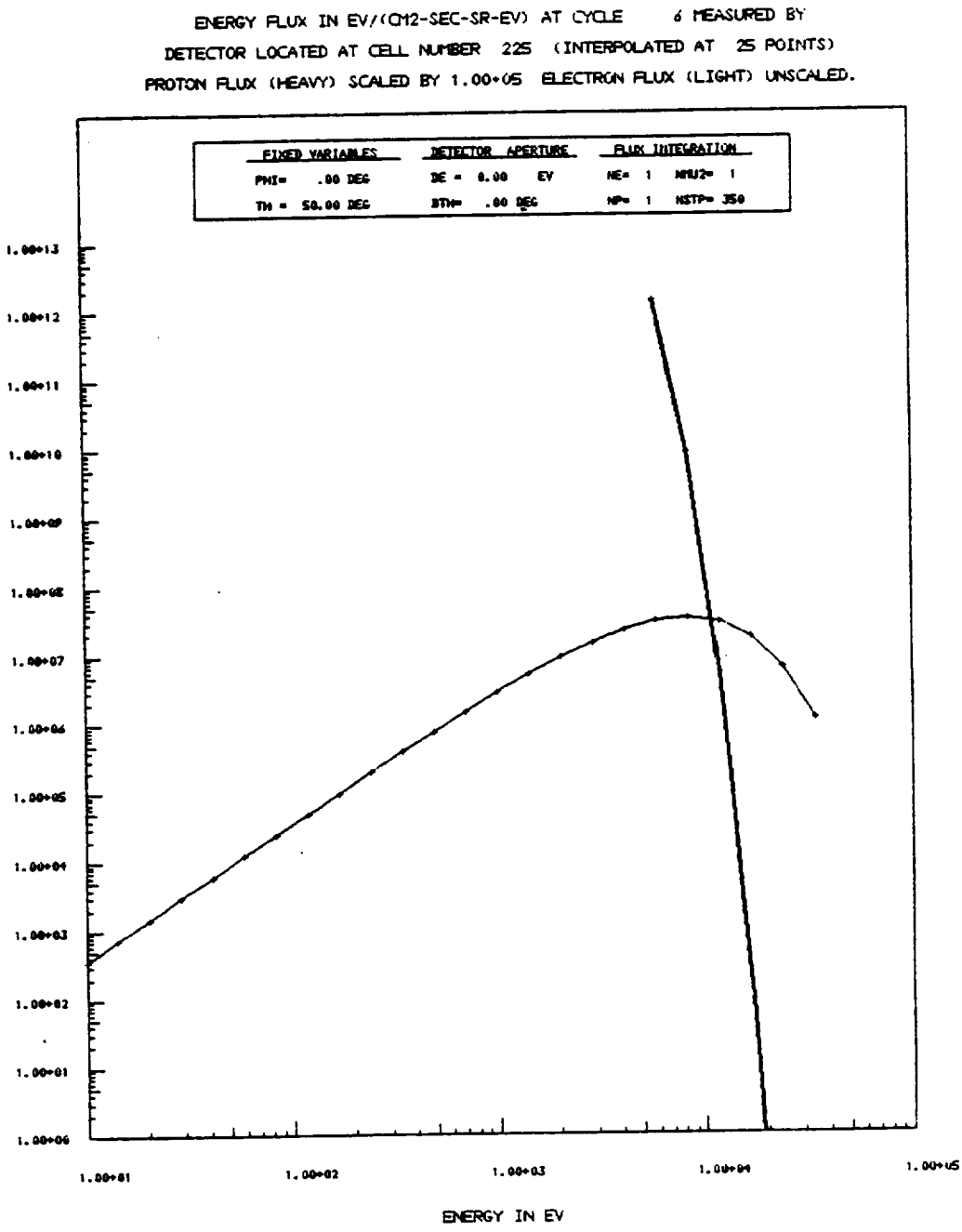


Figure 9.12. Detector logarithmic energy scan. Energy and angular apertures set to zero width. Detector surface cell potential = - 4.5 keV. (Note absence of proton flux below 4.5 keV.)

9.5 IMPLEMENTATION: NASCAP*PLOTREAD

The main program NASCAP does not contain any dependence on the user's locally implemented graphics library. Rather, NASCAP writes a "neutral" plot file (file 2) consisting of subroutine calls and their arguments. (A list of these subroutines appears as Table 9.1. NASCAP*PLOTREAD contains a main program which reads file 2 and reconstructs the subroutine calls. The subroutines of NASCAP*PLOTREAD then call the appropriate user graphics library routines.

Versions of NASCAP*PLOTREAD have been written for the DISSPLA graphics package at S-Cubed, the IGS package at NASA/LeRC, and the PLOT*PLOT package at Jet Propulsion Laboratory.

TABLE 9.1. NASCAP-PSEUDO GRAPHICS SUBROUTINES

SUBROUTINE	ARGUMENTS	FUNCTION
ADF	None	Eject current plot frame
APRNTV	(IDX,IDY,N,TEXT,IX,IY)	Print horizontal or vertical plot labels
AXISXV	(X,Y,XEND)	Draw horizontal line
AXISYV	(X,Y,YEND)	Draw vertical line
CONECT	(X1,X2,Y1,Y2,SL1,SL2,NLL)	Connect line segments for contours
CURVV	(N,X,JDX,Y,JDY,IDUM)	Draw connected line segments
DLINEV	(N,IX,IY)	N = 1: Draw line to raster position IX,IY N = 0: Move to raster position IX,IY N =-1: Draw increment IX,IY N =-2: Move increment IX,IY
DRAWV	(LINE,N,IX,IY,KEYPOS,KCSIZE)	Draw vector characters
FINSHV	None	Close plot file; process plot destination
IGFBUF	(NWDS,NAME)	Process plot buffer
LINEUV	(X1,Y1,X2,Y2)	Draw line between two points
LQUADV	(N,X,Y)	Fill in a quadrangle with solid lines
OUTLIN	None	Draw box around plot
PLOTCV	(N,X,Y,IC)	Plot a character (or dot) at listed points
SBLIN	(NN,KK)	Print scale values for linear baseline NN subdivisions KK Format 0 I6 1-5 F6.0 - F6.4 6-12 E12.1 - E12.7

TABLE 9.1. NASCAP PSEUDO-GRAPHICS SUBROUTINES (Concluded)

SUBROUTINE	ARGUMENTS	FUNCTION
SETUAV	(XL,XR,YB,YT,IXL,IXR,IYB,IYT)	Define user area and establish raster coordinates
SETUPV	None	Open plot file
SLLIN	(NN,KK)	Print scale values for linear grid left line (See SBLIN)
SWPEN	(COLOR)	Switch pen color
TLINEV	(MODE,X2,Y2,LW)	MODE = 0 Set CP = X2, Y2 MODE = 1 Draw line to X2, Y2 with thickness 30 LW rasters
TYPEV	(ITEXT,N,IX,IY)	Write N letters of text starting at IX,IY

10. PRINTED OUTPUT

10.1. INTRODUCTION

The output printed by NASCAP for each module is largely self explanatory. Some lines of output bear directly on the user's problem, while others serve primarily to monitor the progress of the calculation. Only the former type of output is of interest to the everyday user of the code. In this section we provide a quick reference to the blocks of printed output produced by each module.

10.2 CAPACI

Sample output from module CAPACI is shown in Figure 10.1. The references shown are as follows:

1. The inverse of the PCOND values give the capacitance of the object to infinity in code units. The code unit of capacitance is printed out by RDOPT.

2. This is the radius of a sphere of equivalent capacitance.

3. These are the stray capacitances between higher numbered conductors and conductor 1.

The remaining output is for diagnostic purposes.

```
******CAPACI
  POTENTIALS TO BE SET BY SETALL TO   1.00+000/(4*PI*R)
AVERAGE RADIUS (RO) =   4.00+000 CODE UNITS
              47 POTENTIAL ITERATIONS COMPLETED.
                 RDOTR/RDRMAX=  1.85-009/  2.78-001
1 PCOND =    2.0106-002   2.0106-002
  QCOND =    7.8569-001   2.1436-001
    VBAR=  2.0054-002 -- CS SCALED BY  1.0026+000
2   CROEFF --- EFFECTIVE OBJECT RADIUS =       .0793 METERS
              50 POTENTIAL ITERATIONS COMPLETED.
                 RDOTR/RDRMAX=  2.38-003/  3.42+005
  PCOND =   -2.1205+000   7.8795+000
  QCOND =   -3.5585+002   3.5581+002
3   SMALL INTERCONDUCTOR CAPACITANCES:
                      -2.73+001  2.72+001
```

Figure 10.1. CAPACI output.

10.3 DETECT

Figure 10.2 shows sample DETECT output. The references are as follows:

1. The DETECT input file is echoed and interpreted.

2. The definition of each detector is summarized.

3. The environment description read from IFLUX is summarized.

4. The energies and velocities of each particle tracked (for ions and electrons) are listed. Particles originating from the spacecraft are not included in the flux collected by the detector.

```
******DETECT 23
 ASGFIL -- @ASG    2. .
1    ICELL 170                  ICELL SET TO       170
     ENERGY 1                   INITIAL ENERGY SET TO   1.000000+000
     DEK 10                     DEK SET TO   1.000000+001
     THETA -88                  INITIAL THETA SET TO  -8.800000+001
     DTH 1                      DTH SET TO   1.000000+000
     PHI 0                      INITIAL PHI SET TO    .000000
     NE 1                       NE SET TO         1
     AUTOS                      FLUX PLOT AUTO-SCALE OPTION SET FOR THIS DETECTOR
     INDVAR=THETA               INDEPENDENT VARIABLE FOR FLUX PLOT IS THET
     FINALV 88                  FINAL VALUE OF INDEPENDENT VARIABLE  SET TO   8.800000+001
     N 10                       N SET TO        10
     PLPART                     PARTICLE PLOT FLAG SET FOR THIS DETECTOR
     NGRND 1                    NGRND SET TO         1
     LIMGRD 2                   LIMGRD SET TO          2
     END
```

Figure 10.2. DETECT sample output.

```
          PARAMETER DEFINITION SUMMARY FOR PARTICLE DETECTORS
                  NUMBER OF PARTICLE DETECTORS = 1

-------------------------------------------------------------------------------
DETECTOR NUMBER 1:
2       SURFACE CELL LOCATION =   170

ENERGY FLUX INTEGRAL PARAMETERS

   DE   =   10.00 %        NE   =   1
   NSTP =  500             NP   =   1
   DTH  =    1.00 DEG      NMU2 =   1

ELECTRON CHARGE =  -1.60300-019 COUL   ELECTRON MASS =   9.10910-031 KG
PROTON CHARGE   =   1.60200-019 COUL   PROTON MASS   =   1.67252-027 KG

     INDEPENDENT VARIABLE FOR PLOT = THET
     SCAN RANGE =  10 POINTS FROM -8.80+001 DEG TO  8.80+001 DEG

FIXED VARIABLES

          ENERGY =1.000+000 EV
             PHI =      .00 DEG

     PROTON ENERGY FLUX PLOT SEPARATION SCALE FACTOR =1.00+005
     PROTON ENERGY FLUX PLOT PEN LINE WIDTH = 3 RASTER INCREMENTS
     PARTICLE VELOCITY =    .300 MESH UNITS PER STEP
     HIGHEST GRID IN WHICH I/R POTENTIAL TRACKING IS PERMITED =   2
     ENERGY FLUX SCALE RANGE IS DETERMINED AT EXECUTION TIME

**** PARTICLE TRAJECTORY PLOTS WILL BE PRODUCED FOR THIS DETECTOR ****

     TRAJECTORY PLOT FRAME REPETITION OPTION ACTIVE WITH PARAMETERS SET AS FOLLOWS:

          GRID BOUNDARY INDEX OF FIRST FRAME (NGBND) =   1
          NUMBER OF FRAMES GENERATED (NGPLOT) =   1
          GRID BOUNDARY INDEX INCREMENT (NGINC) =   0
```

Figure 10.2. (Continued).

```
 QSUMER FOUND QSUM= -3.35+004 CODE UNITS,
        AFTER SCREENING CORRECTION (SCREENING LENGTH=  2.00+003 M.) QSUM= -3.35+004
              QSCALE= -3.47+004          CORRECTED TO  -3.48+004
FLUX DEFINITION SINGLE
                ELECTRON TEMPERATURE =    5.00+003 ELECTRON VOLTS
                ELECTRON DENSITY =        1.00+006 METER**(-3)
                ION TEMPERATURE =         5.00+003 ELECTRON VOLTS
                ION DENSITY =             1.00+006 METER**(-3)
SETBMI SET INVERSE BOOM MATRICES FOR DETECTOR/EMITTER USAGE   NBOOM =  2  NG=  2  XMESH= 2.000-001

 NEXTPA=     0

 EFPREP --    2 GRIDS OUT OF   2 READ IN.
****** DETECTOR ROUTINE EXECUTION INITIATED BY DETRUN ******
```

Figure 10.2. (Continued).

```
4  NDCELLS= 1 IPFLAG= 1 XMESH= 2.00000-001 NMAT= 4 NSURF= 180 QTOT=-3.34876+004 TIME= 1.20920+001
     NX=17 NY=17 NZ=33 NG= 2 ICYC=  3 ITYPE= 2 IDIPF1=11 IDIPF2=28
   PCOND= 1.0+003-5.4+002  :0      :0      :0      :0      :0      :0      :0      :0      :0      :0      :0      :0      :0
   QCOND= 1.5+009-9.5+005  :0      :0      :0      :0      :0      :0      :0      :0      :0      :0      :0      :0      :0


    ASGFIL -- @ASG  38. .
   ENERGY      427.6 EV -- ORIGINAL VELOCITY:  -.4675  -.7014   .5201
   ENERGY      424.9 EV -- ORIGINAL VELOCITY:  -.4721  -.7166   .5134
   ENERGY      427.7 EV -- ORIGINAL VELOCITY:  -.4564  -.7260   .5145
   ENERGY      431.9 EV -- ORIGINAL VELOCITY:  -.4413  -.7270   .5260
5  ENERGY      432.8 EV -- ORIGINAL VELOCITY:  -.4318  -.7231   .5392
   ENERGY      432.9 EV -- ORIGINAL VELOCITY:  -.4274  -.7134   .5554
   ENERGY      432.4 EV -- ORIGINAL VELOCITY:  -.4277  -.6967   .5759
   ENERGY      436.5 EV -- ORIGINAL VELOCITY:  -.4325  -.6761   .5965
   ENERGY      435.2 EV -- ORIGINAL VELOCITY:  -.4411  -.6544   .6141
   ENERGY      437.8 EV -- ORIGINAL VELOCITY:  -.4530  -.6323   .6286

   ***** PARTICLE TRACKING TOTALS FOR DETECTOR  1 SPECIES 1 AT CYCLE     3 *****  NHIT=        0 NINC=        0 NESCAP=       10
   ENERGY       19.3 EV -- ORIGINATED FROM SPACECRAFT.
   ENERGY       17.1 EV -- ORIGINATED FROM SPACECRAFT.
   ENERGY       14.8 EV -- ORIGINATED FROM SPACECRAFT.
6  ENERGY       12.6 EV -- ORIGINATED FROM SPACECRAFT.
   ENERGY       10.7 EV -- ORIGINATED FROM SPACECRAFT.
   ENERGY        9.4 EV -- ORIGINATED FROM SPACECRAFT.
   ENERGY        8.9 EV -- ORIGINATED FROM SPACECRAFT.
   ENERGY        9.2 EV -- ORIGINATED FROM SPACECRAFT.
   ENERGY       10.2 EV -- ORIGINATED FROM SPACECRAFT.
   ENERGY       11.8 EV -- ORIGINATED FROM SPACECRAFT.

   ***** PARTICLE TRACKING TOTALS FOR DETECTOR  1 SPECIES 2 AT CYCLE     3 *****  NHIT=       10 NINC=        0 NESCAP=        0
   CALLED DETECT
   CALLED DETPLT  LABABV=  D
   IN PLPART IDET=   1 ISPEC=1 IG=   1 IGS=          1 GSCALE=  1.0000000+000 IVIEW=   1
   IN PLPART IDET=   1 ISPEC=2 IG=   1 IGS=          1 GSCALE=  1.0000000+000 IVIEW=   1
   CALLED PLPART IXYZ= 1  LABABV=  C
7  IN PLPART IDET=   1 ISPEC=1 IG=   1 IGS=          1 GSCALE=  1.0000000+000 IVIEW=   1
   IN PLPART IDET=   1 ISPEC=2 IG=   1 IGS=          1 GSCALE=  1.0000000+000 IVIEW=   1
   CALLED PLPART IXYZ= 2  LABABV=  B
   IN PLPART IDET=   1 ISPEC=1 IG=   1 IGS=          1 GSCALE=  1.0000000+000 IVIEW=   1
   IN PLPART IDET=   1 ISPEC=2 IG=   1 IGS=          1 GSCALE=  1.0000000+000 IVIEW=   1
   CALLED PLPART IXYZ= 3  LABABV=  A

   ******END

   CEND NASCAP)

   @ASG,A NASCAP*PLOTREAD.

   @XQT NASCAP*PLOTREAD.
   DEVICE OPTION =  3.
```

Figure 10.2. (Concluded).

10.4. HIDCEL

Output is shown in Figure 10.3. The output is purely diagnostic.

```
******HIDCEL
 DISTANCE EQUALS  999.99998
FINAL NAI =    62
```

Figure 10.3. HIDCEL output.

10.5 IPS

Sample output from module IPS is shown in Figure 10.4. The references are as follows:

1. The IPS input cards are echoed.

2. The potentials in space are set to the monopole potential with the radius and charge given.

3. The new surface cell potentials are summarized.

4. Potentials and charges on the conductors are summarized.

```
******IPS 5
  OBJECT DEFINITION INFORMATION BEING READ FROM FILE
 *** INITIAL POTENTIAL SPECIFICATION ***

PCOND 2 -2000
PCOND 1 -1000
BOOM 1 -2000
BOOM 2 -3000
ALL KAPTON -3000
END
   TOTAL CHARGE FOR INITIALLY SPECIFIED POTENTIALS ESTIMATED TO BE    -1.30+005 CODE UNITS.
  POTENTIALS TO BE SET BY SETALL TO  -1.30+005/(4*PI*R)
AVERAGE RADIUS (RO)  =   4.00+000 CODE UNITS



 SURFACE POTENTIALS - ALL  184 CELLS
 CELL NO.                                                                                                                                                CELL NO.
   1   -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003                                          10
  11   -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003                                          20
  21   -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003                                          30
  31   -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003                                          40
  41   -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003                                          50
  51   -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003                                          60
  61   -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003                                          70
  71   -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003                                          80
  81   -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003                                          90
  91   -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003                                         100
 101   -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003                                         110
 111   -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003 -3.000+003                                         120
 121   -3.000+003 -3.000+003 -3.000+003 -3.000+003 -1.000+003 -3.000+003 -1.000+003 -3.000+003 -1.000+003 -3.000+003                                         130
 131   -3.000+003 -1.000+003 -3.000+003 -1.000+003 -1.000+003 -1.000+003 -3.000+003 -1.000+003 -3.000+003 -1.000+003                                         140
 141   -1.000+003 -1.000+003 -3.000+003 -1.000+003 -3.000+003 -3.000+003 -1.000+003 -3.000+003 -1.000+003 -3.000+003                                         150
 151   -1.000+003 -3.000+003 -3.000+003 -1.000+003 -2.000+003 -2.000+003 -2.000+003 -2.000+003 -2.000+003 -2.000+003                                         160
 161   -2.000+003 -2.000+003 -2.000+003 -2.000+003 -2.000+003 -2.000+003 -2.000+003 -2.000+003 -2.000+003 -2.000+003                                         170
 171   -2.000+003 -2.000+003 -2.000+003 -2.000+003 -2.000+003 -2.000+003 -2.000+003 -2.000+003 -2.000+003 -2.000+003                                         180
 181   -1.000+003 -1.000+003 -1.000+003 -1.000+003

            19 POTENTIAL ITERATIONS COMPLETED.
               RDOTR/RDRMAX=  4.65+003/  4.85+009
PCOND =   -1.0000+003  -2.0000+003
QCOND =    1.5210+009  -5.9287+005
  NLXTRA=      0

 EFPRLP --    1 GRIDS OUT OF   1 READ IN.

IP = 14  IR = 13  IU = 10  ISPARE = 12  IPSAVE = 10

LAST CYCLE COMPLETED IS   0.

IP = 10  IR = 13  IU = 14  ISPARE = 12  IPSAVE = 10
```

Figure 10.4. IPS sample output.

10.6 NEWMAT

Sample NEWMAT output is shown in Figure 10.5. References are as follows:

1. NEWMAT input is echoed.

2. The property table for each redefined material is printed.

```
******NEWMAT 5
  OBJECT DEFINITION INFORMATION BEING READ FROM FILE

GOLD                MATERIAL PROPERTIES
1                1.00+000   1.00-003  -1.00+000   7.90+001   8.80-001   8.00-001   8.88+001   9.20-001   5.35+001   1.73+000
                 4.13-001   1.35+002   2.90-005  -1.00+000   1.00+004   2.00+003   1.70+001   1.80+001   1.90+001   2.00+001
```

```
PREPROCESSING OF MATERIAL PROPERTIES

MATERIAL   1:  GOLD

                 PROPERTY                          INPUT VALUE          CODE VALUE
2          1     DIELECTRIC CONSTANT            1.00+000 (NONE)      1.00+000 (NONE)
           2     THICKNESS                      1.00-003 METERS      5.00-003 MESH
           3     CONDUCTIVITY                  -1.00+000 MHO/M      -1.00+000 MHO/M
           4     ATOMIC NUMBER                  7.90+001 (NONE)      7.90+001 (NONE)
           5     DELTA MAX     >COEFF           8.80-001 (NONE)      2.93+000 (NONE)
           6     E-MAX         >DEPTH**-1       8.00-001 KEV         2.02-002 ANG-01
           7     RANGE                          8.88+001 ANG.        8.17+001 ANG.
           8     EXPONENT      > RANGE          9.20-001 (NONE)      9.25+001 ANG.
           9     RANGE > EXPONENT               5.35+001 ANG.        9.20-001 (NONE)
          10     EXPONENT                       1.73+000 (NONE)      1.73+000 (NONE)
          11     YIELD FOR 1KEV PROTONS         4.13-001 (NONE)      4.13-001 (NONE)
          12     MAX DE/DX FOR PROTONS          1.35+002 KEV         1.35+002 KEV
          13     PHOTOCURRENT                   2.90-005 A/M**2      2.90-005 A/M**2
          14     SURFACE RESISTIVITY           -1.00+000 OHMS       -1.77-012 V-S/Q
          15     SPACE DISCHARGE POT'L          1.00+004 VOLTS       1.00+004 VOLTS
          16     INTERNAL DISCHARGEPOT'L        2.00+003 VOLTS       2.00+003 VOLTS
          17     RADN INDUCEDCOND'YCOEFFT       1.70+001 MHOMS3      1.70+001 MHOMS3
          18     RADN INDUCEDCOND'YPOWER        1.80+001 (NONE)      1.80+001 (NONE)
          19     DENSITY                        1.90+001 KG/M**3     1.90+001 KG/M**3
          20                                    2.00+001             -1.00+000
```

Figure 10.5. NEWMAT sample output.

10.7. OBJDEF

Sample output is shown in Figure 10.6. References are as follows:

1. The object definition file is echoed as read.

2. Each building block definition is confirmed in absolute grid coordinates (centered at 9, 9, (NZ+1)/2).

3. The surface cell list is printed (absolute coordinates). IX, IY, IZ are the coordinates of the lowest indexed vertex of the associated volume element.

4. The material properties are summarized.

```
******OBJDEF

1
COMMENT WORKED EXAMPLE (CHAPTER 10)
COMMENT ZONE SIZE IS 0.02 M
COMMENT DEFINE MATERIAL GOLD AND SOLAR
GOLD                MATERIAL PROPERTIES
          1.00+000   1.00-003  -1.00+000   7.90+001   8.80-001   8.00-001   8.88+001   9.20-001   5.35+001   1.73+000
          4.13-001   1.35+002   2.90-005  -1.00+000   1.00+004   2.00+003   1.00-013   1.00+000   1.00+003   2.00+001
SOLAR               MATERIAL PROPERTIES
          3.80+000   1.79-004   1.00-017   1.00+001   2.05+000   4.10-001   7.75+001   4.50-001   1.56+002   1.73+000
          2.44-001   2.30+002   2.00-005   1.00+019   1.00+004   2.00+003   1.00-013   1.00+000   1.00+003   2.00+001
COMMENT PROPERTIES OF KAPTON AND ALUMINUM FROM DEFAULT TABLE.
CONDUCTOR 1
COMMENT CENTRAL CUBOID
```

Figure 10.6. OBJDEF.

```
2       RECTAN
         OBJECT NOW DEFINED.
                                          6<X< 12
                                          7<Y< 11
                                         15<Z< 19

        SURFACE +X GOLD
        SURFACE -X KAPTON
        SURFACE +Y KAPTON
        SURFACE -Y KAPTON
        SURFACE +Z KAPTON
        SURFACE -Z KAPTON
        ENDOBJ

        COMMENT BOOM TO KAPTON SPHERE

        BOOM

        BOOM DEFINED
        BEGINNING AT                              9    9   19 (GRID 1 COORDINATES)
        EXTENDING PARALLEL TO THE Z AXIS TO       9    9   21 (GRID 1 COORDINATES)

        RADI         .05000

        SURF     ALUM

        COMMENT BOOM TO SOLAR SPHERE

        BOOM

        BOOM DEFINED
        BEGINNING AT                              9    9   15 (GRID 1 COORDINATES)
        EXTENDING PARALLEL TO THE Z AXIS TO       9    9   13 (GRID 1 COORDINATES)

        RADI         .05000

        SURF     ALUM

        COMMENT KAPTON SPHERE

        QSPHERE

            DEFINING Q-SPHERE
                  CENTER =   9   9   22
                  DIAMETER =   3      SIDE =   1
                  MATERIAL = KAPT

            OCTAGON DEFINED
                  AXIS = (   9   9   22) TO (  10   9   22)
                  WIDTH =    3          SIDE =   1
```

Figure 10.6. (Continued).

```
   OCTAGON DEFINED
         AXIS = (  9   9  22) TO (  9  10  22)
         WIDTH =   3                SIDE =    1
   OCTAGON DEFINED
         AXIS = (  9   9  22) TO (  9   9  23)
         WIDTH =   3                SIDE =    1
COMMENT SOLAR SPHERE (ON SEPARATE CONDUCTOR)
CONDUCTOR 2
QSPHERE
   DEFINING Q-SPHERE
         CENTER =   9   9  11
         DIAMETER =   3      SIDE =   1
         MATERIAL = SOLA
   OCTAGON DEFINED
         AXIS = (  9   9  11) TO (  10   9  11)
         WIDTH =   3                SIDE =    1
   OCTAGON DEFINED
         AXIS = (  9   9  11) TO (  9  10  11)
         WIDTH =   3                SIDE =    1
   OCTAGON DEFINED
         AXIS = (  9   9  11) TO (  9   9  12)
         WIDTH =   3                SIDE =    1
ENDSAT
```

Figure 10.6. (Continued).

3

SURFACE CELL LIST

CELL NO.	CODE	CONDUCTOR	IX	IY	IZ	NORMAL	MATERIAL
1	00460717030 3	1	6	7	15	0 0 -1	KAPT
2	00460717140 3	1	6	7	15	0 -1 0	KAPT
3	00460717600 3	1	6	7	15	-1 0 0	KAPT
4	00460720140 3	1	6	7	16	-1 0 0	KAPT
5	00460720600 3	1	6	7	16	-1 0 0	KAPT
6	00460721140 3	1	6	7	17	-1 0 0	KAPT
7	00460721600 3	1	6	7	17	-1 0 0	KAPT
8	00460722010 3	1	6	7	18	-1 0 0	KAPT
9	00460722140 3	1	6	7	18	-1 0 0	KAPT
10	00460722600 3	1	6	7	18	-1 0 0	KAPT
11	00461017030 3	1	6	8	15	0 1 0	KAPT
12	00461017600 3	1	6	8	15	-1 0 0	KAPT
13	00461020600 3	1	6	8	16	-1 0 0	KAPT
14	00461021600 3	1	6	8	17	-1 0 0	KAPT
15	00461022010 3	1	6	8	18	-1 0 0	KAPT
16	00461022600 3	1	6	8	18	-1 0 0	KAPT
17	00461117030 3	1	6	9	15	0 1 0	KAPT
18	00461117600 3	1	6	9	15	-1 0 0	KAPT
19	00461120600 3	1	6	9	16	-1 0 0	KAPT
20	00461121600 3	1	6	9	17	-1 0 0	KAPT
21	00461122010 3	1	6	9	18	-1 0 0	KAPT
22	00461122600 3	1	6	9	18	-1 0 0	KAPT
23	00461217030 3	1	6	10	15	0 1 0	KAPT
24	00461217040 3	1	6	10	15	0 1 0	KAPT
25	00461217600 3	1	6	10	15	-1 0 0	KAPT
26	00461220040 3	1	6	10	16	-1 0 0	KAPT
27	00461220600 3	1	6	10	16	-1 0 0	KAPT
28	00461221040 3	1	6	10	17	-1 0 0	KAPT
29	00461221600 3	1	6	10	17	-1 0 0	KAPT
30	00461222010 3	1	6	10	18	-1 0 0	KAPT
31	00461222040 3	1	6	10	18	-1 0 0	KAPT
32	00461222600 3	1	6	10	18	-1 0 0	KAPT
33	00470717030 3	1	7	7	15	0 1 0	KAPT
34	00470717140 3	1	7	7	16	0 1 0	KAPT
35	00470720140 3	1	7	7	17	0 1 0	KAPT
36	00470721140 3	1	7	7	18	0 1 0	KAPT
37	00470722010 3	1	7	7	18	0 1 0	KAPT
38	00470722140 3	1	7	7	18	0 1 0	KAPT
39	00471017030 3	1	7	8	15	0 1 0	KAPT
40	00471022010 3	1	7	8	15	0 1 0	KAPT
41	00471117030 3	1	7	9	15	0 1 0	KAPT
42	00471122010 3	1	7	9	15	0 1 0	KAPT
43	00471217030 3	1	7	10	15	0 1 0	KAPT
44	00471217040 3	1	7	10	15	0 1 0	KAPT
45	00471220040 3	1	7	10	16	0 1 0	KAPT
46	00471221040 3	1	7	10	17	0 1 0	KAPT
47	00471222010 3	1	7	10	18	0 1 0	KAPT
48	00471222040 3	1	7	10	18	0 1 0	KAPT
49	00500717030 3	1	8	7	15	0 -1 0	KAPT
50	00500717140 3	1	8	7	15	0 -1 0	KAPT

Figure 10.6. (Continued).

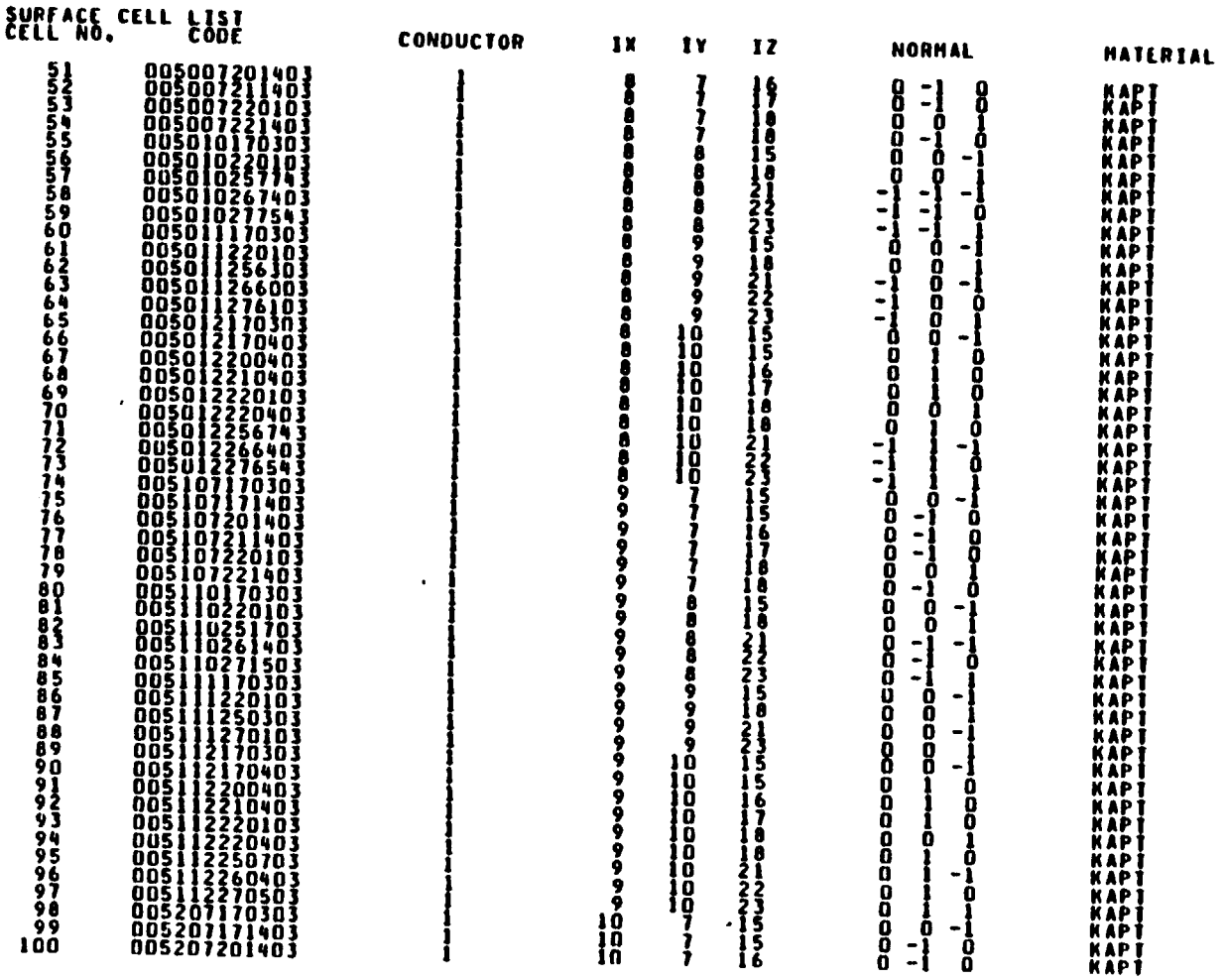
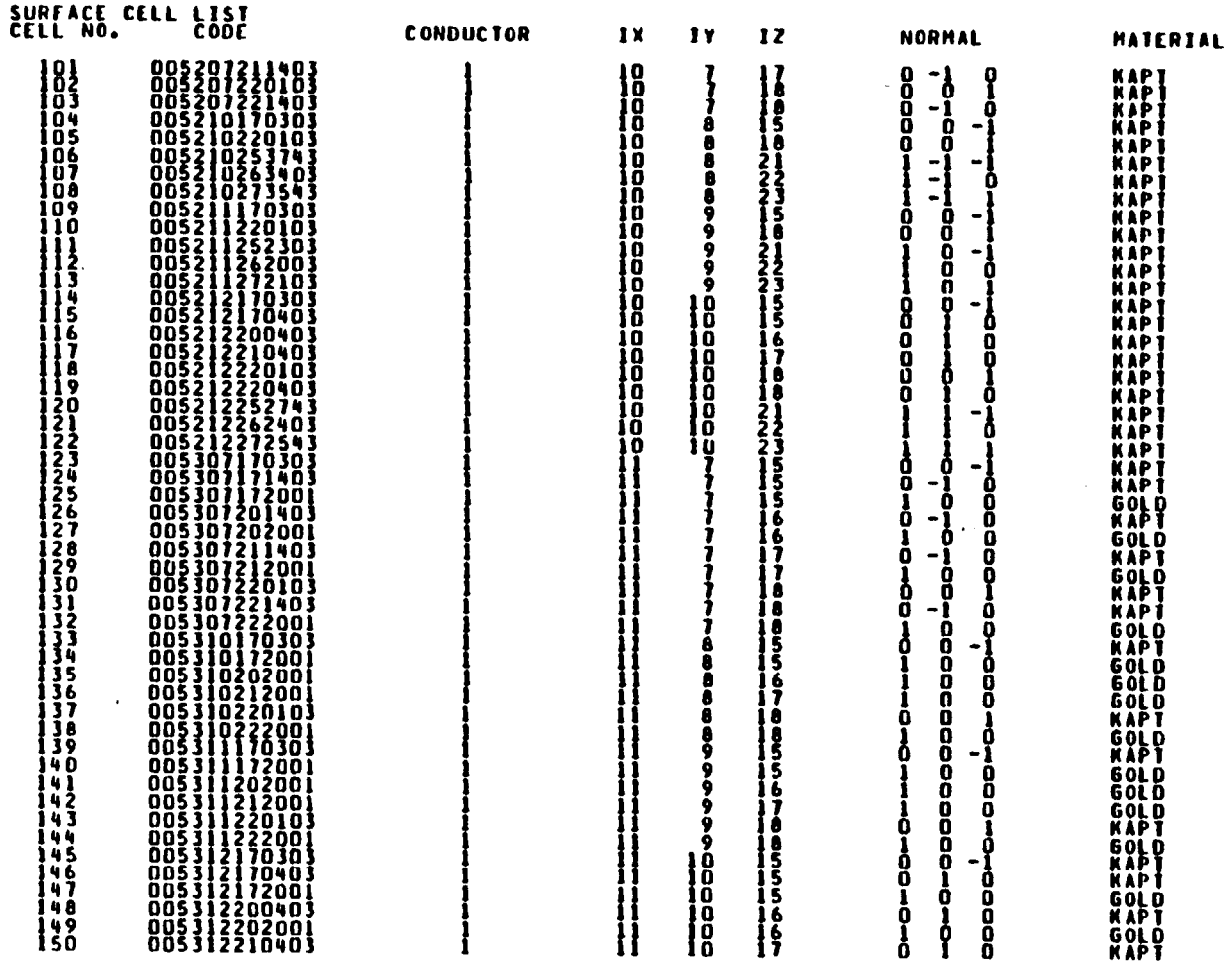


Figure 10.6. (Continued).



SURFACE CELL LIST CELL NO.	CODE	CONDUCTOR	IX	IY	IZ	NORMAL	MATERIAL
101	00520721140 3	1	10	7	17	0 -1 0	KAPT
102	00520722010 3	1	10	7	18	0 0 1	KAPT
103	00520722140 3	1	10	8	15	0 0 -1	KAPT
104	00521017030 3	1	10	8	16	0 1 0	KAPT
105	00521022010 3	1	10	8	17	0 1 0	KAPT
106	00521025374 3	1	10	8	18	0 1 0	KAPT
107	00521026340 3	1	10	8	22	0 1 0	KAPT
108	00521027354 3	1	10	8	23	0 1 0	KAPT
109	00521117030 3	1	10	8	24	0 1 0	KAPT
110	00521122010 3	1	10	8	25	0 1 0	KAPT
111	00521125230 3	1	10	9	15	0 0 -1	KAPT
112	00521126200 3	1	10	9	16	0 1 0	KAPT
113	00521127210 3	1	10	9	17	0 1 0	KAPT
114	00521217030 3	1	10	9	18	0 1 0	KAPT
115	00521217040 3	1	10	9	22	0 1 0	KAPT
116	00521220040 3	1	10	9	23	0 1 0	KAPT
117	00521221040 3	1	10	9	24	0 1 0	KAPT
118	00521222010 3	1	10	9	25	0 1 0	KAPT
119	00521222040 3	1	10	10	15	0 0 -1	KAPT
120	00521225274 3	1	10	10	16	0 1 0	KAPT
121	00521226240 3	1	10	10	17	0 1 0	KAPT
122	00521227254 3	1	10	10	18	0 1 0	KAPT
123	00530717030 3	1	11	7	15	0 -1 0	KAPT
124	00530717140 3	1	11	7	16	0 -1 0	KAPT
125	00530717200 1	1	11	7	17	0 -1 0	GOLD
126	00530720140 3	1	11	7	18	0 -1 0	KAPT
127	00530720200 1	1	11	7	22	0 -1 0	GOLD
128	00530721140 3	1	11	7	23	0 -1 0	KAPT
129	00530721200 1	1	11	7	24	0 -1 0	GOLD
130	00530722010 3	1	11	7	25	0 -1 0	KAPT
131	00530722140 3	1	11	8	15	0 0 -1	KAPT
132	00530722200 1	1	11	8	16	0 -1 0	GOLD
133	00531017030 3	1	11	8	17	0 -1 0	KAPT
134	00531017200 1	1	11	8	18	0 -1 0	GOLD
135	00531020200 1	1	11	8	22	0 -1 0	GOLD
136	00531021200 1	1	11	8	23	0 -1 0	GOLD
137	00531022010 3	1	11	8	24	0 -1 0	KAPT
138	00531022200 1	1	11	8	25	0 -1 0	GOLD
139	00531117030 3	1	11	9	15	0 0 -1	KAPT
140	00531117200 1	1	11	9	16	0 -1 0	GOLD
141	00531120200 1	1	11	9	17	0 -1 0	GOLD
142	00531121200 1	1	11	9	18	0 -1 0	GOLD
143	00531122010 3	1	11	9	22	0 -1 0	KAPT
144	00531122200 1	1	11	9	23	0 -1 0	GOLD
145	00531217030 3	1	11	9	24	0 0 -1	KAPT
146	00531217040 3	1	11	9	25	0 0 -1	KAPT
147	00531217200 1	1	11	10	15	0 -1 0	GOLD
148	00531220040 3	1	11	10	16	0 1 0	KAPT
149	00531220200 1	1	11	10	17	0 1 0	GOLD
150	00531221040 3	1	11	10	17	0 1 0	KAPT

Figure 10.6. (Continued).

SURFACE CELL LIST

CELL NO.	CODE	CONDUCTOR	IX	IY	IZ	NORMAL	MATERIAL
151	00531221200 1	1	11	10	17	1 0 0	GOLD
152	00531222010 3	1	11	10	18	1 0 0	KAPT
153	00531222040 3	1	11	10	18	1 0 0	KAPT
154	00531222220 1	1	11	10	18	1 0 0	GOLD
155	01101012774 2	2	8	8	8	- - 1	SOLA
156	01101013740 2	2	8	8	8	- - 1	SOLA
157	01101014754 2	2	8	8	8	- - 1	SOLA
158	01101111263 2	2	8	8	9	- - 1	SOLA
159	01101111360 2	2	8	8	9	- - 1	SOLA
160	01101111461 2	2	8	8	9	- - 1	SOLA
161	01101212674 2	2	8	8	10	- - 1	SOLA
162	01101213640 2	2	8	8	10	- - 1	SOLA
163	01101214654 2	2	8	8	10	- - 1	SOLA
164	01111101217 0 2	2	9	8	8	- - 1	SOLA
165	01111101314 0 2	2	9	8	8	- - 1	SOLA
166	01111101415 0 2	2	9	8	8	- - 1	SOLA
167	01111111203 0 2	2	9	9	9	- - 1	SOLA
168	01111111401 0 2	2	9	9	9	- - 1	SOLA
169	01111212070 2	2	9	9	10	- - 1	SOLA
170	01111212304 0 2	2	9	9	10	- - 1	SOLA
171	01111212405 0 2	2	9	9	10	- - 1	SOLA
172	01121012374 2	2	10	8	8	- - 1	SOLA
173	01121013340 2	2	10	8	8	- - 1	SOLA
174	01121014354 2	2	10	8	8	- - 1	SOLA
175	01121111223 0 2	2	10	9	9	- - 1	SOLA
176	01121111320 0 2	2	10	9	9	- - 1	SOLA
177	01121111421 0 2	2	10	9	9	- - 1	SOLA
178	01121212274 2	2	10	10	10	- - 1	SOLA
179	01121213240 2	2	10	10	11	- - 1	SOLA
180	01121214254 2	2	10	10	11	- - 1	SOLA

BOOM SURFACE CELL LIST

CELL NO.	CODE	CONDUCTOR	IX	IY	IZ	GRID	AXIS	BOOM	INT	MATERIAL
181	00006111112 3	1	9	9	19	1	2	1	1	ALUM
182	00006111112 4	1	9	9	20	1	2	1	1	ALUM
183	00006211111 5	1	9	9	13	1	2	2	1	ALUM
184	00006211111 6	1	9	9	14	1	2	2	1	ALUM

LIST OF BOOM PROPERTIES

BOOM	RADIUS	AXIS	MATERIAL	CONDUC
1	.050	2	ALUM	1
2	.050	2	ALUM	1

Figure 10.6. (Continued).

4

PREPROCESSING OF MATERIAL PROPERTIES

MATERIAL 1: GOLD

	PROPERTY	INPUT VALUE	CODE VALUE
1	DIELECTRIC CONSTANT	1.00+000 (NONE)	1.00+000 (NONE)
2	THICKNESS	1.00-003 METERS	5.00-002 MESH
3	CONDUCTIVITY	-1.00+000 MHO/M	-1.00+000 MHO/M
4	ATOMIC NUMBER	7.90+001 (NONE)	7.90+001 (NONE)
5	DELTA MAX >COEFF	8.80-001 (NONE)	2.93+000 (NONE)
6	E-MAX >DEPTH**-1	8.00-001 KEV	2.02-002 ANG-01
7	RANGE	8.88+001 ANG.	8.17+001 ANG.
8	EXPONENT > RANGE	9.20-001 (NONE)	9.25+001 ANG.
9	RANGE > EXPONENT	5.35+001 ANG.	9.20-001 (NONE)
10	EXPONENT	1.73+000 (NONE)	1.73+000 (NONE)
11	YIELD FOR 1KEV PROTONS	4.13-001 (NONE)	4.13-001 (NONE)
12	MAX DE/DX FOR PROTONS	1.35+002 KEV	1.35+002 KEV
13	PHOTOCURRENT	2.90-005 A/M**2	2.90-005 A/M**2
14	SURFACE RESISTIVITY	-1.00+000 OHMS	-1.77-013 V-S/Q
15	SPACE DISCHARGE POT'L	1.00+004 VOLTS	1.00+004 VOLTS
16	INTERNAL DISCHARGEPOT'L	2.00+003 VOLTS	2.00+003 VOLTS
17	RADN INDUCEDCOND'YCOEFFT	1.00-013 MHOMS3	1.00-013 MHOMS3
18	RADN INDUCEDCOND'YPOWER	1.00+000 (NONE)	1.00+000 (NONE)
19	DENSITY	1.00+003 KG/M**3	1.00+003 KG/M**3
20		2.00+001	-1.00+000

MATERIAL 2: SOLA

	PROPERTY	INPUT VALUE	CODE VALUE
1	DIELECTRIC CONSTANT	3.80+000 (NONE)	3.80+000 (NONE)
2	THICKNESS	1.79-004 METERS	8.95-003 MESH
3	CONDUCTIVITY	1.00-017 MHO/M	1.00-017 MHO/M
4	ATOMIC NUMBER	1.00+001 (NONE)	1.00+001 (NONE)
5	DELTA MAX >COEFF	2.05+000 (NONE)	1.31+001 (NONE)
6	E-MAX >DEPTH**-1	4.10-001 KEV	3.17-002 ANG-01
7	RANGE	7.75+001 ANG.	3.49+001 ANG.
8	EXPONENT > RANGE	4.50-001 (NONE)	2.70+002 ANG.
9	RANGE > EXPONENT	1.56+002 ANG.	4.50-001 (NONE)
10	EXPONENT	1.73+000 (NONE)	1.73+000 (NONE)
11	YIELD FOR 1KEV PROTONS	2.44-001 (NONE)	2.44-001 (NONE)
12	MAX DE/DX FOR PROTONS	2.30+002 KEV	2.30+002 KEV
13	PHOTOCURRENT	2.00-005 A/M**2	2.00-005 A/M**2
14	SURFACE RESISTIVITY	1.00+019 OHMS	1.77+006 V-S/Q
15	SPACE DISCHARGE POT'L	1.00+004 VOLTS	1.00+004 VOLTS
16	INTERNAL DISCHARGEPOT'L	2.00+003 VOLTS	2.00+003 VOLTS
17	RADN INDUCEDCOND'YCOEFFT	1.00-013 MHOMS3	1.00-013 MHOMS3
18	RADN INDUCEDCOND'YPOWER	1.00+000 (NONE)	1.00+000 (NONE)
19	DENSITY	1.00+003 KG/M**3	1.00+003 KG/M**3
20		2.00+001	1.00-017

MATERIAL 3: KAPT

	PROPERTY	INPUT VALUE	CODE VALUE
1	DIELECTRIC CONSTANT	3.50+000 (NONE)	3.50+000 (NONE)
2	THICKNESS	1.27-004 METERS	6.35-003 MESH
3	CONDUCTIVITY	1.00-016 MHO/M	1.00-016 MHO/M
4	ATOMIC NUMBER	5.00+000 (NONE)	5.00+000 (NONE)
5	DELTA MAX >COEFF	2.10+000 (NONE)	4.06+001 (NONE)
6	E-MAX >DEPTH**-1	1.50-001 KEV	8.74-002 ANG-01
7	RANGE	7.15+001 ANG.	4.29+001 ANG.
8	EXPONENT > RANGE	6.00-001 (NONE)	5.52+002 ANG.
9	RANGE > EXPONENT	3.12+002 ANG.	6.00-001 (NONE)
10	EXPONENT	1.77+000 (NONE)	1.77+000 (NONE)
11	YIELD FOR 1KEV PROTONS	4.55-001 (NONE)	4.55-001 (NONE)
12	MAX DE/DX FOR PROTONS	1.40+002 KEV	1.40+002 KEV
13	PHOTOCURRENT	2.00-005 A/M**2	2.00-005 A/M**2
14	SURFACE RESISTIVITY	1.00+016 OHMS	1.77+003 V-S/Q
15	SPACE DISCHARGE POT'L	1.00+004 VOLTS	1.00+004 VOLTS
16	INTERNAL DISCHARGEPOT'L	2.00+003 VOLTS	2.00+003 VOLTS
17	RADN INDUCEDCOND'YCOEFFT	1.00-013 MHOMS3	1.00-013 MHOMS3
18	RADN INDUCEDCOND'YPOWER	1.00+000 (NONE)	1.00+000 (NONE)
19	DENSITY	1.00+003 KG/M**3	1.00+003 KG/M**3

Figure 10.6. (Continued).

```
20                                          2.00+001            1.00-016

   MATERIAL   4:  ALUM

    PROPERTY                                 INPUT VALUE          CODE VALUE
 1     DIELECTRIC CONSTANT                  1.00+000 (NONE)     1.00+000 (NONE)
 2     THICKNESS                            1.00-003 METERS     5.00-002 MESH
 3     CONDUCTIVITY                        -1.00+000 MHO/M     -1.00+000 MHO/M
 4     ATOMIC NUMBER                        1.30+001 (NONE)     1.30+001 (NONE)
 5     DELTA MAX     >COEFF                 9.70-001 (NONE)     9.18+000 (NONE)
 6     E-MAX         >DEPTH**-1             3.00-001 KEV        3.00-002 ANG-01
 7     RANGE                                1.54+002 ANG.       1.23+002 ANG.
 8     EXPONENT     > RANGE                 8.00-001 (NONE)     3.87+002 ANG.
 9     RANGE > EXPONENT                     2.20+002 ANG.       8.00-001 (NONE)
10     EXPONENT                             1.76+000 (NONE)     1.76+000 (NONE)
11     YIELD FOR 1KEV PROTONS               2.44-001 (NONE)     2.44-001 (NONE)
12     MAX DE/DX FOR PROTONS                2.30+002 KEV        2.30+002 KEV
13     PHOTOCURRENT                         4.00-005 A/M**2     4.00-005 A/M**2
14     SURFACE RESISTIVITY                 -1.00+000 OHMS      -1.77-013 V-S/Q
15     SPACE DISCHARGE POT'L                1.00+004 VOLTS      1.00+004 VOLTS
16     INTERNAL DISCHARGEPOT'L              2.00+003 VOLTS      2.00+003 VOLTS
17     RADN INDUCEDCOND'YCOEFFT             1.00-013 MHOMS3     1.00-013 MHOMS3
18     RADN INDUCEDCOND'YPOWER              1.00+000 (NONE)     1.00+000 (NONE)
19     DENSITY                              1.00+003 KG/M**3    1.00+003 KG/M**3
20                                          2.00+001           -1.00+000

      180 VOLUME CELLS NUMBERED BY NUMLTB.

 INSLST --  164 INSULATING SURFACE CELLS FOUND
                164 INCLUDING BOOM CELLS

SOLA HAS SURFACE RESISTIVITY OF    1.0+019 OHMS
KAPT HAS SURFACE RESISTIVITY OF    1.0+016 OHMS


 FNDSCE --  328 SURFACE CONDUCTING EDGES FOUND

 BOOMEJ --  328 EDGES FOUND

       668 ENTRIES IN REVISED VIXL
```

Figure 10.6. (Concluded).

10.8 RDOPT

Sample output is shown in Figure 10.7. References are as follows:

1. Option file input cards are echoed.

2. In UNIVAC versions temporary files are automatically assigned.

3. A summary of all options, including defaults, is printed.

```
@XQT

******RDOPT
```

```
                KEYWORD INPUT
1       XMESH 0.02
        NCYC 1
        DELTA 5
        SURFACE CELL 20
        SURFACE CELL 129
        SURFACE CELL 28
        SURFACE CELL 77
        SURFACE CELL 88
        SURFACE CELL 167
        SURFACE CELL 181

                CELL   20 INFORMATION TO BE PRINTED.
                CELL  129 INFORMATION TO BE PRINTED.
                CELL   28 INFORMATION TO BE PRINTED.
                CELL   77 INFORMATION TO BE PRINTED.
                CELL   88 INFORMATION TO BE PRINTED.
                CELL  167 INFORMATION TO BE PRINTED.
                CELL  181 INFORMATION TO BE PRINTED.

        LONGTIMESTEP
        SUNINT 1.0
2       SUNDIR 1 1 0
        DEST ELEC
        END
         ASGFIL -- @ASG  10. :
         ASGFIL -- @ASG  11. :
         ASGFIL -- @ASG  12. :
         ASGFIL -- @ASG  25. :
         ASGFIL -- @ASG  13. :
         ASGFIL -- @ASG  14. :
         ASGFIL -- @ASG  15. :
         ASGFIL -- @ASG  19. :
         ASGFIL -- @ASG  18. :
         ASGFIL -- @ASG  17. :
         ASGFIL -- @ASG  16. :
         ASGFIL -- @ASG  21. :
         ASGFIL -- @ASG  26. :
         ASGFIL -- @ASG  27. :
```

Figure 10.7. RDOPT

```
                                        NASA CHARGING ANALYZER PROGRAM
                                              OPTION SUMMARY

3   TITLE =NASCAP

    GRID SIZE OPTIONS:    NX    NY    NZ    NG
                          17    17    33     2
              FULL OUTER GRID USED
              ADDITIONAL OPTION WORDS: OFFSET, TANKSIZE, ZTRUNC, TANK RADIUS, TANK AXIS

    LOGICAL UNIT NUMBERS

              INPUT FILES: IKEYWD   ISAT    IFLUX   ISPCTR
                             26      20      22       9

              RESTART FILES: IP    IROUS  IPOCND  ILIBL  ICNOW  IAREA
                             10     15      16      17     21     27

              SCRATCH FILES: IAUN   IR    IDIV    IU   ISPARE   IOBJ  IOBPLT  IPART
                             11     12     25     13     14      18     19     28

    RUN MODE OPTIONS: ICREST  IPREST  NCYC  MCYC
                        0       0      1     1

                       DELTA     DELFAC
                    5.00+000  1.00+000
              DEADLINE = NONE
              ADDITIONAL KEYWORD = [RESTART]

    POTENTIAL SOLVER OPTIONS: POTCON    MAXITR   IOUTER   SCALE
                              NOTSET      99        2      SCAL
                        SCALING KEYWORDS: SCALE, NOSCALE, DSCALE
              AMBIENT SPACE CHARGE OPTION [KEYWORD DEBYE]=NONE

    CONDUCTOR FIXING AND BIASING:KEYWORDS FIXP, BIAS, FLOAT

    INTERCONDUCTOR CAPACITANCES:  KEYWORD CIJ
              THE CODE UNIT OF CHARGE IS   1.771-013 COULOMBS.
              THE CODE UNIT OF CAPACITANCE IS   1.77-013 FARADS.
              NO INTERCONDUCTOR CAPACITANCES SPECIFIED.

    LONGTIMESTEP AND DISCHARGE OPTIONS
              KEYWORDS: LONGTIMESTEP, NOLONGTIMESTEP, DISCHARGE, FLASHOVER
              LONGTIMESTEP REQUESTED WITH DVLIM=  1000.0 VOLTS.
              DISCHARGE ANALYSIS OFF

    ILLUMINATION SPECIFICATIONS:
              SUNINT= 1.000     SUNDIR =    .7071    .7071    .0000
              SHADOWING FORMULATION [KEYWORD=CONVEX]=SHAD

    ENVIRONMENT TYPE AND MESH SIZE
              ITYPE=   2     UPDATE=OFF       XMESH=  2.00-002

               SECONDARY EMISSION FORMULATION ='ANGL'
               EFFECTIVE PHOTOSHEATH CONDUCTIVITY [EFFCON] = OFF
               FIELD-ENHANCED BULK CONDUCTIVITY [FLDCON] = OFF
               RADIATION-INDUCED BULK CONDUCTIVITY [RADCON] = OFF

    OUTPUT OPTIONS:
                        NGPRT [APRT]    TIMER [NOTIMER]
                           0               NO
                        ICNVP [CONVERGENCE PLOTS]= 0
              PRINT [NOPRINT]:  POTENT    LIMCEL     OBJDEF     HIDCEL
                                 NO         NO         SOME       NO

        7 SURFACE CELLS SPECIFIED FOR I/O:
                  20    28    77    88   129   167   181
              KEYWORDS: [SURFACE CELL], [SURFACE AT], [SURFACE CORNER]

    PLOT OPTIONS:  TITLE=NASCAP
              NGPLOT    ICON      REPEAT     ITPART     ITCUR      IROUSP
                 0        0         1          0          0          0
```

Figure 10.7. (Continued).

```
DEST = ELEC
NCON      NDIR
  0         3
ADDITIONAL KEYWORDS: TANKCUR TANKTRAJ 3D-VIEW MATVIEW CONTOUR

NO. OF ADDITIONAL CONTOUR PLOT CUTS =      0

NO. OF 3-D PLOT VIEWS =      3

VECTORS FROM SATELLITE CENTER TOWARD VIEWER ARE
                                          .5000     .8000     .5000
                                         -.5000     .8000     .5000
                                          .2000    -.5000     .5000

   6 MATERIAL PLOT VIEWS REQUESTED:
          VIEW FROM +X DIRECTION BETWEEN   -8 AND    8
          VIEW FROM -X DIRECTION BETWEEN   -8 AND    8
          VIEW FROM +Y DIRECTION BETWEEN   -8 AND    8
          VIEW FROM -Y DIRECTION BETWEEN   -8 AND    8
          VIEW FROM +Z DIRECTION BETWEEN  -16 AND   16
          VIEW FROM -Z DIRECTION BETWEEN  -16 AND   16

PARTICLE TRACKING OPTIONS:
     KEYWORDS: EMITTER, NOEMITTER, SHEATH, SHEATH SELF-CONSISTENT

      NO EMITTERS REQUESTED

MAGNETIC FIELD OPTIONS: KEYWORDS [BFIELD], [DIPOLE]
     CONSTANT MAGNETIC FIELD =(    .00       .00       .00    ) W/M**2.
     NO MAGNETIC DIPOLES
```

Figure 10.7. (Concluded).

10.9 ROTATE

Sample ROTATE output is shown in Figure 10.8. References are as follows:

1. The time elapsed since the beginning of the first cycle is printed.
2. The sun direction vector, following rotation of the satellite is printed. This will be the direction for the next call to TRILIN.

```
      ******ROTATE 5
1       TIME =     7.0920 SECONDS
2          SUN ROTATED TO      1.4101      .1077      .0000
     DISTANCE EQUALS  999.99999
     FINAL NAI =     68
```

Figure 10.8. ROTATE sample output.

10.10. SATPLT

Sample output is shown in Figure 10.9. It is all purely diagnostic.

```
******SATPLT
 ASGFIL -- @ASG    2.,
 DISTANCE EQUALS   999.99998

FINAL NA1 =     95
 DISTANCE EQUALS   999.99998

FINAL NA1 =     95
 DISTANCE EQUALS   999.99999

FINAL NA1 =     93
```

Figure 10.9. SATPLT output.

10.11 SPIN

Sample SPIN output is shown in Figure 10.10. References are as follows:

1. The normalized sun direction vector for the first view is printed.

2. The number of views, and the spin axis vector are echoed.

3. Each line represents a call to HIDCEL. In this case there are four views and hence four calls.

```
      ******SPIN 5
       ASGFIL -- @ASG   2. .
      AVERAGE SOLAR ILLUMINATION BEING OBTAINED
1     THE INITIAL SUN DIRECTION IS       .707      .707      .000
2        4 VIEWS WILL BE GENERATED ABOUT THE AXIS       .000      .000     1.000
       DISTANCE EQUALS  999.99998
      FINAL NA1 =    62
       DISTANCE EQUALS  999.99999
      FINAL NA1 =    62
3      DISTANCE EQUALS  999.99998
      FINAL NA1 =    62
       DISTANCE EQUALS  999.99999
      FINAL NA1 =    62
```

Figure 10.10. SPIN sample output.

10.12. STRESS

Sample STRESS output is shown in Figure 10.11. References are as follows:

1. The number of cells requested (10) is echoed.

2. For each cell in order of decreasing stress, the potential, stress field and descriptive information is printed out.

```
******STRESS 10

1
ELECTRIC FIELD STRESS
CELLS   1 THROUGH  10 ON LIST OF DECREASING STRENGTH


-----------------------------------------------------------

2   SURFACE CELL NO.    88      CODE =          005111270103
                                LOCATION =       9  9 23
                                NORMAL =         0  0  1
                                MATERIAL =   KAPT
          POTENTIAL = -1.006+003 VOLTS
          FIELD =  1.582+007 VOLTS/METER
-----------------------------------------------------------

    SURFACE CELL NO.     1      CODE =          004607170303
                                LOCATION =       6  7 15
                                NORMAL =         0  0 -1
                                MATERIAL =   KAPT
          POTENTIAL = -1.006+003 VOLTS
          FIELD =  1.582+007 VOLTS/METER
-----------------------------------------------------------

    SURFACE CELL NO.     8      CODE =          004607220103
                                LOCATION =       6  7 18
                                NORMAL =         0  0  1
                                MATERIAL =   KAPT
          POTENTIAL = -1.006+003 VOLTS
          FIELD =  1.582+007 VOLTS/METER
-----------------------------------------------------------

    SURFACE CELL NO.    23      CODE =          004612170303
                                LOCATION =       6 10 15
                                NORMAL =         0  0 -1
                                MATERIAL =   KAPT
          POTENTIAL = -1.006+003 VOLTS
          FIELD =  1.582+007 VOLTS/METER
-----------------------------------------------------------

    SURFACE CELL NO.    30      CODE =          004612220103
                                LOCATION =       6 10 18
                                NORMAL =         0  0  1
                                MATERIAL =   KAPT
          POTENTIAL = -1.006+003 VOLTS
          FIELD =  1.582+007 VOLTS/METER
-----------------------------------------------------------

    SURFACE CELL NO.   123      CODE =          005307170303
                                LOCATION =      11  7 15
                                NORMAL =         0  0 -1
                                MATERIAL =   KAPT
          POTENTIAL = -1.006+003 VOLTS
          FIELD =  1.582+007 VOLTS/METER
```

Figure 10.11. STRESS sample output.

```
-----------------------------------------------------

 SURFACE CELL NO.  130      CODE =        005307220103
                           LOCATION =    11  7 18
                           NORMAL =       0  0  1
                           MATERIAL =   KAPT
       POTENTIAL = -1.006+003 VOLTS
       FIELD =  1.582+007 VOLTS/METER

-----------------------------------------------------

 SURFACE CELL NO.  145      CODE =        005312170303
                           LOCATION =    11 10 15
                           NORMAL =       0  0 -1
                           MATERIAL =   KAPT
       POTENTIAL = -1.006+003 VOLTS
       FIELD =  1.582+007 VOLTS/METER

-----------------------------------------------------

 SURFACE CELL NO.  152      CODE =        005312220103
                           LOCATION =    11 10 18
                           NORMAL =       0  0  1
                           MATERIAL =   KAPT
       POTENTIAL = -1.006+003 VOLTS
       FIELD =  1.582+007 VOLTS/METER

-----------------------------------------------------

 SURFACE CELL NO.   15      CODE =        004610220103
                           LOCATION =     6  8 18
                           NORMAL =       0  0  1
                           MATERIAL =   KAPT
       POTENTIAL = -1.006+003 VOLTS
       FIELD =  1.582+007 VOLTS/METER
```

Figure 10.11. (Concluded).

10.13. TANK

Sample TANK output is shown in Figure 10.12. References are as follows:

1. A message is printed, showing that a shadowing table exists from a previous TANK execution.

2. The TANK input is echoed.

3. Successful definition is confirmed for each of the four guns.

4. A fresh call to HIDCEL is made for each gun to create a new shadowing table.

```
******TANK 5

  OBJECT DEFINITION INFORMATION BEING READ FROM FILE

1 A SHADOWING TABLE WAS PREVIOUSLY GENERATED
   FOR THIS OBJECT USING THE GUNS OPTION
2 GUN AT 0 16 16
  ENERGY 6. KEV
  CURRENT 5.E-6
  BEAMWIDTH 30 DEGREES
  DIRECTION 0 -1 -1
  GUN AT 0 -16 16
  ENERGY 6. KEV
  CURRENT 5.E-6
  BEAMWIDTH 30 DEGREES
  DIRECTION 0 1 -1


  GUN AT 0 -16 -16
  ENERGY 6. KEV
  CURRENT 5.E-6
  BEAMWIDTH 30 DEGREES
  DIRECTION 0 1 1
  GUN AT 0 16 -16
  ENERGY 6. KEV
  CURRENT 5.E-6
  BEAMWIDTH 30 DEGREES
  DIRECTION 0 -1 1
  END

3  GUN DEFINITION ------
  GUN  1 HAS BEEN DEFINED AS AN ELECTRON GUN
  GUN IS LOCATED AT GRID COORDINATES   9.00  25.00  25.00
  GUN DIRECTION IS     .00  -1.00  -1.00
  BEAM  1: ENERGY=  6.00+003 EV    CURRENT=  5.00-006 AMPS   CUT-OFF ANGLE= 30.0000 DEGREES

   GUN DEFINITION ------
  GUN  2 HAS BEEN DEFINED AS AN ELECTRON GUN
  GUN IS LOCATED AT GRID COORDINATES   9.00  -7.00  25.00
  GUN DIRECTION IS     .00   1.00  -1.00
  BEAM  1: ENERGY=  6.00+003 EV    CURRENT=  5.00-006 AMPS   CUT-OFF ANGLE= 30.0000 DEGREES

   GUN DEFINITION ------
  GUN  3 HAS BEEN DEFINED AS AN ELECTRON GUN
  GUN IS LOCATED AT GRID COORDINATES   9.00  -7.00  -7.00
  GUN DIRECTION IS     .00   1.00   1.00
  BEAM  1: ENERGY=  6.00+003 EV    CURRENT=  5.00-006 AMPS   CUT-OFF ANGLE= 30.0000 DEGREES

   GUN DEFINITION ------
  GUN  4 HAS BEEN DEFINED AS AN ELECTRON GUN
  GUN IS LOCATED AT GRID COORDINATES   9.00  25.00  -7.00
  GUN DIRECTION IS     .00  -1.00   1.00
  BEAM  1: ENERGY=  6.00+003 EV    CURRENT=  5.00-006 AMPS   CUT-OFF ANGLE= 30.0000 DEGREES
  SHADOWING BEING CALCULATED FOR GUN   1
4  DISTANCE EQUALS  22.627417

 FINAL NA1 =    20
 SHADOWING BEING CALCULATED FOR GUN   2
  DISTANCE EQUALS  22.627417

 FINAL NA1 =    20
 SHADOWING BEING CALCULATED FOR GUN   3
  DISTANCE EQUALS  22.627417

 FINAL NA1 =    20
 SHADOWING BEING CALCULATED FOR GUN   4
  DISTANCE EQUALS  22.627417

 FINAL NA1 =    20
```

Figure 10.12. TANK sample output.

10.14 TRILIN

Sample output from TRILIN is shown in Figure 10.13. The references are as follows:

1. The flux definition input is summarized.

2. The present state of the charging calculation is summarized.

3. A flux breakdown is printed for the cells requested.

4. The net current to the whole object at the beginning of the timestep is printed, with and without the effect of electric field suppression of low energy emission.

5. The capacitance of the object to infinity is stated.

6. The average flux, over the timestep, to the cells chosen for a flux breakdown is printed.

7. A summary of charging activity and new conductor potentials for the cycle is printed.

8. A summary of final surface cell potentials for the present cycle is printed.

```
      ******TRILIN
1     FLUX DEFINITION SINGLE MAXWELLIAN
                    ELECTRON TEMPERATURE =    5.00+003 ELECTRON VOLTS
                    ELECTRON DENSITY =        1.20+006 METER**(-3)
                    ION TEMPERATURE =         3.00+003 ELECTRON VOLTS
                    ION DENSITY =             8.00+005 METER**(-3)
       POTENTIALS TO BE SET BY SETALL TO   1.00+000/(4*PI*R)
      AVERAGE RADIUS (RO)  =    4.00+000 CODE UNITS
2      *** THE SYSTEM IS NOW AT TIME     .000     SECONDS.     1 CYCLES HAVE BEEN REQUESTED.
                                  DELTA=  5.00+000 SECONDS.     DELFAC=  1.00+000.

               BEGIN CYCLE NO.     1          TIME =     .000     SECONDS.

        QSUMER FOUND QSUM=  1.00+000 CODE UNITS.
               AFTER SCREENING CORRECTION (SCREENING LENGTH=  2.00+002 M.) QSUM=  1.00+000
                         QSCALE=  1.00+000        CORRECTED TO   1.00+000
                         QSUM =  1.0012+000
                         PCOND =  1.989-002   1.989-002
                         QCOND =   .000         .000
      ------------------------------------------------------------------------------

        EXPLICITLY CALCULATED FLUXES FOR CYCLE    1     TIME =    .000     SECONDS.
        DURING THIS TIMESTEP, NASCAP WILL TAKE INTO ACCOUNT SUCH
        ADDITIONAL EFFECTS AS SURFACE CONDUCTIVITY, DISCHARGES, EMITTER OPERATION,
        AND VARIATION OF LIMITING FACTORS FOR LOW-ENERGY EMITTED ELECTRONS.
      ------------------------------------------------------------------------------
```

Figure 10.13. TRILIN output.

```
3  SURFACE CELL NO.   20                                    CODE =       004611216003
                                                            LOCATION =     6  9 17
                                                            NORMAL =      -1  0  0
                                                            MATERIAL =  KAPT

                              POTENTIAL =    .000     VOLTS
                              STRESS =  1.566+002 VOLTS/METER
                              EXTERNAL FIELD =   .000     VOLTS/METER
                              LIMITING FACTOR =  1.000+000

   FLUXES IN A/M**2
         INCIDENT ELECTRONS                              2.28-006
              RESULTING SECONDARIES                      9.75-007
              RESULTING BACKSCATTER                      6.01-007
         INCIDENT PROTONS                                2.75-008
              RESULTING SECONDARIES                      4.91-008
         BULK CONDUCTIVITY                               1.57-014
         PHOTOCURRENT                                     .00
                                                        ----------
        NET FLUX                                        -6.27-007
-------------------------------------------------------------------------------

   SURFACE CELL NO.   28                                    CODE =       004612210403
                                                            LOCATION =     6 10 17
                                                            NORMAL =       0  1  0
                                                            MATERIAL =  KAPT

                              POTENTIAL =    .000     VOLTS
                              STRESS =  1.566+002 VOLTS/METER
                              EXTERNAL FIELD =   .000     VOLTS/METER
                              LIMITING FACTOR =  1.000+000

   FLUXES IN A/M**2
         INCIDENT ELECTRONS                              2.28-006
              RESULTING SECONDARIES                      9.75-007
              RESULTING BACKSCATTER                      6.01-007
         INCIDENT PROTONS                                2.75-008
              RESULTING SECONDARIES                      4.91-008
         BULK CONDUCTIVITY                               1.57-014
         PHOTOCURRENT                                    1.41-005
                                                        ----------
        NET FLUX                                         1.35-005
-------------------------------------------------------------------------------

   SURFACE CELL NO.   77                                    CODE =       005107211403
                                                            LOCATION =     9  7 17
                                                            NORMAL =       0 -1  0
                                                            MATERIAL =  KAPT

                              POTENTIAL =    .000     VOLTS
                              STRESS =  1.566+002 VOLTS/METER
                              EXTERNAL FIELD =   .000     VOLTS/METER
                              LIMITING FACTOR =  1.000+000

   FLUXES IN A/M**2
         INCIDENT ELECTRONS                              2.28-006
              RESULTING SECONDARIES                      9.75-007
              RESULTING BACKSCATTER                      6.01-007
         INCIDENT PROTONS                                2.75-008
              RESULTING SECONDARIES                      4.91-008
         BULK CONDUCTIVITY                               1.57-014
         PHOTOCURRENT                                     .00
                                                        ----------
        NET FLUX                                        -6.27-007
-------------------------------------------------------------------------------
```

Figure 10.13. (Continued).

```
SURFACE CELL NO.   88                                    CODE =        0051112701O3
                                                         LOCATION =     9  9 23
                                                         NORMAL =       0  0  1
                                                         MATERIAL =   KAPT

                          POTENTIAL =    .000     VOLTS
                          STRESS =   1.566+002 VOLTS/METER
                          EXTERNAL FIELD =    .000     VOLTS/METER
                          LIMITING FACTOR =   1.000+000
 FLUXES IN A/M**2
       INCIDENT ELECTRONS                          2.28-006
            RESULTING SECONDARIES                  9.75-007
            RESULTING BACKSCATTER                  6.01-007
       INCIDENT PROTONS                            2.75-008
            RESULTING SECONDARIES                  4.91-008
       BULK CONDUCTIVITY                           1.57-014
       PHOTOCURRENT                                 .00
                                                   ----------
       NET FLUX                                    -6.27-007
-------------------------------------------------------------------------------

SURFACE CELL NO.   129                                   CODE =        0053072120O1
                                                         LOCATION =    11  7 17
                                                         NORMAL =       1  0  0
                                                         MATERIAL =   GOLD

                          POTENTIAL =    .000     VOLTS
                          EXTERNAL FIELD =    .000     VOLTS/METER
                          LIMITING FACTOR =   1.000+000
 FLUXES IN A/M**2
       INCIDENT ELECTRONS                          2.28-006
            RESULTING SECONDARIES                  1.46-006
            RESULTING BACKSCATTER                  1.48-006
       INCIDENT PROTONS                            2.75-008
            RESULTING SECONDARIES                  4.45-008
       PHOTOCURRENT                                2.05-005
                                                   ----------
       NET FLUX                                    2.12-005
-------------------------------------------------------------------------------

SURFACE CELL NO.   167                                   CODE =        011111120302
                                                         LOCATION =     9  9 10
                                                         NORMAL =       0  0 -1
                                                         MATERIAL =   SOLA

                          POTENTIAL =    .000     VOLTS
                          STRESS =   1.111+002 VOLTS/METER
                          EXTERNAL FIELD =    .000     VOLTS/METER
                          LIMITING FACTOR =   1.000+000
 FLUXES IN A/M**2
       INCIDENT ELECTRONS                          2.28-006
            RESULTING SECONDARIES                  1.83-006
            RESULTING BACKSCATTER                  7.77-007
       INCIDENT PROTONS                            2.75-008
            RESULTING SECONDARIES                  2.69-008
       BULK CONDUCTIVITY                           1.11-015
       PHOTOCURRENT                                 .00
                                                   ----------
       NET FLUX                                    3.81-007
-------------------------------------------------------------------------------

BOOM SURFACE CELL NO.   181                              CODE =        000061111123
                                                         LOCATION =     9  9 19    ( 1)
                                                         DIRECTION =    Z
                                                         MATERIAL =   ALUM

                          POTENTIAL =    .000     VOLTS
                          FIELD =    .000     VOLTS/METER
                          LIMITING FACTOR =   1.000+000
 FLUXES IN A/M**2
       INCIDENT ELECTRONS                          2.28-006
            RESULTING SECONDARIES                  8.52-007
            RESULTING BACKSCATTER                  8.51-007
       INCIDENT PROTONS                            2.75-008
            RESULTING SECONDARIES                  2.69-008
       PHOTOCURRENT                                1.27-005
                                                   ----------
       NET FLUX                                    1.21-005
```

Figure 10.13. (Continued).

```
4   INITIAL NET CHARGING CURRENT (WITHOUT LIMITING) =  3.60-007 AMPERES.
    INITIAL NET CHARGING CURRENT (WITH    LIMITING) =  3.60-007 AMPERES.

5   TOTAL CAPACITANCE TO INFINITY =    49.9 CODE UNITS;    8.83-012 FARADS.
      ICCG --- RDOTR/RDOTR1 =   1.16-014/  4.16+011
    LEAVING ICCG1 -- VCTR1 =  2.067+005  1.939+005
      ICCG --- RDOTR/RDOTR1 =   3.53-025/  1.95+006
    LEAVING ICCG1 -- VCTR1 =    .000       .000
      ICCG --- RDOTR/RDOTR1 =   2.71-025/  1.94+006
    LEAVING ICCG1 -- VCTR1 =    .000       .000
     VFIX ---   59 OUT OF  164 NODES FIXED.
  CONDUCTOR   1 FIXED TO     3.03 VOLTS.
      ICCG --- RDOTR/RDOTR1 =   1.65-025/  1.14+006
    LEAVING ICCG1 -- VCTR1 =  3.034+000  1.721+000
    NO DISCHARGE ANALYSIS
    NO DISCHARGE ANALYSIS
      ICCG --- RDOTR/RDOTR1 =   4.00-021/  9.79+006
    LEAVING ICCG2 -- VCTR1 =  3.040+000  1.726+000
   AVERAGE FLUXES (ONLY AVAILABLE FOR INSULATING CELLS)
```

Figure 10.13. (Continued).

```
6    AVERAGE FLUX TO CELL    20 IS    -6.252-007 A/M**2
     AVERAGE FLUX TO CELL    28 IS    -7.173-008 A/M**2
     AVERAGE FLUX TO CELL    77 IS    -6.252-007 A/M**2
     AVERAGE FLUX TO CELL    88 IS    -6.252-007 A/M**2
     AVERAGE FLUX TO CELL   167 IS    -4.740-008 A/M**2

     NEW CONDUCTOR POTENTIALS

7                VNEW                    DQ                VOLD        CONDUCTOR
           3.0404+000      7.6946+005          .0000                          1
           1.7256+000     -9.7015-005          .0000                          2

       TOTAL CHANGE IN CHARGE =    -1.966+002 CODE UNITS
                                   -3.482-011 COULOMBS

       AVERAGE NET CHARGING CURRENT =    -6.965-012 AMPERES
                                         -3.933+001 CODE UNITS/SEC.

     CONDUCTOR CURRENTS (AMPS; POSITIVE INTO CONDUCTORS):

                                                1             2

     NET CURRENT(AVG DQ/DT):                 2.73-008     -3.44-018

     CONDUCTIVITY CURRENT (NEW)
       (FROM INSULATING CELLS):             -4.71-013     -1.88-018

     PLASMA CURRENT (INITIAL)
       (TO BARE CELLS):                      1.42-007       .00

     REMAINDER CURRENT:                     -1.15-007     -1.55-018

     CONTINUE CYCLE NO.     1 AT UPDATED TIME =    5.000+000 SECONDS.
              QSUM = -1.9665+002
```

Figure 10.13. (Continued).

Figure 10.13. Continued.

8

SURFACE POTENTIALS - ALL 184 CELLS

CELL NO.											CELL NO.
1	-9.765+000	-9.765+000	-9.765+000	-9.767+000	-9.767+000	-9.767+000	-9.767+000	-9.765+000	-9.765+000	-9.765+000	10
11	-9.767+000	-9.767+000	-9.768+000	-9.768+000	-9.767+000	-9.767+000	-9.768+000	-9.767+000	-9.768+000	-9.768+000	20
21	-9.768+000	-9.767+000	-9.765+000	1.343-001	-9.765+000	1.570+000	-9.767+000	1.570+000	-9.767+000	-9.765+000	30
31	1.343-001	-9.765+000	-9.768+000	-9.767+000	-9.769+000	-9.769+000	-9.768+000	-9.767+000	-9.770+000	-9.770+000	40
41	-9.770+000	-9.770+000	-9.768+000	1.569+000	4.441+000	4.441+000	-9.768+000	1.569+000	-9.768+000	-9.768+000	50
51	-9.769+000	-9.769+000	-9.768+000	-9.768+000	-9.770+000	-9.770+000	-9.767+000	-9.765+000	-9.764+000	-9.770+000	60
61	-9.770+000	-9.768+000	-9.765+000	-9.763+000	-9.769+000	1.569+000	4.441+060	4.441+000	-9.769+000	1.569+000	70
71	-9.767+000	-9.765+000	-9.763+000	-9.768+000	-9.768+n00	-9.769+000	-9.769+000	-9.768+000	-9.768+000	-9.770+000	80
81	-9.770+000	-9.768+000	-9.765+000	-9.763+000	-9.770+000	-9.770+000	-9.769+000	-9.763+000	-9.769+000	1.569+000	90
91	4.441+000	4.441+000	-9.769+000	1.569+000	1.742-001	1.541+000	1.730-001	-9.768+000	-9.767+000	-9.769+000	100
101	-9.769+000	-9.768+000	-9.767+000	-9.770+000	-9.770+000	-9.767+000	-9.765+000	-9.763+000	-9.770+000	-9.770+000	110
111	1.743-001	1.541+000	1.730-001	-9.768+000	1.569+000	4.441+000	4.441+000	-9.768+000	1.569+000	3.839+000	120
121	4.706+000	3.840+000	-9.765+000	-9.765+000	3.040+000	-9.767+000	3.040+000	-9.767+000	3.040+000	-9.765+000	130
131	-9.765+000	3.040+000	-9.768+000	3.040+000	3.040+000	3.040+000	-9.768+000	3.040+000	-9.768+000	3.040+000	140
141	3.040+000	3.040+000	-9.768+000	3.040+000	-9.766+000	2.112+000	3.040+000	4.207+000	3.040+000	4.207+000	150
151	3.040+000	-9.766+000	2.112+000	3.040+000	4.642-001	4.642-001	4.642-001	4.642-001	4.642-001	4.642-001	160
161	4.642-001	4.642-001	4.642-001	4.642-001	4.642-001	4.642-001	4.642-001	4.642-001	3.418+000	4.027+000	170
171	3.418+000	4.642-001	4.642-001	4.642-001	3.418+000	4.027+000	3.418+000	4.705+000	5.027+000	4.705+000	180
181	3.040+000	3.040+000	3.040+000	3.040+000							

34 POTENTIAL ITERATIONS COMPLETED.
RDOTR/RDRMAX= 5.27-005/ 1.01+004

```
PCOND =    3.0404+000   1.7256+000
QCOND =    7.4810+005  -1.1685+002
  NEXTRA=     0

EFPREP --     1 GRIDS OUT OF    1 READ IN.

IP = 12  IR = 14  IU = 10  ISPARE = 13  IPSAVE = 10

LAST CYCLE COMPLETED IS    1.

IP = 10  IR = 14  IU = 12  ISPARE = 13  IPSAVE = 10
```

Figure 10.13. (Concluded).

11. A WORKED EXAMPLE

11.1 INTRODUCTION

In this chapter we work through a real NASCAP example. We describe the NASCAP runs that were made and how we decided on the options and other parameters that were used. In this way, we illustrate the use of NASCAP at a practical hands-on level.

No one example could use all of the features of the code. (This would almost certainly be confirmed by anyone who has just read the previous ten chapters!) Examples showing the use of important options that are not part of this worked example are included in the relevant earlier chapters.

In the example we have chosen to work through, we assume that we are supplied with a design for a proposed satellite, and a description of the type of plasma environment it might be expected to encounter in orbit. This gives us a good starting point for the preparation of two of the three major user input files: The object definition file and the flux definition file. The makeup of the third input file, (the run options file), depends on the type of simulation that we want to carry out.

Let us assume that the satellite is to have a particle detector mounted on its surface. If the satellite charges differentially (i.e., the different dielectric materials acquire different surface potentials) the spectrum of particles collected by the detector might be affected. We want to use NASCAP to analyse

(a) the charging of the satellite, exposed to the chosen plasma spectrum, to equilibrium.

(b) how the satellite being charged in this way affects the operation of the detector.

We begin this study by establishing the object, its capacitance, and shadowing. In a series of runs we determine the charging response of the object with the supplied plasma spectrum. Finally, we examine the operation of the detector using the DETECT module.

11.2 OBJECT DEFINITION

The first step in our study is to define the object at hand. The satellite in our example consists of a central cuboid and two spherical globes, each at the end of a metallic boom. One of the globes is electrically isolated from the rest and forms a separate conductor. All but one face of the satellite body is covered with KAPTON. The remaining face is covered with GOLD foil. The booms are made of ALUMINUM. One of the globes is covered with KAPTON. The second, electrically isolated globe, is covered with SOLAR cell cover glass material - called "SOLAR". This is SiO_2 glass covered with a MgF_2 non-reflective layer.

The object definition file defining a NASCAP representation of this satellite is shown in Figure 11.1. The materials GOLD and SOLAR have their properties definited explicitly. The remaining two materials specified, KAPTON and ALUMINUM are default materials, and their properties are read in from the default materials table. The object consists of five building blocks: The central RECTAN, two BOOMS, and two QSPHERES. The second QSPHERE forms CONDUCTOR 2.

```
  1:COMMENT WORKED EXAMPLE (CHAPTER 11)
  2:COMMENT ZONE SIZE IS 0.02 M
  3:COMMENT DEFINE MATERIAL GOLD AND SOLAR
  4:GOLD
  5:1.00      .001      -1.       79.       .88       .8        88.8      .92
  6:53.48     1.73      .413      135.      .000029   -1.       10000.    2000.
  7:1.E-13    1.        1.E+3     20.
  8:SOLAR
  9:3.8       .000179       1.E-17 10.      2.05      .41       77.5      .45
 10:156.1     1.73      .244      230.      .00002       1.E+19 10000.    2000.
 11:1.E-13    1.        1.E+3     20.
 12:COMMENT PROPERTIES OF KAPTON AND ALUMINUM FROM DEFAULT TABLE.
 13:CONDUCTOR 1
 14:COMMENT CENTRAL CUBOID
 15:RECTAN
 16:CORNER -3 -2 -2
 17:DELTAS 6 4 4
 18:SURFACE +X GOLD
 19:SURFACE -X KAPTON
 20:SURFACE +Y KAPTON
 21:SURFACE -Y KAPTON
 22:SURFACE +Z KAPTON
 23:SURFACE -Z KAPTON
 24:ENDOBJ
 25:COMMENT BOOM TO KAPTON SPHERE
 26:BOOM
 27:AXIS 0 0 2 0 0 4
 28:RADIUS 0.05
 29:SURFACE ALUMINUM
 30:ENDOBJ
 31:COMMENT BOOM TO SOLAR SPHERE
 32:BOOM
 33:AXIS 0 0 -2 0 0 -4
 34:RADIUS 0.05
 35:SURFACE ALUMINUM
 36:ENDOBJ
 37:COMMENT KAPTON SPHERE
 38:QSPHERE
 39:CENTER 0  0  5
 40:DIAMETER 3
 41:SIDE 1
 42:MATERIAL KAPTON
 43:ENDOBJ
 44:COMMENT SOLAR SPHERE (ON SEPARATE CONDUCTOR)
 45:CONDUCTOR 2
 46:QSPHERE
 47:CENTER 0 0 -6
 48:DIAMETER 3
 49:SIDE 1
 50:MATERIAL SOLAR
 51:ENDOBJ
 52:ENDSAT
EOF:52
0:)
```

Figure 11.1. Object definition file.

The choice of coordinates for each building block is determined by the physical size of the object and the choice of XMESH. Let us assume that our object has the following dimensions:

Part	Size
Globe diameter	63 mm
Boom length	41.5 mm
Cuboid	78 x 78 x 124 mm
Boom radius	1 mm

A choice of XMESH = 0.020 m (20 mm) allows these dimensions to be replaced by mesh units as follows:

Part	Size (mesh units)
Globe diameter	3 ≡ (60 mm)
Boom length	2 ≡ (40 mm)
Cuboid	4 x 4 x 6 (≡ 80 x 80 x 120 mm)
Boom radius	0.05 (≡ 1 mm)

It is always almost impossible to reproduce the dimensions of the object exactly. XMESH usually turns out to be a compromise choice, giving the best overall representation of the object. We could have chosen XMESH to be smaller and still have been able to fit the object within the 17 x 17 x 33 inner mesh. However, since the object is fairly simple a detailed representation results in little gain in accuracy compared with the extra computational effort involved.

11.3 THE FLUX DEFINITION FILE

Let's suppose we are lucky and the plasma environment we have been given is in Maxwellian form, with the following parameters.

	Electrons	Ions
Density	1.2×10^6 m^{-3}	0.8×10^6 m^{-3}
Temperature	5.0 keV	3.0 keV

This data can be entered directly into the flux definition file as shown in Figure 11.2.

If the environment description was in some other form it might first be necessary to reduce it to either a single Maxwellian or double Maxwellian form by a least squares fit. Tables of data can be entered directly (5.4.3), but this is not recommended.

The angular distribution of the plasma is isotropic.

```
1:SINGLE MAXWELLIAN
2:5.0 KEV
3:1.2 CGS
4:3.0 KEV
5:0.8E06 MKS
6:END
EOF:6
0:>
```

Figure 11.2. FLUX definition file.

11.4 THE OPTIONS FILE

The options file for the first run is shown in Figure 11.3. XMESH has been set to 20 mm, as decided during the object definition. The purpose of our first NASCAP run is to establish the object and make one trial call to TRILIN. Hence, just one short (5 second) cycle is requested using DELTA and NCYC. As we shall see later in Section 11.6, the results of this trial cycle will give us insight into the parameters we shall choose for the subsequent, charging runs.

When orbiting the earth the satellite will find itself exposed to sunlight. We assume that the sun lies in the XY plane of the satellite and shines with a normal intensity. These assumptions are introduced into the run using the SUNDIR and SUNINT cards as shown.

The LONGTIMESTEP option is specifically requested. This is always a good idea, unless a detailed simulation of the transient charging response is required (see Section 6.2.6). Any plots produced are set to be routed to the S-Cubed electrostatic plotter.

Finally, a detailed flux breakdown is requested for the seven surface cells shown using the SURFACE CELL option. These cells are not chosen at random, but on the basis of a preliminary interactive run.

```
     1:XMESH 0.02
     2:NCYC 1
     3:DELTA 5
     4:SURFACE CELL 20
     5:SURFACE CELL 129
     6:SURFACE CELL 28
     7:SURFACE CELL 77
     8:SURFACE CELL 88
     9:SURFACE CELL 167
    10:SURFACE CELL 181
    11:LONGTIMESTEP
    12:SUNINT 1.0
    13:SUNDIR 1 1 0
    14:DEST ELEC
    15:END
EOF:15
0:>
```

Figure 11.3. The OPTION file (first run).

11.5 A PRELIMINARY LOOK AT THE OBJECT

Before submitting the first batch run, it is a good practice to check to see if your object definition file actually defines the object you had in mind. This can be done quickly and easily by running NASCAP interactively from a graphics terminal. The input files are prepared as described in Sections 11.2 - 11.4. NASCAP is executed like any other interactive program and the primary keywords RDOPT, OBJDEF and SATPLT are entered at the keyboard as prompted. Since output is routed to the terminal immediate feedback is available and mistakes can be readily corrected. Plots can be routed to the terminal or plotter using the DEST option (Section 6.6.3).

The same effect can be achieved more easily using the NASCAP auxiliary code NASCAP*OBJCHECK.[20] This is a fully interactive combination of OBJDEF and SATPLT, specifically designed to check out the definition of objects at a graphics terminal.

As a byproduct of an interactive look at the object a surface cell list is displayed. This allows us to pick out the cell numbers to be included on SURFACE CELL cards in the options file. In our example, cells on the cuboid pointing in the $\pm x$ and $\pm y$ directions were chosen, along with cells pointing in the $\pm z$ directions on the globes, and a boom cell. This selection gives an all-around look at the spacecraft and samples all building blocks and all materials. The flux breakdowns from these cells will be very useful in understanding the physics behind the charging of the satellite during the simulation.

11.6 THE FIRST RUN

A UNIVAC version of the NASCAP runstream used for the first run is shown in Figure 11.4. The sequence of cards can be classified into 6 groups, labeled A–F.

A. Simple utility cards initiate the run and create a heading.

B. Temporary work files are assigned.

C. The prefixed, permanent files are copied into their temporary counterparts. (This protects any permanent information.)

D. The NASCAP absolute is executed.

E. The NASCAP primary keywords are read by the main program.

F. If NASCAP has executed successfully, the permanent files are updated. If execution is aborted these steps are never reached.

All NASCAP runstreams follow this pattern. Only the sequence of primary keywords changes.

In this first run RDOPT is the first module to be executed. This is true of every run. The next four modules OBJDEF, SATPLT, CAPACI AND HIDCEL establish the object: OBJDEF formally defines it, SATPLT produces 3D-VIEWS (6.6.1) and MATVIEWS (6.6.4), CAPACI determines its capacitances, and HIDCEL its shadowing table. Finally a call to TRILIN is made for a trial charging cycle.

The printed output produced by this run is shown in Figure 11.5. The graphical output is shown in Figure 11.6.

```
A  1:@RUN,M/R PRS,11182-00,STANNARD-P,45,500  .  NASCAP RUN STREAM
   2:@HDG,N .B,8 .M,88,8,8
   3:@BIG-NAME,N
   4:MANUAL
   5:BOX 19
   6:@ASG,T TPFS.,F///1000
B  7:@ASG,T 2.
   8:@ASG,T 10.
   9:@ASG,T 11.
  10:@ASG,T 12.
  11:@ASG,T 13.
  12:@ASG,T 14.
  13:@ASG,T 15.
  14:@ASG,T 16.
  15:@ASG,T 17.
  16:@ASG,T 20.
  17:@ASG,T 21.
  18:@ASG,T 22.
  19:@ASG,T 25.
  20:@ASG,T 26.
  21:@ASG,T 27.
C 22:@COPY MANUALOBJ.,20.
  23:@COPY MANUALFLX.,22.
  24:@COPY MANUALOPT.,26.
  25:@COPY MANUAL10.,10.
  26:@COPY MANUAL15.,15.
  27:@COPY MANUAL16.,16.
  28:@COPY MANUAL17.,17.
  29:@COPY MANUAL21.,21.
  30:@COPY MANUAL27.,27.
D 31:@ASG,A NASCAP*NPROG.
  32:@COPY,A NASCAP*NPROG.NASCAP
  33:@FREE NASCAP*NPROG.
  34:@XQT
E 35:RDOPT
  36:OBJDEF
  37:SATPLT
  38:CAPACI
  39:HIDCEL
  40:TRILIN
  41:END
  42:@PMD,EL
F 43:@COPY 10.,MANUAL10.
  44:@COPY 15.,MANUAL15.
  45:@COPY 16.,MANUAL16.
  46:@COPY 17.,MANUAL17.
  47:@COPY 21.,MANUAL21.
  48:@COPY 27.,MANUAL27.
  49:@BIG-NAME,N
  50:END
  51:BOX 19
  52:@FIN
EOF:52
@!>
```

Figure 11.4. NASCAP runstream (first run).

```
axqt

******RDOPT
```

```
          KEYWORD INPUT
XMESH 0.02
NCYC 1
DELTA 5
SURFACE CELL 20          CELL   20 INFORMATION TO BE PRINTED.
SURFACE CELL 129         CELL  129 INFORMATION TO BE PRINTED.
SURFACE CELL 28          CELL   28 INFORMATION TO BE PRINTED.
SURFACE CELL 77          CELL   77 INFORMATION TO BE PRINTED.
SURFACE CELL 88          CELL   88 INFORMATION TO BE PRINTED.
SURFACE CELL 167         CELL  167 INFORMATION TO BE PRINTED.
SURFACE CELL 181         CELL  181 INFORMATION TO BE PRINTED.
LONGTIMESTEP
SUNINT 1.0
SUNDIR 1 1 0
DEST ELEC
END
 ASGFIL -- @ASG  10. .
 ASGFIL -- @ASG  11. .
 ASGFIL -- @ASG  12. .
 ASGFIL -- @ASG  25. .
 ASGFIL -- @ASG  13. .
 ASGFIL -- @ASG  14. .
 ASGFIL -- @ASG  15. .
 ASGFIL -- @ASG  19. .
 ASGFIL -- @ASG  18. .
 ASGFIL -- @ASG  17. .
 ASGFIL -- @ASG  16. .
 ASGFIL -- @ASG  21. .
 ASGFIL -- @ASG  28. .
 ASGFIL -- @ASG  27. .
```

Figure 11.5. First run printed output.

```
                                    NASA CHARGING ANALYZER PROGRAM
                                          OPTION SUMMARY

TITLE =NASCAP

GRID SIZE OPTIONS:   NX   NY   NZ   NG
                     17   17   33    2
          FULL OUTER GRID USED
          ADDITIONAL OPTION WORDS: OFFSET, TANKSIZE, ZTRUNC, TANK RADIUS, TANK AXIS

LOGICAL UNIT NUMBERS

          INPUT FILES: IKEYWD   ISAT    IFLUX   ISPCTR
                         26      20      22       9

          RESTART FILES: IP    IROUS  IPOCND  ILTBL  ICNOW  IAREA
                         10     15      16      17     21     27

          SCRATCH FILES: IAUN   IR    IDIV   IU    ISPARE   IOBJ  IOBPLT  IPART
                         11     12     25     13      14      18     19     28

RUN MODE OPTIONS: ICREST  IPREST  NCYC  MCYC
                     0       0      1     1

                   DELTA     DELFAC
                 5.00+000  1.00+000
          DEADLINE = NONE
          ADDITIONAL KEYWORD = [RESTART]

POTENTIAL SOLVER OPTIONS: POTCON    MAXITR   IOUTER   SCALE
                          NOTSET      99       2      SCAL
                  SCALING KEYWORDS: SCALE, NOSCALE, DSCALE
          AMBIENT SPACE CHARGE OPTION [KEYWORD DEBYE]=NONE

CONDUCTOR FIXING AND BIASING:KEYWORDS FIXP, BIAS, FLOAT

INTERCONDUCTOR CAPACITANCES:  KEYWORD CIJ
          THE CODE UNIT OF CHARGE IS  1.771-013 COULOMBS.
          THE CODE UNIT OF CAPACITANCE IS   1.77-013 FARADS.
          NO INTERCONDUCTOR CAPACITANCES SPECIFIED.

LONGTIMESTEP AND DISCHARGE OPTIONS
          KEYWORDS: LONGTIMESTEP, NOLONGTIMESTEP, DISCHARGE, FLASHOVER
          LONGTIMESTEP REQUESTED WITH DVLIM=  1000.0 VOLTS.
          DISCHARGE ANALYSIS OFF

ILLUMINATION SPECIFICATIONS:
         SUNINT= 1.000     SUNDIR =   .7071   .7071   .0000
         SHADOWING FORMULATION [KEYWORD=CONVEX]=SHAD

ENVIRONMENT TYPE AND MESH SIZE
         ITYPE=   2     UPDATE=OFF      XMESH=  2.00-002

          SECONDARY EMISSION FORMULATION ='ANGL'
          EFFECTIVE PHOTOSHEATH CONDUCTIVITY [EFFCON] = OFF
          FIELD-ENHANCED BULK CONDUCTIVITY (FLDCON) = OFF
          RADIATION-INDUCED BULK CONDUCTIVITY (RADCON) = OFF

OUTPUT OPTIONS:
                    NGPRT [APRT]    TIMER [NOTIMER]
                        0                NO
                   ICNVP [CONVERGENCE PLOTS]= 0
          PRINT [NOPRINT]:  POTENT    LIMCEL    OBJDEF    HIDCEL
                             NO         NO        SOME      NO

    7 SURFACE CELLS SPECIFIED FOR I/O:
                    20   28   77   88  129  167  181
          KEYWORDS: [SURFACE CELL], [SURFACE AT], [SURFACE CORNER]

PLOT OPTIONS:  TITLE=NASCAP
          NGPLOT    ICON      REPEAT    ITPART    ITCUR     IROUSP
            0         0         1         0         0         0
```

Figure 11.5. (Continued).

```
      DEST = ELEC
      NCON      NDIR
        0         3
      ADDITIONAL KEYWORDS: TANKCUR TANKTRAJ 3D-VIEW MATVIEW CONTOUR

   NO. OF ADDITIONAL CONTOUR PLOT CUTS =      0

   NO. OF 3-D PLOT VIEWS =      3

  VECTORS FROM SATELLITE CENTER TOWARD VIEWER ARE
                                                    .5000      .8000      .5000
                                                   -.5000      .8000      .5000
                                                    .2000     -.5000      .5000

     6 MATERIAL PLOT VIEWS REQUESTED:
                 VIEW FROM +X DIRECTION BETWEEN    -8 AND     8
                 VIEW FROM -X DIRECTION BETWEEN    -8 AND     8
                 VIEW FROM +Y DIRECTION BETWEEN    -8 AND     8
                 VIEW FROM -Y DIRECTION BETWEEN    -8 AND     8
                 VIEW FROM +Z DIRECTION BETWEEN   -16 AND    16
                 VIEW FROM -Z DIRECTION BETWEEN   -16 AND    16

PARTICLE TRACKING OPTIONS:
      KEYWORDS: EMITTER, NOEMITTER, SHEATH, SHEATH SELF-CONSISTENT

       NO EMITTERS REQUESTED

MAGNETIC FIELD OPTIONS: KEYWORDS [BFIELD], [DIPOLE]
       CONSTANT MAGNETIC FIELD =(    .00        .00        .00    ) W/M**2.
       NO MAGNETIC DIPOLES


******OBJDEF
```

Figure 11.5. (Continued).

```
COMMENT WORKED EXAMPLE (CHAPTER 11)
COMMENT ZONE SIZE IS 0.02 M
COMMENT DEFINE MATERIAL GOLD AND SOLAR
GOLD                MATERIAL PROPERTIES
          1.00+000   1.00-003  -1.00+000   7.90+001   8.80-001   8.00-001   8.88+001   9.20-001   5.35+001   1.73+000
          4.13-001   1.35+002   2.90-005  -1.00+000   1.00+004   2.00+003   1.00-013   1.00+000   1.00+003   2.00+001
SOLAR               MATERIAL PROPERTIES
          3.80+000   1.79-004   1.00-017   1.00+001   2.05+000   4.10-001   7.75+001   4.50-001   1.56+002   1.73+000
          2.44-001   2.30+002   2.00-005   1.00+019   1.00+004   2.00+003   1.00-013   1.00+000   1.00+003   2.00+001
COMMENT PROPERTIES OF KAPTON AND ALUMINUM FROM DEFAULT TABLE.
CONDUCTOR 1
COMMENT CENTRAL CUBOID
RECTAN
 OBJECT NOW DEFINED.
                                  6<X< 12
                                  7<Y< 11
                                 15<Z< 19

SURFACE +X GOLD
SURFACE -X KAPTON
SURFACE +Y KAPTON
SURFACE -Y KAPTON
SURFACE +Z KAPTON
SURFACE -Z KAPTON
ENDOBJ
COMMENT BOOM TO KAPTON SPHERE
BOOM

BOOM DEFINED
BEGINNING AT                          9    9   19 (GRID 1 COORDINATES)
EXTENDING PARALLEL TO THE Z AXIS TO   9    9   21 (GRID 1 COORDINATES)

RADI        .05000
SURF    ALUM
COMMENT BOOM TO SOLAR SPHERE
BOOM

BOOM DEFINED
BEGINNING AT                          9    9   15 (GRID 1 COORDINATES)
EXTENDING PARALLEL TO THE Z AXIS TO   9    9   13 (GRID 1 COORDINATES)

RADI        .05000
SURF    ALUM
COMMENT KAPTON SPHERE
QSPHERE

   DEFINING Q-SPHERE
         CENTER =   9   9  22
         DIAMETER =   3     SIDE =   1
         MATERIAL = KAPT

   OCTAGON DEFINED
         AXIS = (   9   9  22) TO (  10   9  22)
         WIDTH =    3          SIDE =   1
```

Figure 11.5. (Continued).

```
   OCTAGON DEFINED
         AXIS = (   9   9  22) TO (   9  10  22)
         WIDTH =    3            SIDE =    1

   OCTAGON DEFINED
         AXIS = (   9   9  22) TO (   9   9  23)
         WIDTH =    3            SIDE =    1
COMMENT SOLAR SPHERE (ON SEPARATE CONDUCTOR)
CONDUCTOR 2
QSPHERE
   DEFINING Q-SPHERE
         CENTER =   9   9  11
         DIAMETER =   3     SIDE =   1
         MATERIAL = SOLA

   OCTAGON DEFINED
         AXIS = (   9   9  11) TO (  10   9  11)
         WIDTH =    3            SIDE =    1

   OCTAGON DEFINED
         AXIS = (   9   9  11) TO (   9  10  11)
         WIDTH =    3            SIDE =    1

   OCTAGON DEFINED
         AXIS = (   9   9  11) TO (   9   9  12)
         WIDTH =    3            SIDE =    1
ENDSAT
```

Figure 11.5. (Continued).

SURFACE CELL LIST

CELL NO.	CODE	CONDUCTOR	IX	IY	IZ	NORMAL	MATERIAL
1	004607170303	1	6	7	15	0 0 -1	KAPT
2	004607171403	1	6	7	15	0 -1 0	KAPT
3	004607176003	1	6	7	15	-1 0 0	KAPT
4	004607201403	1	6	7	16	0 -1 0	KAPT
5	004607206003	1	6	7	16	-1 0 0	KAPT
6	004607211403	1	6	7	17	0 -1 0	KAPT
7	004607216003	1	6	7	17	-1 0 0	KAPT
8	004607220103	1	6	7	18	0 0 1	KAPT
9	004607221403	1	6	7	18	0 -1 0	KAPT
10	004607226003	1	6	7	18	-1 0 0	KAPT
11	004610170303	1	6	8	15	0 0 -1	KAPT
12	004610176003	1	6	8	15	-1 0 0	KAPT
13	004610206003	1	6	8	16	-1 0 0	KAPT
14	004610216003	1	6	8	17	-1 0 0	KAPT
15	004610220103	1	6	8	18	0 0 1	KAPT
16	004610226003	1	6	8	18	-1 0 0	KAPT
17	004611170303	1	6	9	15	0 0 -1	KAPT
18	004611176003	1	6	9	15	-1 0 0	KAPT
19	004611206003	1	6	9	16	-1 0 0	KAPT
20	004611216003	1	6	9	17	-1 0 0	KAPT
21	004611220103	1	6	9	18	0 0 1	KAPT
22	004611226003	1	6	9	18	-1 0 0	KAPT
23	004612170303	1	6	10	15	0 0 -1	KAPT
24	004612170403	1	6	10	15	0 -1 0	KAPT
25	004612176003	1	6	10	15	-1 0 0	KAPT
26	004612200403	1	6	10	16	0 1 0	KAPT
27	004612206003	1	6	10	16	-1 0 0	KAPT
28	004612210403	1	6	10	17	0 1 0	KAPT
29	004612216003	1	6	10	17	-1 0 0	KAPT
30	004612220103	1	6	10	18	0 0 1	KAPT
31	004612220403	1	6	10	18	0 1 0	KAPT
32	004612226003	1	6	10	18	-1 0 0	KAPT
33	004707170303	1	7	7	15	0 0 -1	KAPT
34	004707171403	1	7	7	15	0 -1 0	KAPT
35	004707201403	1	7	7	16	0 -1 0	KAPT
36	004707211403	1	7	7	17	0 -1 0	KAPT
37	004707220103	1	7	7	18	0 0 1	KAPT
38	004707221403	1	7	7	18	0 -1 0	KAPT
39	004710170303	1	7	8	15	0 0 -1	KAPT
40	004710220103	1	7	8	18	0 0 1	KAPT
41	004711170303	1	7	9	15	0 0 -1	KAPT
42	004711220103	1	7	9	18	0 0 1	KAPT
43	004712170303	1	7	10	15	0 0 -1	KAPT
44	004712170403	1	7	10	15	0 -1 0	KAPT
45	004712200403	1	7	10	16	0 1 0	KAPT
46	004712210403	1	7	10	17	0 1 0	KAPT
47	004712220103	1	7	10	18	0 0 1	KAPT
48	004712220403	1	7	10	18	0 1 0	KAPT
49	005007170303	1	8	7	15	0 0 -1	KAPT
50	005007171403	1	8	7	15	0 -1 0	KAPT

Figure 11.5. (Continued).

SURFACE CELL NO.	CELL LIST CODE	CONDUCTOR	IX	IY	IZ	NORMAL	MATERIAL
51	005007201403	1	8	7	16	0 -1 0	KAPT
52	005007211403	1	8	7	17	0 -1 0	KAPT
53	005007220103	1	8	7	18	0 0 1	KAPT
54	005007221403	1	8	8	15	0 -1 0	KAPT
55	005010170303	1	8	8	16	0 0 -1	KAPT
56	005010220103	1	8	8	21	-1 -1 -1	KAPT
57	005010225743	1	8	8	22	-1 -1 0	KAPT
58	005010267403	1	8	8	23	-1 -1 0	KAPT
59	005010277543	1	8	9	15	0 0 -1	KAPT
60	005011170303	1	8	9	16	0 0 -1	KAPT
61	005011220103	1	8	9	21	-1 -1 -1	KAPT
62	005011256303	1	8	9	22	-1 -1 0	KAPT
63	005011266003	1	8	9	23	-1 -1 0	KAPT
64	005011276103	1	8	10	15	0 0 -1	KAPT
65	005012170303	1	8	10	16	0 0 1	KAPT
66	005012170403	1	8	10	17	0 0 1	KAPT
67	005012200403	1	8	10	18	0 0 1	KAPT
68	005012210403	1	8	10	21	-1 -1 -1	KAPT
69	005012220103	1	8	10	22	-1 -1 0	KAPT
70	005012220403	1	8	10	23	-1 -1 0	KAPT
71	005012256743	1	8	11	15	0 0 -1	KAPT
72	005012266403	1	8	11	16	0 0 1	KAPT
73	005012276543	1	8	11	17	0 0 1	KAPT
74	005107170303	1	9	7	15	0 -1 0	KAPT
75	005107171403	1	9	7	16	0 -1 0	KAPT
76	005107201403	1	9	7	17	0 0 1	KAPT
77	005107211403	1	9	7	18	0 0 1	KAPT
78	005107220103	1	9	8	15	0 -1 0	KAPT
79	005107221403	1	9	8	16	0 0 -1	KAPT
80	005110170303	1	9	8	21	-1 -1 -1	KAPT
81	005110220103	1	9	8	22	-1 -1 0	KAPT
82	005110251703	1	9	8	23	-1 -1 0	KAPT
83	005110261403	1	9	9	15	0 0 -1	KAPT
84	005110271503	1	9	9	16	0 0 -1	KAPT
85	005111170303	1	9	9	21	-1 -1 -1	KAPT
86	005111220103	1	9	9	22	-1 -1 -1	KAPT
87	005111250303	1	9	9	23	-1 -1 -1	KAPT
88	005111270103	1	9	10	15	0 0 -1	KAPT
89	005112170303	1	9	10	16	0 0 1	KAPT
90	005112170403	1	9	10	17	0 0 1	KAPT
91	005112200403	1	9	10	18	0 0 1	KAPT
92	005112210403	1	9	10	21	-1 -1 -1	KAPT
93	005112220103	1	9	10	22	-1 -1 -1	KAPT
94	005112220403	1	9	10	23	-1 -1 -1	KAPT
95	005112250703	1	9	11	15	0 0 -1	KAPT
96	005112260403	1	9	11	16	0 0 1	KAPT
97	005112270503	1	9	11	17	0 0 1	KAPT
98	005207170303	1	10	7	15	0 -1 0	KAPT
99	005207171403	1	10	7	15	0 -1 0	KAPT
100	005207201403	1	10	7	16	0 -1 0	KAPT

Figure 11.5. (Continued).

SURFACE CELL LIST

CELL NO.	CODE	CONDUCTOR	IX	IY	IZ	NORMAL	MATERIAL
101	005207211403	1	10	7	17	0 -1 0	KAPT
102	005207220103	1	10	7	18	0 0 1	KAPT
103	005207221403	1	10	7	18	0 -1 0	KAPT
104	005210170303	1	10	8	15	0 0 -1	KAPT
105	005210220103	1	10	8	18	0 0 1	KAPT
106	005210253743	1	10	8	21	1 -1 -1	KAPT
107	005210263403	1	10	8	22	1 -1 0	KAPT
108	005210273543	1	10	8	23	1 -1 1	KAPT
109	005211170303	1	10	9	15	0 0 -1	KAPT
110	005211220103	1	10	9	18	0 0 1	KAPT
111	005211252303	1	10	9	21	1 0 -1	KAPT
112	005211262003	1	10	9	22	1 0 0	KAPT
113	005211272103	1	10	9	23	1 0 1	KAPT
114	005212170303	1	10	10	15	0 0 -1	KAPT
115	005212170403	1	10	10	15	0 1 0	KAPT
116	005212200403	1	10	10	16	0 1 0	KAPT
117	005212210403	1	10	10	17	0 1 0	KAPT
118	005212220103	1	10	10	18	0 0 1	KAPT
119	005212220403	1	10	10	18	0 1 0	KAPT
120	005212252743	1	10	10	21	1 1 -1	KAPT
121	005212262403	1	10	10	22	1 1 0	KAPT
122	005212272543	1	10	10	23	1 1 1	KAPT
123	005307170303	1	11	7	15	0 0 -1	KAPT
124	005307171403	1	11	7	15	0 -1 0	KAPT
125	005307172001	1	11	7	15	1 0 0	GOLD
126	005307201403	1	11	7	16	0 -1 0	KAPT
127	005307202001	1	11	7	16	1 0 0	GOLD
128	005307211403	1	11	7	17	0 -1 0	KAPT
129	005307212001	1	11	7	17	1 0 0	GOLD
130	005307220103	1	11	7	18	0 0 1	KAPT
131	005307221403	1	11	7	18	0 -1 0	KAPT
132	005307222001	1	11	7	18	1 0 0	GOLD
133	005310170303	1	11	8	15	0 0 -1	KAPT
134	005310172001	1	11	8	15	1 0 0	GOLD
135	005310202001	1	11	8	16	1 0 0	GOLD
136	005310212001	1	11	8	17	1 0 0	GOLD
137	005310220103	1	11	8	18	0 0 1	KAPT
138	005310222001	1	11	8	18	1 0 0	GOLD
139	005311170303	1	11	9	15	0 0 -1	KAPT
140	005311172001	1	11	9	15	1 0 0	GOLD
141	005311202001	1	11	9	16	1 0 0	GOLD
142	005311212001	1	11	9	17	1 0 0	GOLD
143	005311220103	1	11	9	18	0 0 1	KAPT
144	005311222001	1	11	9	18	1 0 0	GOLD
145	005312170303	1	11	10	15	0 0 -1	KAPT
146	005312170403	1	11	10	15	0 1 0	KAPT
147	005312172001	1	11	10	15	1 0 0	GOLD
148	005312200403	1	11	10	16	0 1 0	KAPT
149	005312202001	1	11	10	16	1 0 0	GOLD
150	005312210403	1	11	10	17	0 1 0	KAPT

Figure 11.5. (Continued).

SURFACE CELL LIST

CELL NO.	CODE	CONDUCTOR	IX	IY	IZ	NORMAL	MATERIAL
151	005312212001	1	11	10	17	1 0 0	GOLD
152	005312220103	1	11	10	18	0 0 1	KAPT
153	005312220403	1	11	10	18	0 1 0	KAPT
154	005312222001	1	11	10	18	1 0 0	GOLD
155	011010127742	2	8	8	10	-1 -1 -1	SOLA
156	011010137402	2	8	8	11	-1 -1 0	SOLA
157	011010147542	2	8	8	12	-1 -1 1	SOLA
158	011011126302	2	8	9	10	-1 0 -1	SOLA
159	011011136002	2	8	9	11	-1 0 0	SOLA
160	011011146102	2	8	9	12	-1 0 1	SOLA
161	011012126742	2	8	10	10	-1 1 -1	SOLA
162	011012136402	2	8	10	11	-1 1 0	SOLA
163	011012146542	2	8	10	12	-1 1 1	SOLA
164	011110121702	2	9	8	10	0 -1 -1	SOLA
165	011110131402	2	9	8	11	0 -1 0	SOLA
166	011110141502	2	9	8	12	0 -1 1	SOLA
167	011111120302	2	9	9	10	0 0 -1	SOLA
168	011111140102	2	9	9	12	0 0 1	SOLA
169	011112120702	2	9	10	10	0 1 -1	SOLA
170	011112130402	2	9	10	11	0 1 0	SOLA
171	011112140502	2	9	10	12	0 1 1	SOLA
172	011210123742	2	10	8	10	1 -1 -1	SOLA
173	011210133402	2	10	8	11	1 -1 0	SOLA
174	011210143542	2	10	8	12	1 -1 1	SOLA
175	011211122302	2	10	9	10	1 0 -1	SOLA
176	011211132002	2	10	9	11	1 0 0	SOLA
177	011211142102	2	10	9	12	1 0 1	SOLA
178	011212122742	2	10	10	10	1 1 -1	SOLA
179	011212132402	2	10	10	11	1 1 0	SOLA
180	011212142542	2	10	10	12	1 1 1	SOLA

BOOM SURFACE CELL LIST

CELL NO.	CODE	CONDUCTOR	IX	IY	IZ	GRID	AXIS	BOOM	INT	MATERIAL
181	000061111123	1	9	9	19	1	Z	1	1	ALUM
182	000061111124	1	9	9	20	1	Z	1	1	ALUM
183	000062111115	1	9	9	13	1	Z	2	1	ALUM
184	000062111116	1	9	9	14	1	Z	2	1	ALUM

LIST OF BOOM PROPERTIES

BOOM	RADIUS	AXIS	MATERIAL	CONDUC
1	.050	Z	ALUM	1
2	.050	Z	ALUM	1

Figure 11.5. (Continued).

```
PREPROCESSING OF MATERIAL PROPERTIES

MATERIAL   1:  GOLD

 PROPERTY                                INPUT VALUE          CODE VALUE
 1    DIELECTRIC CONSTANT                1.00+000 (NONE)      1.00+000 (NONE)
 2    THICKNESS                          1.00-003 METERS      5.00-002 MESH
 3    CONDUCTIVITY                      -1.00+000 MHO/M      -1.00+000 MHO/M
 4    ATOMIC NUMBER                      7.90+001 (NONE)      7.90+001 (NONE)
 5    DELTA MAX     >COEFF               8.80-001 (NONE)      2.93+000 (NONE)
 6    E-MAX         >DEPTH**-1           8.00-001 KEV         2.02-002 ANG-01
 7    RANGE                              8.88+001 ANG.        8.17+001 ANG.
 8    EXPONENT      > RANGE              9.20-001 (NONE)      9.25+001 ANG.
 9    RANGE  > EXPONENT                  5.35+001 ANG.        9.20-001 (NONE)
10    EXPONENT                           1.73+000 (NONE)      1.73+000 (NONE)
11    YIELD FOR 1KEV PROTONS             4.13-001 (NONE)      4.13-001 (NONE)
12    MAX DE/DX FOR PROTONS              1.35+002 KEV         1.35+002 KEV
13    PHOTOCURRENT                       2.90-005 A/M**2      2.90-005 A/M**2
14    SURFACE RESISTIVITY               -1.00+000 OHMS       -1.77-013 V-S/Q
15    SPACE DISCHARGE POT'L              1.00+004 VOLTS       1.00+004 VOLTS
16    INTERNAL DISCHARGEPOT'L            2.00+003 VOLTS       2.00+003 VOLTS
17    RADN INDUCEDCOND'YCOEFFT           1.00-013 MHOMS3      1.00-013 MHOMS3
18    RADN INDUCEDCOND'YPOWER            1.00+000 (NONE)      1.00+000 (NONE)
19    DENSITY                            1.00+003 KG/M**3     1.00+003 KG/M**3
20                                       2.00+001            -1.00+000

MATERIAL   2:  SOLA

 PROPERTY                                INPUT VALUE          CODE VALUE
 1    DIELECTRIC CONSTANT                3.80+000 (NONE)      3.80+000 (NONE)
 2    THICKNESS                          1.79-004 METERS      8.95-003 MESH
 3    CONDUCTIVITY                       1.00-017 MHO/M       1.00-017 MHO/M
 4    ATOMIC NUMBER                      1.00+001 (NONE)      1.00+001 (NONE)
 5    DELTA MAX     >COEFF               2.05+000 (NONE)      1.31+001 (NONE)
 6    E-MAX         >DEPTH**-1           4.10-001 KEV         3.17-002 ANG-01
 7    RANGE                              7.75+001 ANG.        3.49+001 ANG.
 8    EXPONENT      > RANGE              4.50-001 (NONE)      2.70+002 ANG.
 9    RANGE  > EXPONENT                  1.56+002 ANG.        4.50-001 (NONE)
10    EXPONENT                           1.73+000 (NONE)      1.73+000 (NONE)
11    YIELD FOR 1KEV PROTONS             2.44-001 (NONE)      2.44-001 (NONE)
12    MAX DE/DX FOR PROTONS              2.30+002 KEV         2.30+002 KEV
13    PHOTOCURRENT                       2.00-005 A/M**2      2.00-005 A/M**2
14    SURFACE RESISTIVITY                1.00+019 OHMS        1.77+006 V-S/Q
15    SPACE DISCHARGE POT'L              1.00+004 VOLTS       1.00+004 VOLTS
16    INTERNAL DISCHARGEPOT'L            2.00+003 VOLTS       2.00+003 VOLTS
17    RADN INDUCEDCOND'YCOEFFT           1.00-013 MHOMS3      1.00-013 MHOMS3
18    RADN INDUCEDCOND'YPOWER            1.00+000 (NONE)      1.00+000 (NONE)
19    DENSITY                            1.00+003 KG/M**3     1.00+003 KG/M**3
20                                       2.00+001             1.00-017

MATERIAL   3:  KAPT

 PROPERTY                                INPUT VALUE          CODE VALUE
 1    DIELECTRIC CONSTANT                3.50+000 (NONE)      3.50+000 (NONE)
 2    THICKNESS                          1.27-004 METERS      6.35-003 MESH
 3    CONDUCTIVITY                       1.00-016 MHO/M       1.00-016 MHO/M
 4    ATOMIC NUMBER                      5.00+000 (NONE)      5.00+000 (NONE)
 5    DELTA MAX     >COEFF               2.10+000 (NONE)      4.06+001 (NONE)
 6    E-MAX         >DEPTH**-1           1.50-001 KEV         8.74-002 ANG-01
 7    RANGE                              7.15+001 ANG.        4.29+001 ANG.
 8    EXPONENT      > RANGE              6.00-001 (NONE)      5.52+002 ANG.
 9    RANGE  > EXPONENT                  3.12+002 ANG.        6.00-001 (NONE)
10    EXPONENT                           1.77+000 (NONE)      1.77+000 (NONE)
11    YIELD FOR 1KEV PROTONS             4.55-001 (NONE)      4.55-001 (NONE)
12    MAX DE/DX FOR PROTONS              1.40+002 KEV         1.40+002 KEV
13    PHOTOCURRENT                       2.00-005 A/M**2      2.00-005 A/M**2
14    SURFACE RESISTIVITY                1.00+016 OHMS        1.77+003 V-S/Q
15    SPACE DISCHARGE POT'L              1.00+004 VOLTS       1.00+004 VOLTS
16    INTERNAL DISCHARGEPOT'L            2.00+003 VOLTS       2.00+003 VOLTS
17    RADN INDUCEDCOND'YCOEFFT           1.00-013 MHOMS3      1.00-013 MHOMS3
18    RADN INDUCEDCOND'YPOWER            1.00+000 (NONE)      1.00+000 (NONE)
19    DENSITY                            1.00+003 KG/M**3     1.00+003 KG/M**3
```

Figure 11.5. (Continued).

```
20                                          2.00+001            1.00-016

   MATERIAL   4:  ALUM

    PROPERTY                                 INPUT VALUE          CODE VALUE
 1     DIELECTRIC CONSTANT                  1.00+000 (NONE)     1.00+000 (NONE)
 2     THICKNESS                            1.00-003 METERS     5.00-002 MESH
 3     CONDUCTIVITY                        -1.00+000 MHO/M     -1.00+000 MHO/M
 4     ATOMIC NUMBER                        1.30+001 (NONE)     1.30+001 (NONE)
 5     DELTA MAX    >COEFF                  9.70-001 (NONE)     9.18+000 (NONE)
 6     E-MAX        >DEPTH**-1              3.00-001 KEV        3.00-002 ANG-01
 7     RANGE                                1.54+002 ANG.       1.23+002 ANG.
 8     EXPONENT     > RANGE                 8.00-001 (NONE)     3.87+002 ANG.
 9     RANGE > EXPONENT                     2.20+002 ANG.       8.00-001 (NONE)
10     EXPONENT                             1.76+000 (NONE)     1.76+000 (NONE)
11     YIELD FOR 1KEV PROTONS               2.44-001 (NONE)     2.44-001 (NONE)
12     MAX DE/DX FOR PROTONS                2.30+002 KEV        2.30+002 KEV
13     PHOTOCURRENT                         4.00-005 A/M**2     4.00-005 A/M**2
14     SURFACE RESISTIVITY                 -1.00+000 OHMS      -1.77-013 V-S/Q
15     SPACE DISCHARGE POT'L                1.00+004 VOLTS      1.00+004 VOLTS
16     INTERNAL DISCHARGEPOT'L              2.00+003 VOLTS      2.00+003 VOLTS
17     RADN INDUCEDCOND'YCOEFFT             1.00-013 MHOMS3     1.00-013 MHOMS3
18     RADN INDUCEDCOND'YPOWER              1.00+000 (NONE)     1.00+000 (NONE)
19     DENSITY                              1.00+003 KG/M**3    1.00+003 KG/M**3
20                                          2.00+001           -1.00+000

      180 VOLUME CELLS NUMBERED BY NUMLTB.

  INSLST --  164 INSULATING SURFACE CELLS FOUND
                 164 INCLUDING BOOM CELLS

SOLA HAS SURFACE RESISTIVITY OF     1.0+019 OHMS
KAPT HAS SURFACE RESISTIVITY OF     1.0+016 OHMS


 FNDSCE --  328 SURFACE CONDUCTING EDGES FOUND

  BOOMEJ --  328 EDGES FOUND

        668 ENTRIES IN REVISED VTXL


******SATPLT
 ASGFIL -- @ASG   2.
 DISTANCE EQUALS  999.99998

FINAL NA1 =    95
 DISTANCE EQUALS  999.99998

FINAL NA1 =    95
 DISTANCE EQUALS  999.99999

FINAL NA1 =    93


******CAPACI

  POTENTIALS TO BE SET BY SETALL TO   1.00+000/(4*PI*R)

AVERAGE RADIUS (RO)  =   4.00+000 CODE UNITS

             47 POTENTIAL ITERATIONS COMPLETED.
               ROOTR/RORMAX=  1.85-009/  2.78-001
PCOND =    2.0106-002   2.0106-002
QCOND =    7.8569-001   2.1436-001

   VBAR=  2.0054-002 -- CS SCALED BY  1.0026+000
```

Figure 11.5. (Continued)

```
  CROEFF --- EFFECTIVE OBJECT RADIUS =       .0793 METERS

             50 POTENTIAL ITERATIONS COMPLETED.
                RDOTR/RDRMAX=  2.38-003/  3.42+005
PCOND =    -2.1205+000   7.8795+000
QCOND =    -3.5585+002   3.5581+002

  SMALL INTERCONDUCTOR CAPACITANCES:
                    -2.73+001  2.72+001


******HIDCEL
 DISTANCE EQUALS  999.99998
FINAL NA1 =    62


******TRILIN
FLUX DEFINITION SINGLE MAXWELLIAN
               ELECTRON TEMPERATURE =   5.00+003 ELECTRON VOLTS
               ELECTRON DENSITY =       1.20+006 METER**(-3)
               ION TEMPERATURE =        3.00+003 ELECTRON VOLTS
               ION DENSITY =            8.00+005 METER**(-3)
  POTENTIALS TO BE SET BY SETALL TO   1.00+000/(4*PI*R)
AVERAGE RADIUS (R0)  =   4.00+000 CODE UNITS
 *** THE SYSTEM IS NOW AT TIME     .000     SECONDS.     1 CYCLES HAVE BEEN REQUESTED.
                          DELTA=  5.00+000 SECONDS.     DELFAC=  1.00+000.
```

Figure 11.5. (Continued).

```
        BEGIN CYCLE NO.     1          TIME =     .000     SECONDS.

 QSUMER FOUND QSUM=  1.00+000 CODE UNITS.
        AFTER SCREENING CORRECTION (SCREENING LENGTH=  2.00+002 M.) QSUM=  1.00+000
                  QSCALE=  1.00+000          CORRECTED TO   1.00+000
                  QSUM =  1.0012+000
                  PCOND =  1.989-002    1.989-002
                  QCOND =   .000         .000
-------------------------------------------------------------------------------

 EXPLICITLY CALCULATED FLUXES FOR CYCLE   1     TIME =    .000     SECONDS.
 DURING THIS TIMESTEP, NASCAP WILL TAKE INTO ACCOUNT SUCH
 ADDITIONAL EFFECTS AS SURFACE CONDUCTIVITY, DISCHARGES, EMITTER OPERATION,
 AND VARIATION OF LIMITING FACTORS FOR LOW-ENERGY EMITTED ELECTRONS.
-------------------------------------------------------------------------------

 SURFACE CELL NO.   20                                          CODE =       00%611216003
                                                                LOCATION =    6  9 17
                                                                NORMAL =     -1  0  0
                                                                MATERIAL =  KAPT
                          POTENTIAL =    .000     VOLTS
                          STRESS =  1.566+002 VOLTS/METER
                          EXTERNAL FIELD =   .000     VOLTS/METER
                          LIMITING FACTOR =  1.000+000
  FLUXES IN A/M**2
       INCIDENT ELECTRONS                          2.28-006
            RESULTING SECONDARIES                  9.75-007
            RESULTING BACKSCATTER                  6.01-007
       INCIDENT PROTONS                            2.75-008
            RESULTING SECONDARIES                  4.91-008
       BULK CONDUCTIVITY                           1.57-014
       PHOTOCURRENT                                 .00
                                                   ----------
     NET FLUX                                      -6.27-007
-------------------------------------------------------------------------------

 SURFACE CELL NO.   28                                          CODE =       00%612210403
                                                                LOCATION =    6 10 17
                                                                NORMAL =      0  1  0
                                                                MATERIAL =  KAPT
                          POTENTIAL =    .000     VOLTS
                          STRESS =  1.566+002 VOLTS/METER
                          EXTERNAL FIELD =   .000     VOLTS/METER
                          LIMITING FACTOR =  1.000+000
  FLUXES IN A/M**2
       INCIDENT ELECTRONS                          2.28-006
            RESULTING SECONDARIES                  9.75-007
            RESULTING BACKSCATTER                  6.01-007
       INCIDENT PROTONS                            2.75-008
            RESULTING SECONDARIES                  4.91-008
       BULK CONDUCTIVITY                           1.57-014
       PHOTOCURRENT                                1.41-005
                                                   ----------
     NET FLUX                                      1.35-005
-------------------------------------------------------------------------------

 SURFACE CELL NO.   77                                          CODE =       00510721%403
                                                                LOCATION =    9  7 17
                                                                NORMAL =      0 -1  0
                                                                MATERIAL =  KAPT
                          POTENTIAL =    .000     VOLTS
                          STRESS =  1.566+002 VOLTS/METER
                          EXTERNAL FIELD =   .000     VOLTS/METER
                          LIMITING FACTOR =  1.000+000
  FLUXES IN A/M**2
       INCIDENT ELECTRONS                          2.28-006
            RESULTING SECONDARIES                  9.75-007
            RESULTING BACKSCATTER                  6.01-007
```

Figure 11.5. (Continued).

```
        INCIDENT PROTONS
             RESULTING SECONDARIES                    2.75-008
                                                      4.91-008
        BULK CONDUCTIVITY                             1.57-014
        PHOTOCURRENT                                    .00
                                                     ----------
      NET FLUX                                       -6.27-007
-------------------------------------------------------------------------------

  SURFACE CELL NO.   88                                      CODE =       005111270103
                                                             LOCATION =     9  9 23
                                                             NORMAL =       0  0  1
                                                             MATERIAL =   KAPT
                          POTENTIAL =    .000     VOLTS
                          STRESS =   1.566+002 VOLTS/METER
                          EXTERNAL FIELD =   .000     VOLTS/METER
                          LIMITING FACTOR =  1.000+000
   FLUXES IN A/M**2
        INCIDENT ELECTRONS                           2.28-006
             RESULTING SECONDARIES                   9.75-007
             RESULTING BACKSCATTER                   6.01-007
        INCIDENT PROTONS                             2.75-008
             RESULTING SECONDARIES                   4.91-008
        BULK CONDUCTIVITY                            1.57-014
        PHOTOCURRENT                                    .00
                                                     ----------
      NET FLUX                                       -6.27-007
-------------------------------------------------------------------------------

  SURFACE CELL NO.  129                                      CODE =       005307212001
                                                             LOCATION =    11  7 17
                                                             NORMAL =       1  0  0
                                                             MATERIAL =   GOLD
                          POTENTIAL =    .000     VOLTS
                          EXTERNAL FIELD =   .000     VOLTS/METER
                          LIMITING FACTOR =  1.000+000
   FLUXES IN A/M**2
        INCIDENT ELECTRONS                           2.28-006
             RESULTING SECONDARIES                   1.46-006
             RESULTING BACKSCATTER                   1.48-006
        INCIDENT PROTONS                             2.75-008
             RESULTING SECONDARIES                   4.45-008
        PHOTOCURRENT                                 2.05-005
                                                     ----------
      NET FLUX                                       2.12-005
-------------------------------------------------------------------------------

  SURFACE CELL NO.  167                                      CODE =       011111120302
                                                             LOCATION =     9  9 10
                                                             NORMAL =       0  0 -1
                                                             MATERIAL =   SOLA
                          POTENTIAL =    .000     VOLTS
                          STRESS =   1.111+002 VOLTS/METER
                          EXTERNAL FIELD =   .000     VOLTS/METER
                          LIMITING FACTOR =  1.000+000
   FLUXES IN A/M**2
        INCIDENT ELECTRONS                           2.28-006
             RESULTING SECONDARIES                   1.83-006
             RESULTING BACKSCATTER                   7.77-007
        INCIDENT PROTONS                             2.75-008
             RESULTING SECONDARIES                   2.69-008
        BULK CONDUCTIVITY                            1.11-015
        PHOTOCURRENT                                    .00
                                                     ----------
      NET FLUX                                       3.81-007
-------------------------------------------------------------------------------

  BOOM SURFACE CELL NO.  181                                 CODE =       000061111123
                                                             LOCATION =     9  9 19    ( 1)
```

Figure 11.5. (Continued).

```
                                                          DIRECTION =   Z
                                                          MATERIAL =  ALUM
                          POTENTIAL =    .000      VOLTS
                          FIELD =    .000      VOLTS/METER
                          LIMITING FACTOR =   1.000+000
   FLUXES IN A/M**2
         INCIDENT ELECTRONS                          2.28-006
              RESULTING SECONDARIES                  8.52-007
              RESULTING BACKSCATTER                  8.51-007
         INCIDENT PROTONS                            2.75-008
              RESULTING SECONDARIES                  2.69-008
         PHOTOCURRENT                                1.27-005
                                                    ----------
       NET FLUX                                      1.21-005

          INITIAL NET CHARGING CURRENT (WITHOUT LIMITING) =  3.60-007 AMPERES.
          INITIAL NET CHARGING CURRENT (WITH    LIMITING) =  3.60-007 AMPERES.

  TOTAL CAPACITANCE TO INFINITY =    49.9 CODE UNITS;    8.83-012 FARADS.

    ICCG --- RDOTR/RDOTR1 =   1.16-014/  4.16+011

  LEAVING ICCG1 -- VCTRI =   2.067+005  1.939+005

    ICCG --- RDOTR/RDOTR1 =   3.53-025/  1.95+006

  LEAVING ICCG1 -- VCTRI =    .000        .000

    ICCG --- RDOTR/RDOTR1 =   2.71-025/  1.94+006

  LEAVING ICCG1 -- VCTRI =    .000        .000

   VFIX ---   59 OUT OF  164 NODES FIXED.
CONDUCTOR   1 FIXED TO     3.03 VOLTS.

    ICCG --- RDOTR/RDOTR1 =   1.65-025/  1.14+006

  LEAVING ICCG1 -- VCTRI =   3.034+000  1.721+000

  NO DISCHARGE ANALYSIS

  NO DISCHARGE ANALYSIS

    ICCG --- RDOTR/RDOTR1 =   4.00-021/  9.79+006

  LEAVING ICCG2 -- VCTRI =   3.040+000  1.726+000

 AVERAGE FLUXES (ONLY AVAILABLE FOR INSULATING CELLS)

AVERAGE FLUX TO CELL    20 IS    -6.252-007 A/M**2
AVERAGE FLUX TO CELL    28 IS    -7.173-008 A/M**2
AVERAGE FLUX TO CELL    77 IS    -6.252-007 A/M**2
AVERAGE FLUX TO CELL    88 IS    -6.252-007 A/M**2
AVERAGE FLUX TO CELL   167 IS    -4.740-008 A/M**2

NEW CONDUCTOR POTENTIALS

          VNEW              DQ            VOLD       CONDUCTOR
     3.0404+000     7.6946+005       .0000                   1
     1.7256+000    -9.7015-005       .0000                   2

  TOTAL CHANGE IN CHARGE =   -1.966+002 CODE UNITS
                             -3.482-011 COULOMBS

  AVERAGE NET CHARGING CURRENT =   -6.965-012 AMPERES
                                   -3.933+001 CODE UNITS/SEC.

CONDUCTOR CURRENTS (AMPS; POSITIVE INTO CONDUCTORS):

                                    1           2

NET CURRENT(AVG DQ/DT):       2.73-008   -3.44-018
```

Figure 11.5. (Continued).

```
 CONDUCTIVITY CURRENT (NEW)
  (FROM INSULATING CELLS):     -4.71-013   -1.88-018
 PLASMA CURRENT (INITIAL)
  (TO BARE CELLS):              1.42-007     .00
 REMAINDER CURRENT:            -1.15-007   -1.55-018
```

```
          CONTINUE CYCLE NO.    1 AT UPDATED TIME =   5.000+000 SECONDS.
                   QSUM = -1.9665+002
SURFACE POTENTIALS - ALL  184 CELLS
CELL NO.
   1   -9.765+000 -9.765+000 -9.765+000 -9.767+000 -9.767+000 -9.767+000 -9.767+000 -9.765+000 -9.765+000 -9.765+000    10
  11   -9.767+000 -9.767+000 -9.768+000 -9.768+000 -9.767+000 -9.767+000 -9.768+000 -9.767+000 -9.768+000 -9.768+000    20
  21   -9.768+000 -9.767+000 -9.765+000  1.343-001 -9.765+000  1.570+000 -9.767+000  1.570+000 -9.767+000 -9.765+000    30
  31    1.343-001 -9.765+000 -9.768+000 -9.767+000 -9.769+000 -9.769+000 -9.768+000 -9.767+000 -9.770+000 -9.770+000    40
  41   -9.770+000 -9.770+000 -9.768+000  1.569+000  4.441+000  4.441+000 -9.768+000  1.569+000 -9.768+000 -9.768+000    50
  51   -9.769+000 -9.769+000 -9.768+000 -9.768+000 -9.770+000 -9.770+000 -9.767+000 -9.765+000 -9.764+000 -9.770+000    60
  61   -9.770+000 -9.768+000 -9.765+000 -9.763+000 -9.769+000  1.569+000  4.441+000  4.441+000 -9.769+000  1.569+000    70
  71   -9.767+000 -9.765+000 -9.763+000 -9.768+000 -9.768+000 -9.769+000 -9.769+000 -9.768+000 -9.768+000 -9.770+000    80
  81   -9.770+000 -9.768+000 -9.765+000 -9.763+000 -9.770+000 -9.770+000 -9.769+000 -9.763+000 -9.769+000  1.569+000    90
  91    4.441+000  4.441+000 -9.769+000  1.569+000  1.742-001  1.541+000  1.730-001 -9.768+000 -9.767+000 -9.769+000   100
 101   -9.769+000 -9.768+000 -9.767+000 -9.770+000 -9.770+000 -9.767+000 -9.765+000 -9.763+000 -9.770+000 -9.770+000   110
 111    1.743-001  1.541+000  1.730-001 -9.768+000  1.569+000  4.441+000  4.441+000 -9.768+000  1.569+000  3.839+000   120
 121    4.706+000  3.040+000 -9.765+000 -9.765+000  3.040+000 -9.767+000  3.040+000 -9.767+000  3.040+000 -9.765+000   130
 131   -9.765+000  3.040+000 -9.768+000  3.040+000  3.040+000  3.040+000 -9.768+000  3.040+000 -9.768+000  3.040+000   140
 141    3.040+000  3.040+000 -9.768+000  3.040+000 -9.766+000  2.112+000  3.040+000  4.207+000  3.040+000  4.207+000   150
 151    3.040+000 -9.766+000  2.112+000  3.040+000  4.642-001  4.642-001  4.642-001  4.642-001  4.642-001  4.642-001   160
 161    4.642-001  4.642-001  4.642-001  4.642-001  4.642-001  4.642-001  4.642-001  4.642-001  3.418+000  4.027+000   170
 171    3.418+000  4.642-001  4.642-001  4.642-001  3.418+000  4.027+000  3.418+000  4.705+000  5.027+000  4.705+000   180
 181    3.040+000  3.040+000  3.040+000  3.040+000
            34 POTENTIAL ITERATIONS COMPLETED.
               RDOTR/RDRMAX=  5.27-005/  1.01+004
PCOND =     3.0404+000   1.7256+000
QCOND =     7.4810+005  -1.1685+002
  NEXTRA=       0
 EFPREP --     1 GRIDS OUT OF    1 READ IN.
IP = 12  IR = 14  IU = 10  ISPARE = 13  IPSAVE = 10
LAST CYCLE COMPLETED IS    1.
IP = 10  IR = 14  IU = 12  ISPARE = 13  IPSAVE = 10

******END
[END NASCAP]

@ASG,A NASCAP*PLOTREAD.
FAC WARNING        040000104000

@XQT NASCAP*PLOTREAD.
DEVICE OPTION =  3.
```

Figure 11.5. (Concluded).

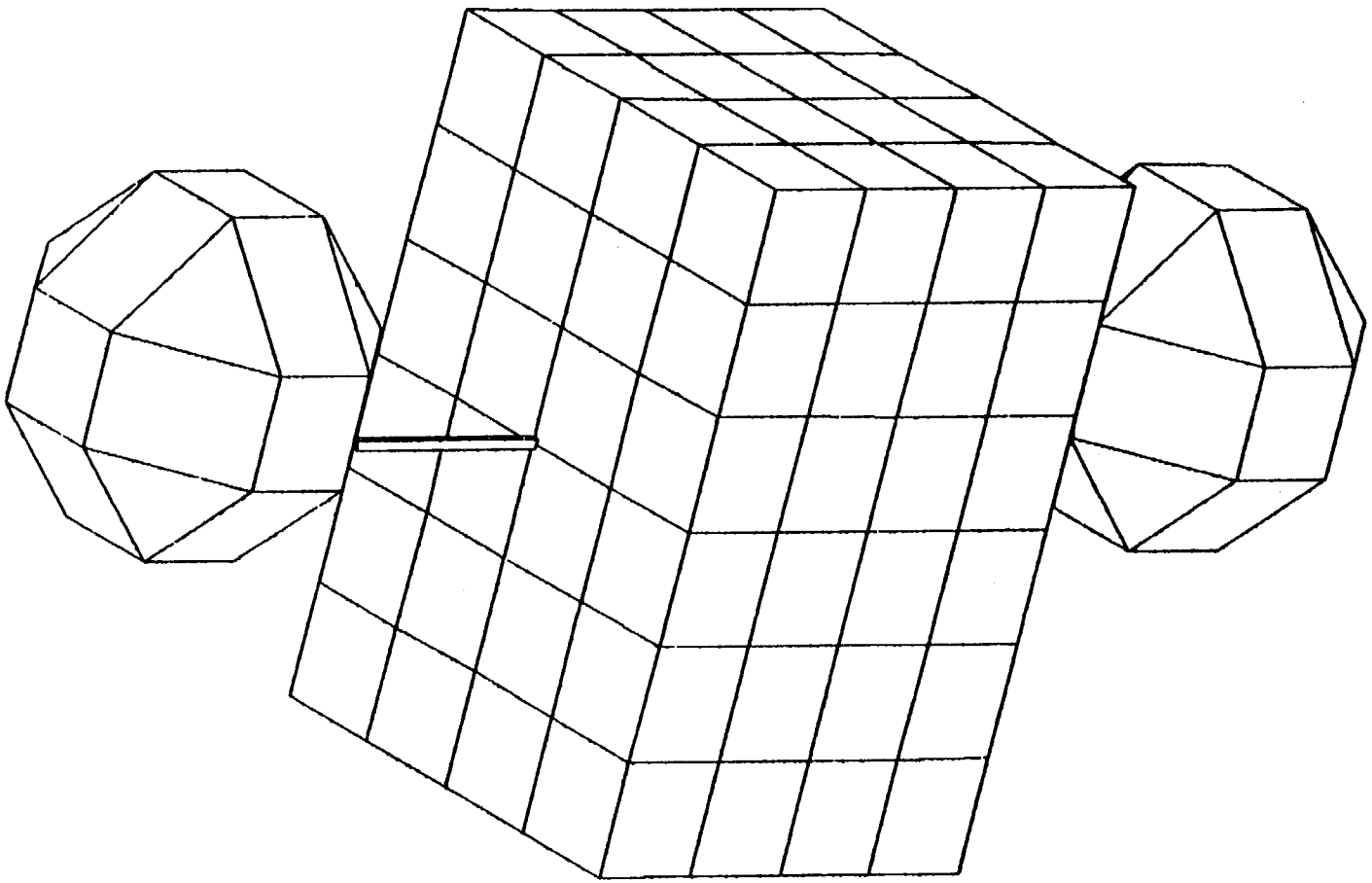


Figure 11.6(a). 3D-VIEW of object produced by SATPLT (Hidden lines).

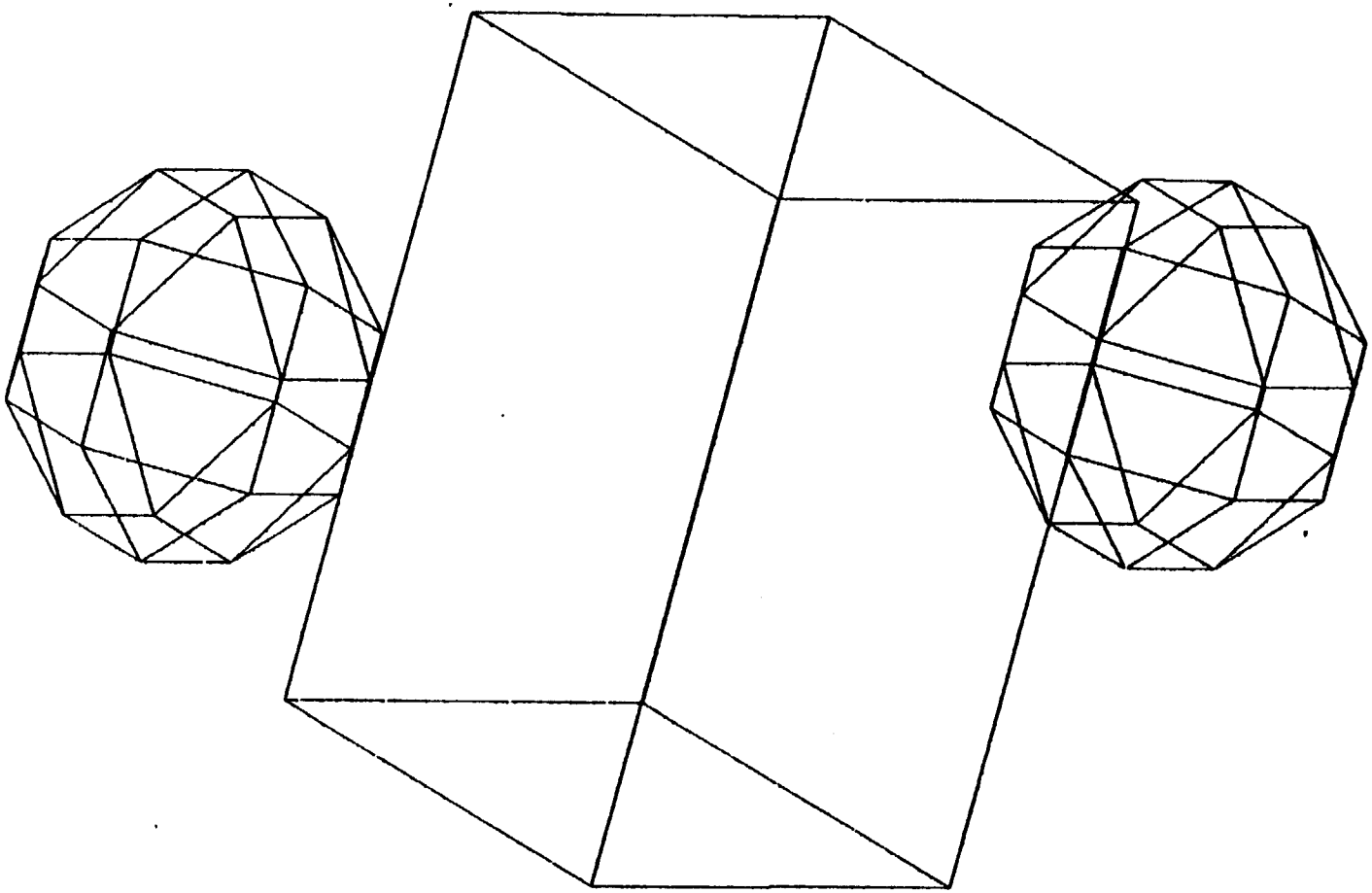


Figure 11.6(b). 3D-VIEW of object produced by SATPLT (No hidden lines).

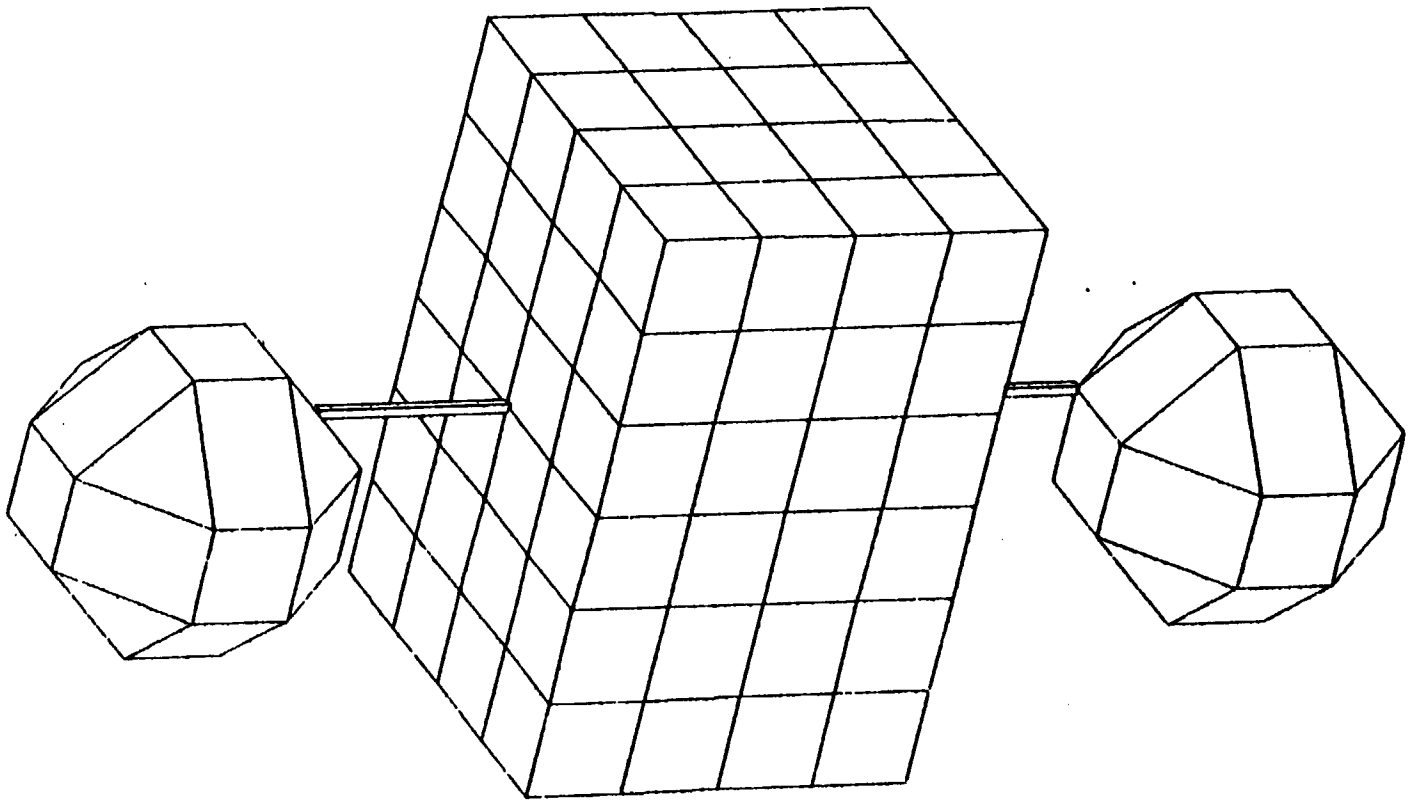


Figure 11.6(c). 3D-VIEW of object produced by SATPLT (Hidden lines).

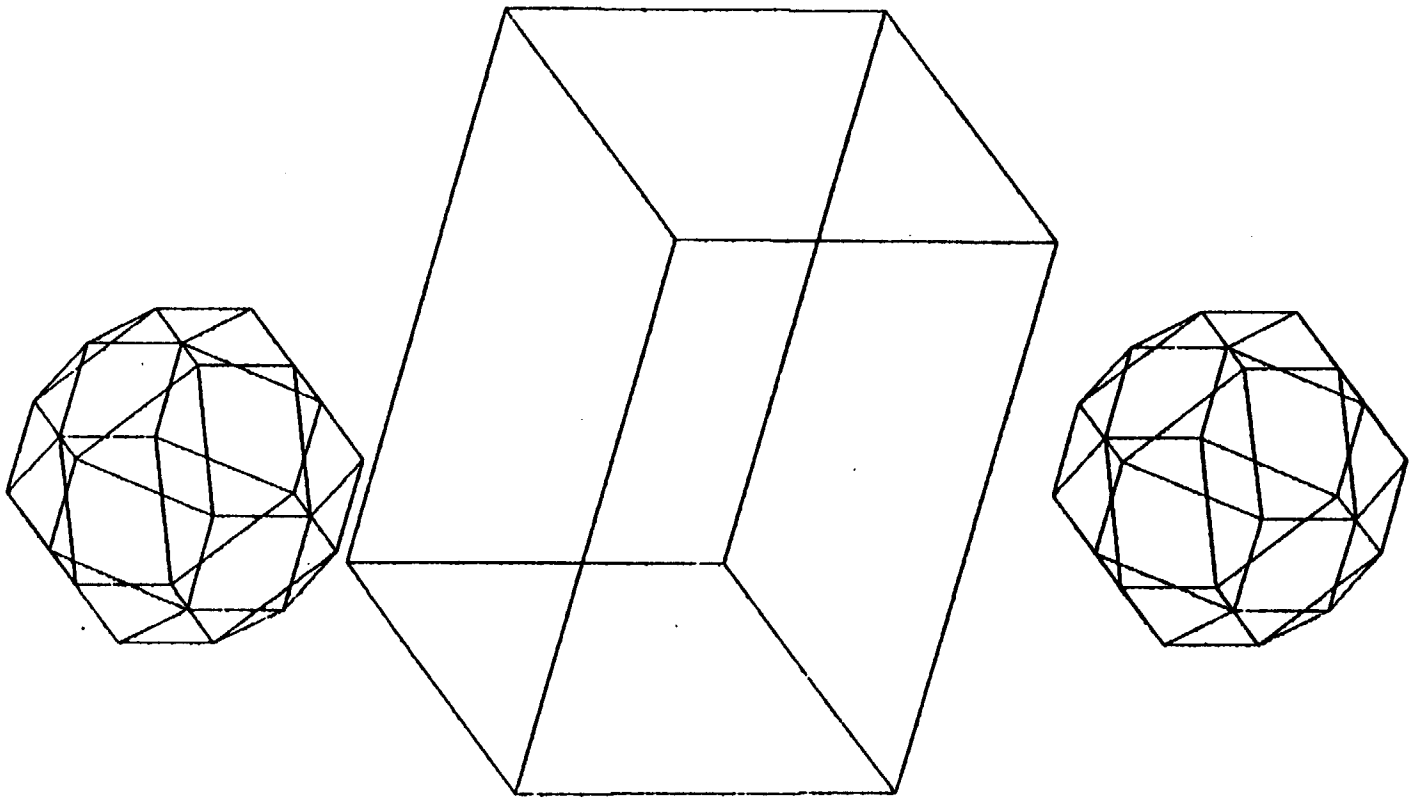


Figure 11.6(d). 3D-VIEW of object produced by SATPLT (No hidden lines).

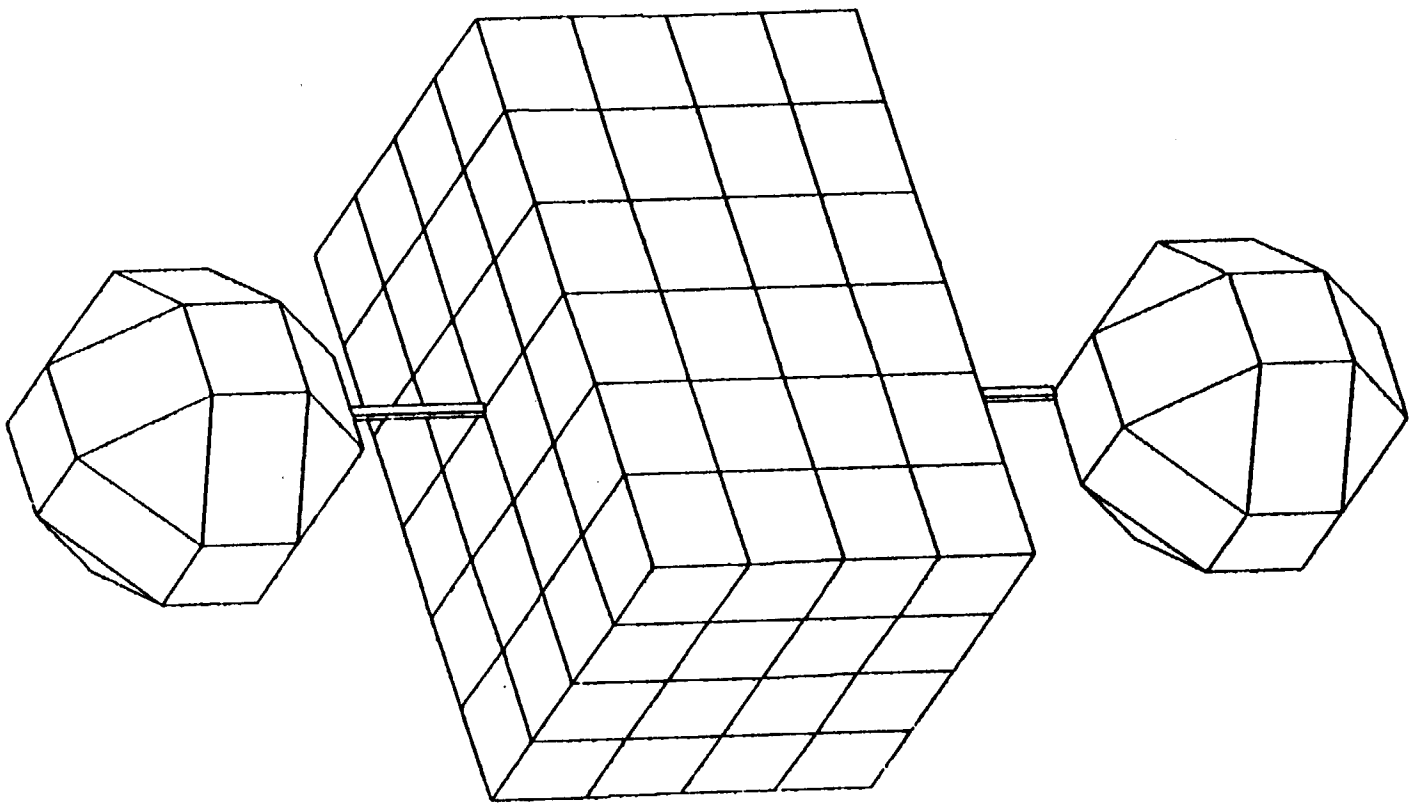


Figure 11.6(e). 3D-VIEW of object produced by SATPLT (Hidden lines).

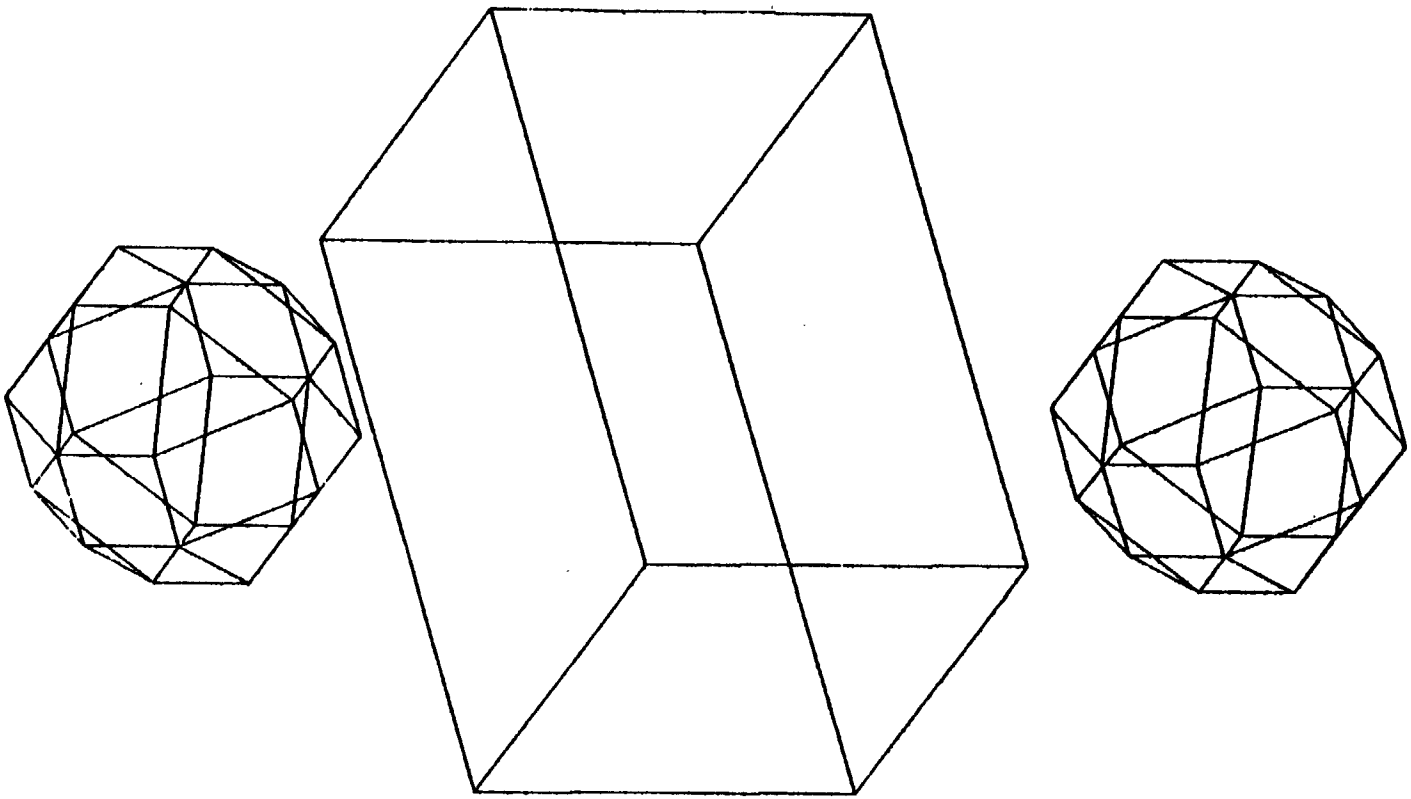


Figure 11.6(f). 3D-VIEW of object produced by SATPLT (No hidden lines).

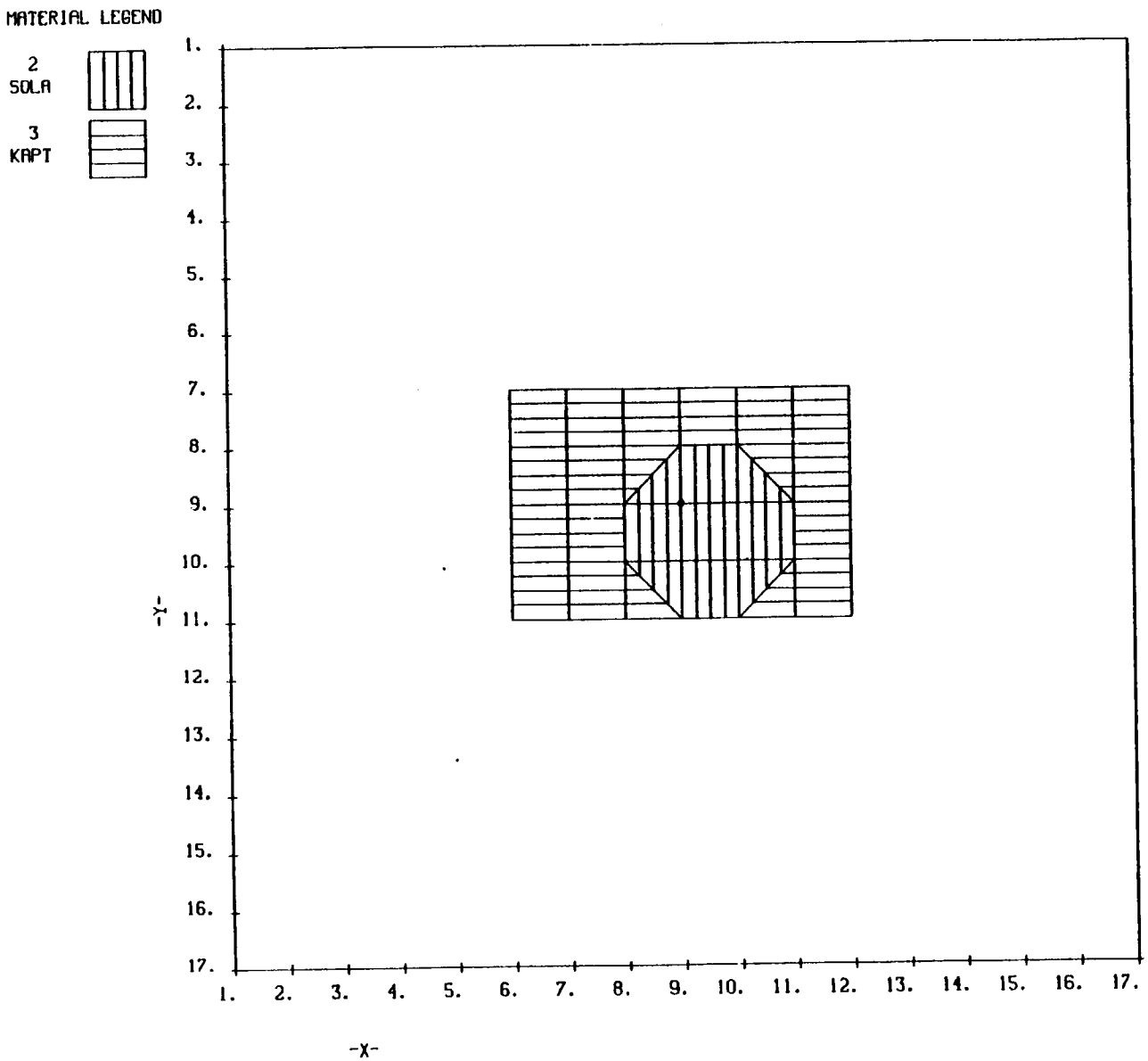


Figure 11.6(g). MATVIEW produced by SATPLT.

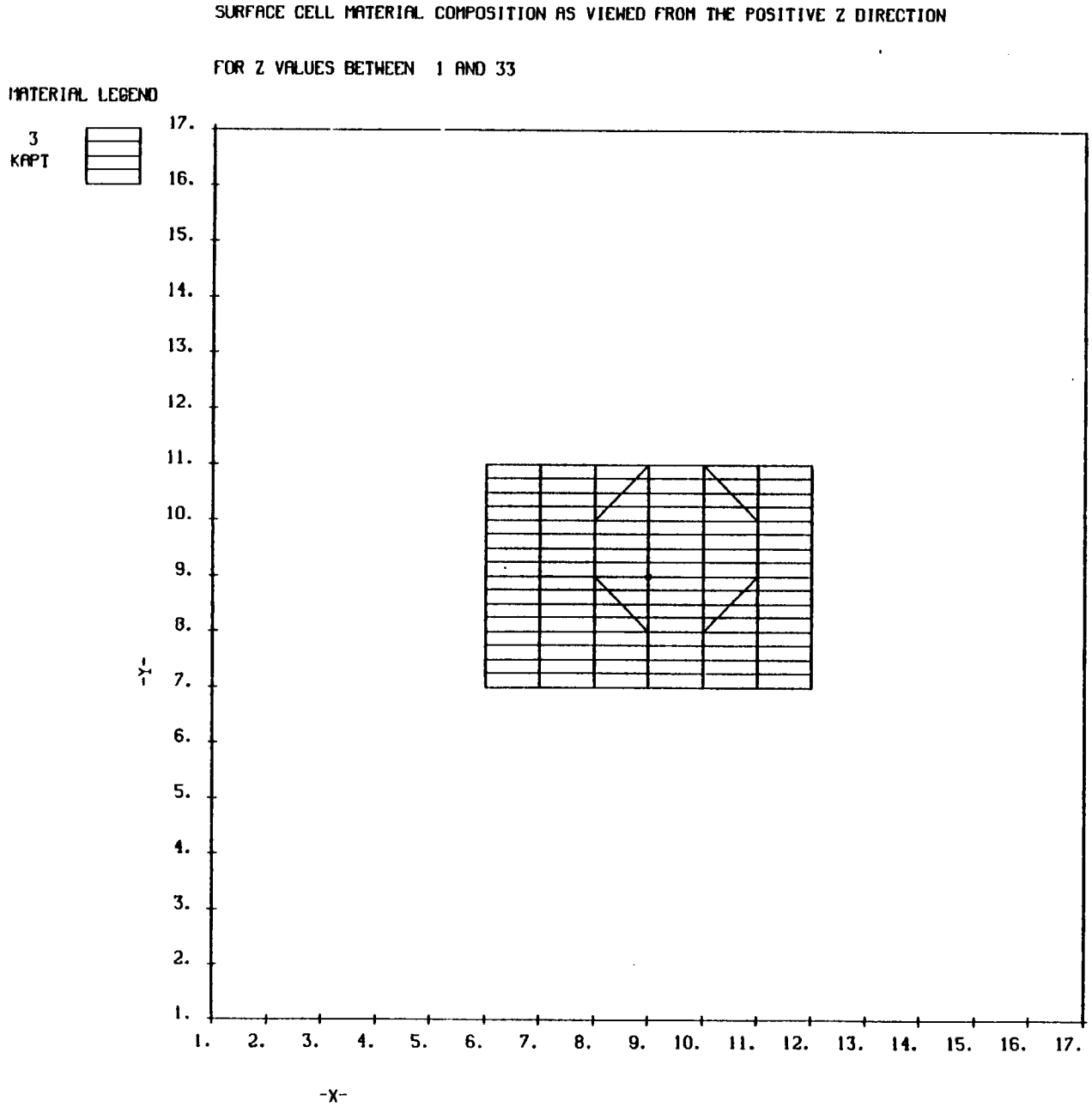


Figure 11.6(h). MATVIEW produced by SATPLT.

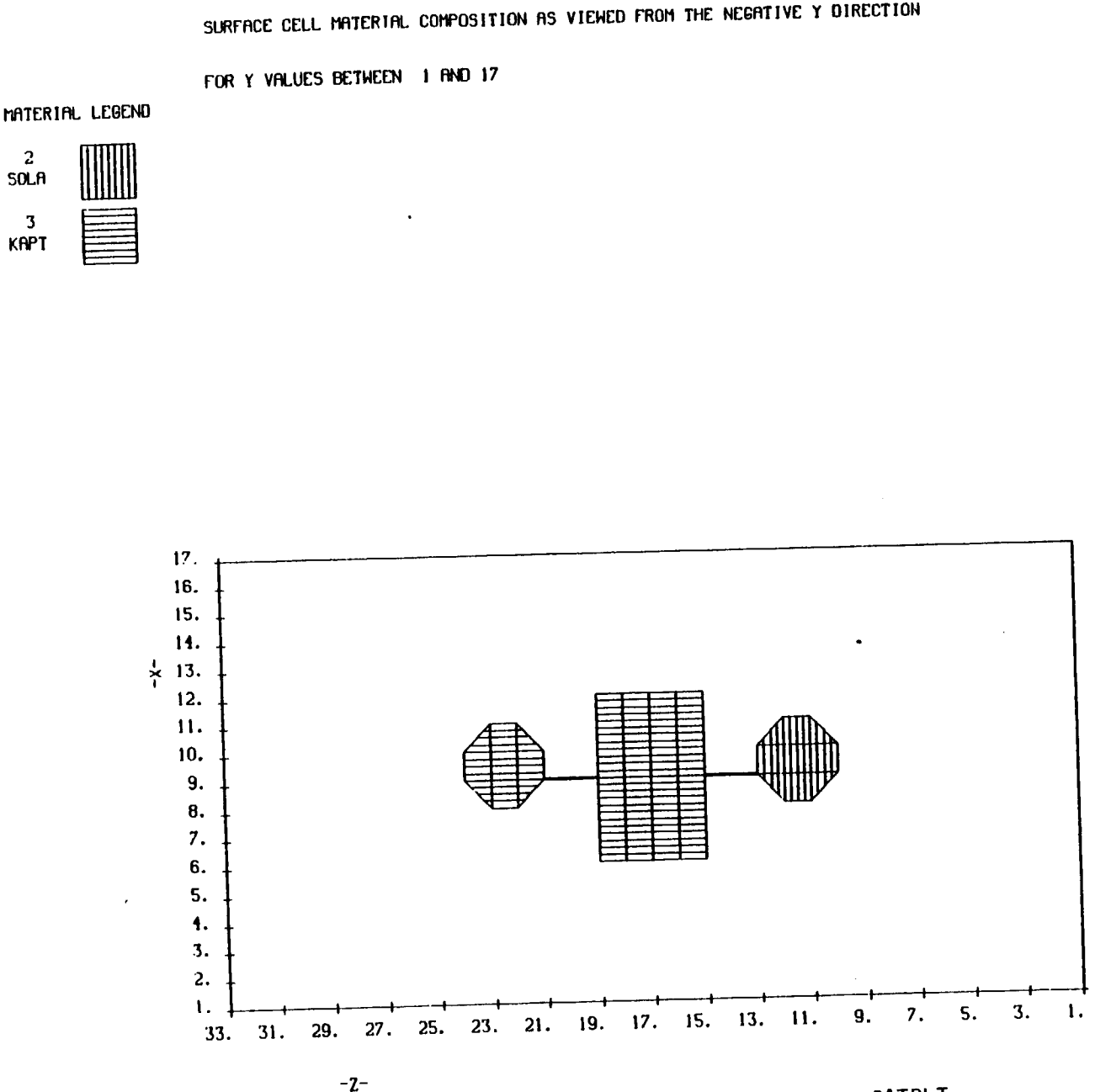


Figure 11.6(i). MATVIEW produced by SATPLT.

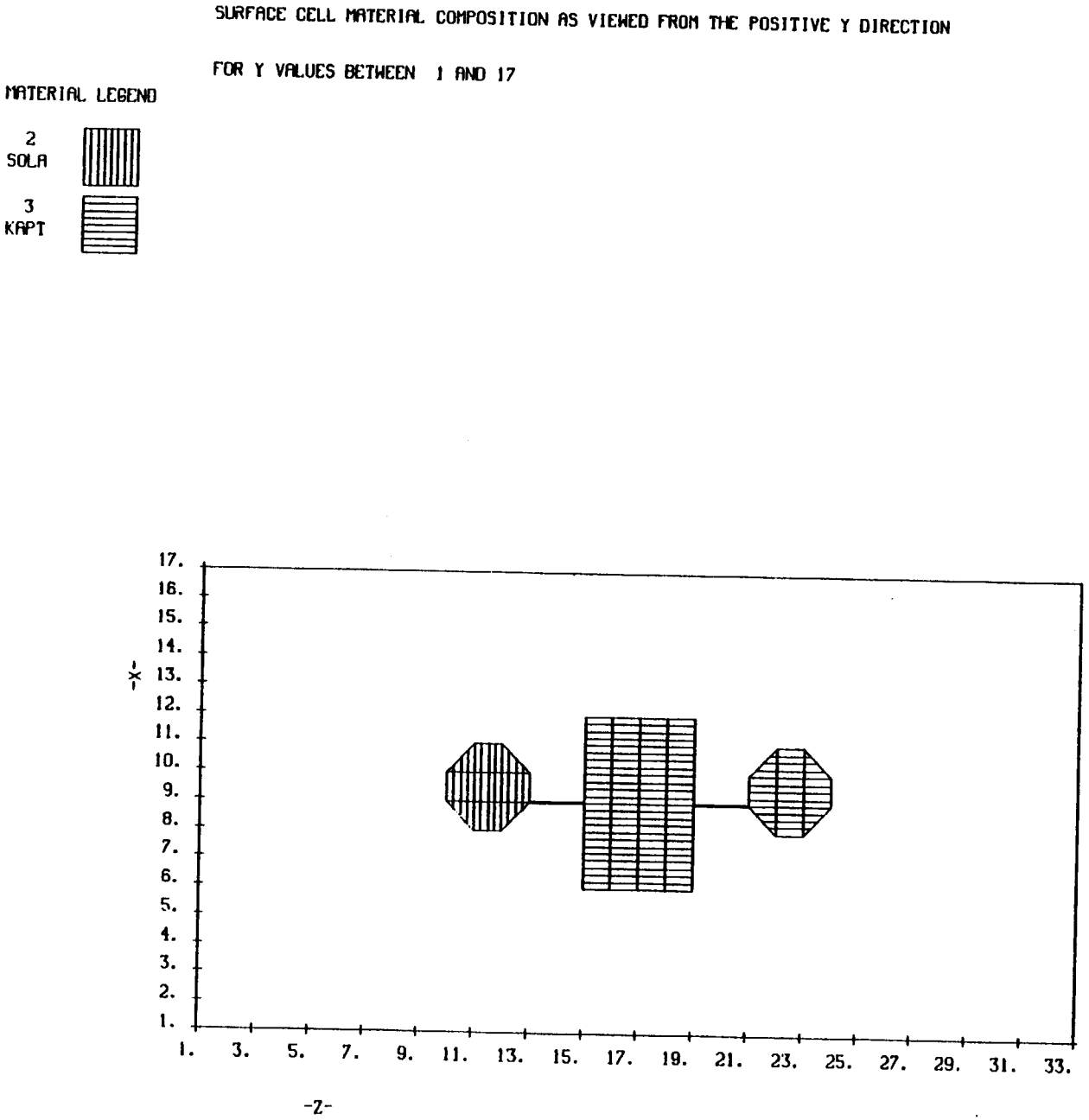


Figure 11.6(j). MATVIEW produced by SATPLT.

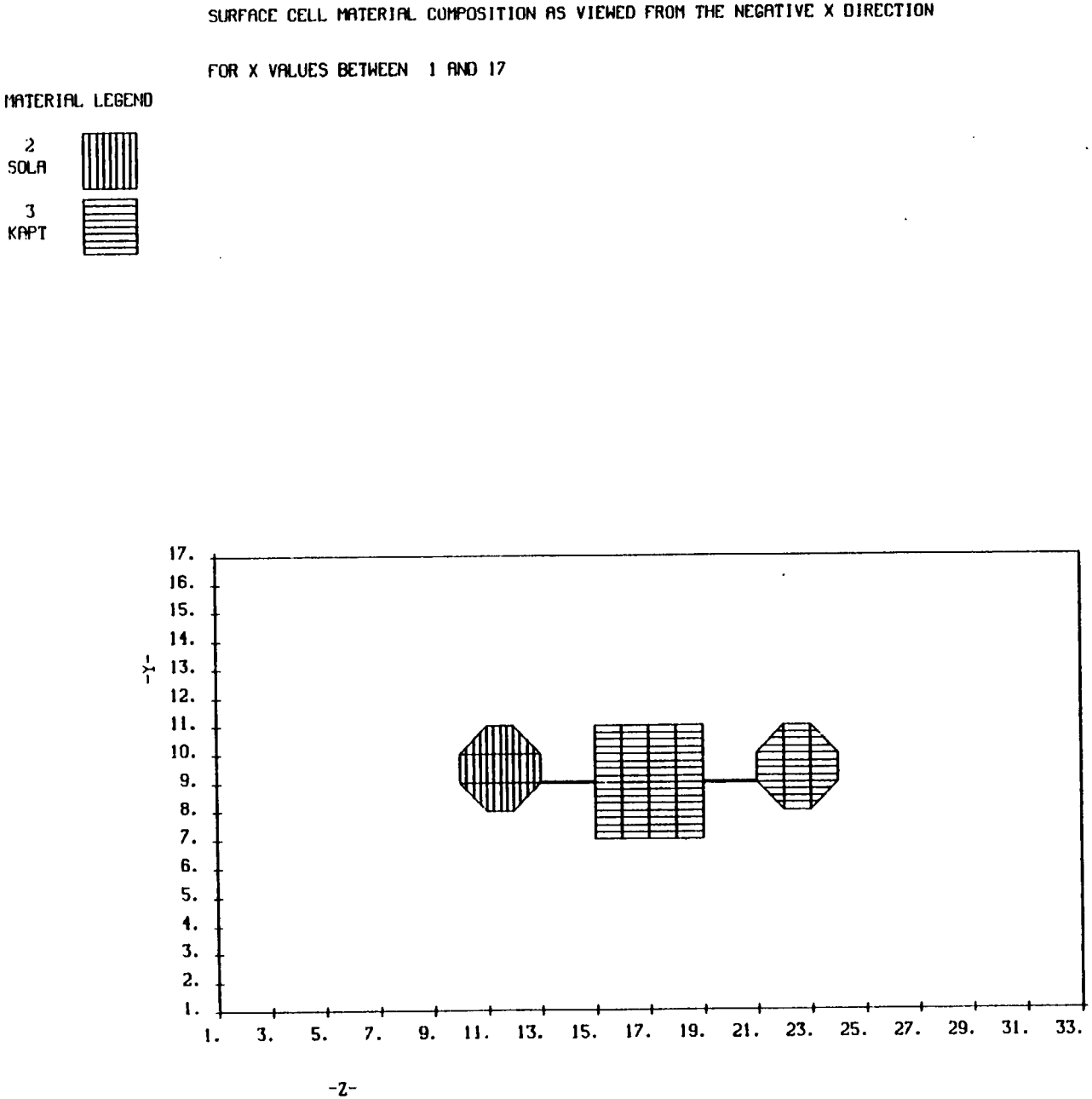


Figure 11.6(k). MATVIEW produced by SATPLT.

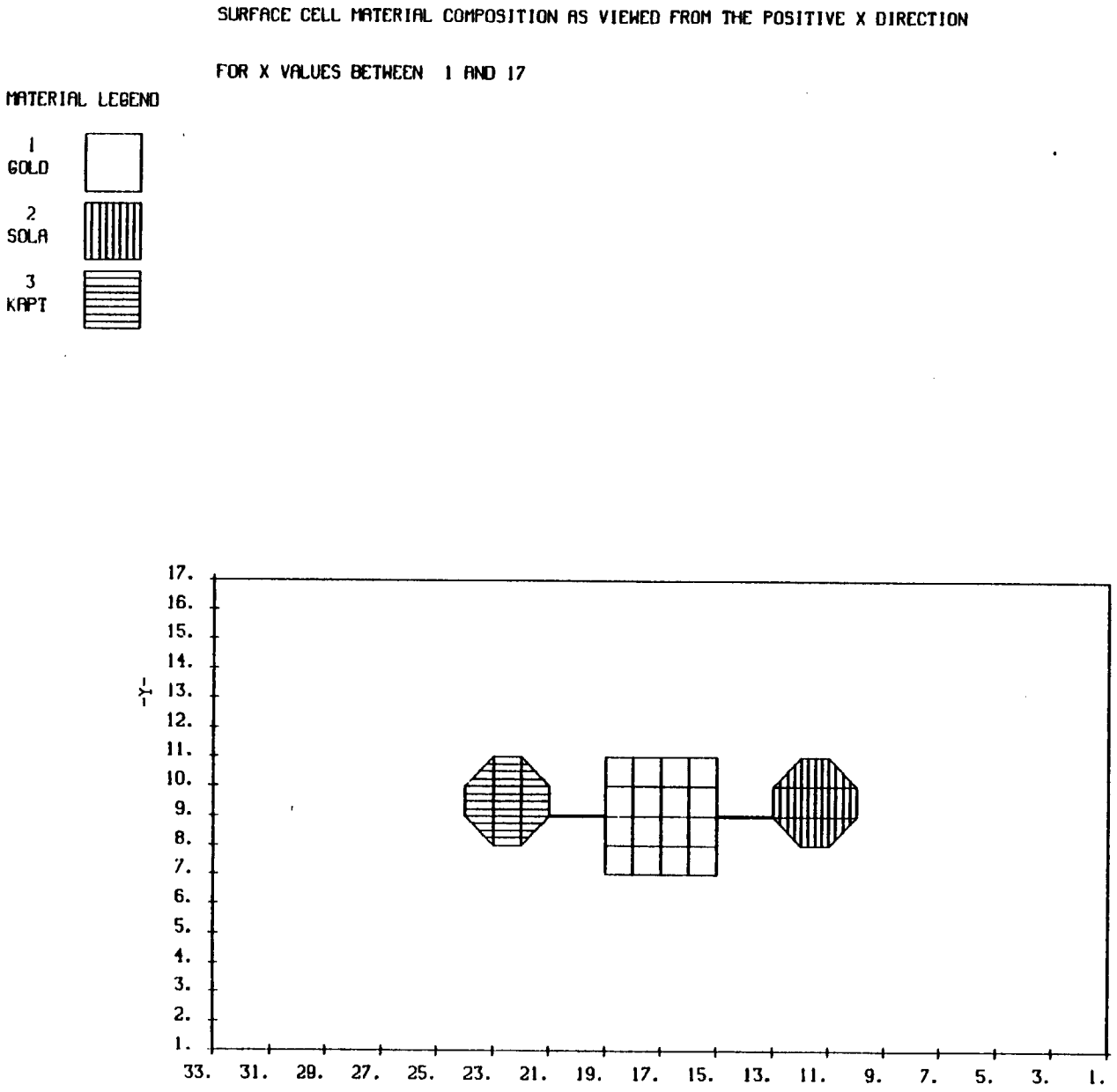


Figure 11.6(1). MATVIEW produced by SATPLT.

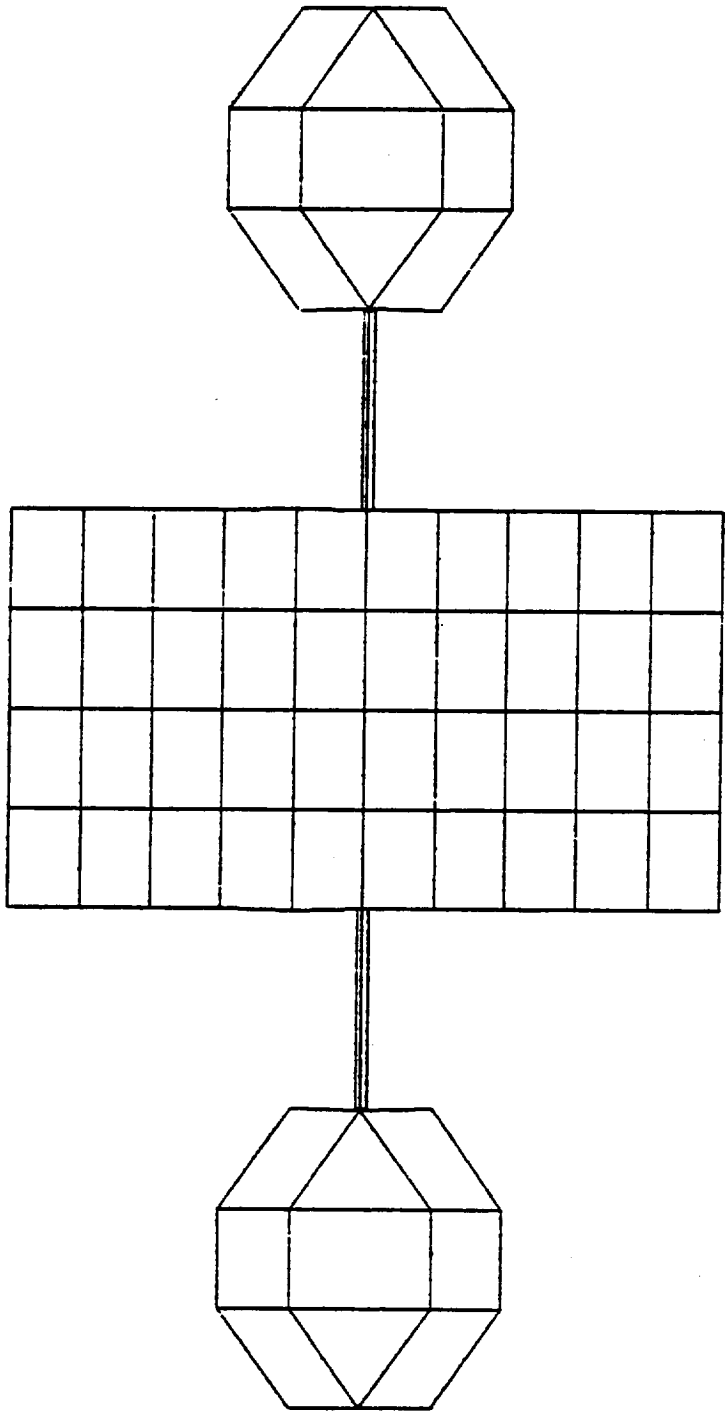


Figure 11.6(m). 3D-VIEW of object generated by HIDCEL.

The printed output for each module follows the same format described in Chapter 10. The plots have the standard forms discussed in Chapter 9.

The output shows that all modules executed successfully and that the object is fully established. Providing the sun direction is not changed, any further runs need involve only RDOPT and TRILIN modules.

Inspection of the TRILIN output shows that only the KAPTON cells in shadow began to charge negatively. The remaining cells have positive net currents, either due to photoemission or high secondary yields. This is reflected in the last of the cell potentials printed at the very end of the TRILIN output. The shaded KAPTON cells all have potentials of around -10 V. The remaining cells are close to neutral or slightly positive.

When only one part of an object is charging negatively, differential potentials between it and the rest of the object soon build up. However the electric fields associated with this differential charging act to limit its magnitude by causing the rest of the object to begin charging too. This occurs because the electric field inhibits the escape of low energy photo and secondary electrons, thereby cutting off the source of positive current to the non-charging cells. Hence, eventually the charging cells (in this case shaded KAPTON) drive the whole object to a negative potential. This type of charging has been described as "bootstrap",[21] "potential barrier",[22] and "saddle point".[23] Because it occurs via differential charging, its timescale is typically long (minutes rather than seconds).

In our example the KAPTON is charging at about 2 volts per second. We shall want to increase the timestep in the second run so that the potential changes by about 500 V per cycle.

11.7 THE SECOND RUN

In this run we call only two modules, and the NASCAP primary keyword input consists of

RDOPT
TRILIN
END

We begin the charging-to-equilibrium simulation with a run involving 5 cycles. If more are needed we can always RESTART a subsequent run and add further cycles. With the initial charging rate of 2V per second, a timestep of 200 s will increase the KAPTON potential by -400 V each cycle. This is a manageable rate of charging. We continue to use the LONGTIMESTEP option, this time with a dvlim of 500 V, instead of the default value of 1000 V. With a higher value of dvlim there is a danger of potential overshoot and oscillation.

The options file used in the second run is shown in Figure 11.7. Changes have been made to NCYC, DELTA and LONGTIMESTEP as described above. The mechanical capacitance between the two conductors has been introduced with option CIJ (1×10^{-12} F).

Contour plots for the last cycle have been requested. The run is RESTARTed from cycle 1.

The output from the second run is shown in Figure 11.8. Inspection of the flux breakdown shows that each cell gradually achieves a negative net current as the low energy emission is suppressed. Consequently more of the cell potentials become negative from cycle to cycle, until the last cycle (number 6) when the whole object has reached almost -1 kV (as measured by the conductor potentials).

```
      1:XMESH 0.02
      2:NCYC 5
      3:DELTA 200
      4:SURFACE CELL 20
      5:SURFACE CELL 129
      6:SURFACE CELL 28
      7:SURFACE CELL 77
      8:SURFACE CELL 88
      9:SURFACE CELL 167
     10:SURFACE CELL 181
     11:LONGTIMESTEP 1000
     12:SUMINT 1.0
     13:SUNDIR 1 1 0
     14:DEST ELEC
     15:CIJ 1 2 1.E-12
     16:CONTOURS STANDARD MOD 5
     17:RESTART
     18:END
EOF:18
0:>
```

Figure 11.7. The Run Options file (second run).

```
@XQT

******RDOPT
```

```
          KEYWORD INPUT
XMESH 0.02
NCYC 5
DELTA 200
SURFACE CELL 20
                        CELL   20 INFORMATION TO BE PRINTED.
SURFACE CELL 129
                        CELL  129 INFORMATION TO BE PRINTED.
SURFACE CELL 28
                        CELL   28 INFORMATION TO BE PRINTED.
SURFACE CELL 77
                        CELL   77 INFORMATION TO BE PRINTED.
SURFACE CELL 88
                        CELL   88 INFORMATION TO BE PRINTED.
SURFACE CELL 167
                        CELL  167 INFORMATION TO BE PRINTED.
SURFACE CELL 181
                        CELL  181 INFORMATION TO BE PRINTED.
LONGTIMESTEP 500
SUNINT 1.0
SUNDIR 1 1 0
DEST ELEC
CIJ 1 2 1.E-12
                        CIJ( 1, 2) SET TO  1.00-012 FARADS
CONTOURS STANDARD MOD 5
RESTART
END
 ASGFIL -- @ASG  10. .
 ASGFIL -- @ASG  11. .
 ASGFIL -- @ASG  12. .
 ASGFIL -- @ASG  25. .
 ASGFIL -- @ASG  13. .
 ASGFIL -- @ASG  14. .
 ASGFIL -- @ASG  15. .
 ASGFIL -- @ASG  19. .
 ASGFIL -- @ASG  18. .
 ASGFIL -- @ASG  17. .
 ASGFIL -- @ASG  16. .
 ASGFIL -- @ASG  21. .
 ASGFIL -- @ASG  20. .
 ASGFIL -- @ASG  27. .
```


Figure 11.8. Printed output (second run).

```
                                                NASA CHARGING ANALYZER PROGRAM
                                                        OPTION SUMMARY
TITLE =NASCAP

GRID SIZE OPTIONS:    NX    NY    NZ    NG
                      17    17    33     2
          FULL OUTER GRID USED
          ADDITIONAL OPTION WORDS: OFFSET, TANKSIZE, ZTRUNC, TANK RADIUS, TANK AXIS

LOGICAL UNIT NUMBERS

          INPUT FILES: IKEYWD    ISAT     IFLUX    ISPCTR
                         26       20       22        9

          RESTART FILES: IP    IROUS   IPQCND   ILTBL   ICNOW   IAREA
                         10     15      16       17      21      27

          SCRATCH FILES: IAUN    IR    IDIV    IU    ISPARE    IOBJ   IOBPLT   IPART
                          11     12     25     13      14       18      19       28

RUN MODE OPTIONS: ICREST  IPREST  NCYC  MCYC
                     1       1      5     1

                    DELTA      DELFAC
                  2.00+002   1.00+000
         DEADLINE = NONE
         ADDITIONAL KEYWORD = [RESTART]

POTENTIAL SOLVER OPTIONS: POTCON     MAXITR   IOUTER    SCALE
                          NOTSET       99       2       SCAL
                  SCALING KEYWORDS: SCALE, NOSCALE, DSCALE
         AMBIENT SPACE CHARGE OPTION [KEYWORD DEBYE]=NONE

CONDUCTOR FIXING AND BIASING:KEYWORDS FIXP, BIAS, FLOAT

INTERCONDUCTOR CAPACITANCES:  KEYWORD CIJ
          THE CODE UNIT OF CHARGE IS    1.771-013 COULOMBS.
          THE CODE UNIT OF CAPACITANCE IS   1.77-013 FARADS.

  CIJ:
   .0      5.6+000     .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
 5.6+000     .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
   .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
   .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
   .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
   .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
   .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
   .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
   .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
   .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
   .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
   .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
   .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
   .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
   .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0

  CIJSUM:
 5.6+000 5.6+000   .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
LONGTIMESTEP AND DISCHARGE OPTIONS
          KEYWORDS: LONGTIMESTEP, NOLONGTIMESTEP, DISCHARGE, FLASHOVER
          LONGTIMESTEP REQUESTED WITH DVLIM=   500.0 VOLTS.
          DISCHARGE ANALYSIS OFF

ILLUMINATION SPECIFICATIONS:
          SUNINT= 1.000     SUNDIR =    .7071    .7071    .0000
         SHADOWING FORMULATION [KEYWORD=CONVEX]=SHAD

ENVIRONMENT TYPE AND MESH SIZE
         ITYPE=   2     UPDATE=OFF       XMESH=  2.00-002
```

Figure 11.8. (Continued).

```
          SECONDARY EMISSION FORMULATION ='ANGL'
          EFFECTIVE PHOTOSHEATH CONDUCTIVITY (EFFCON) = OFF
          FIELD-ENHANCED BULK CONDUCTIVITY (FLDCON) = OFF
          RADIATION-INDUCED BULK CONDUCTIVITY (RADCON) = OFF

OUTPUT OPTIONS:
                    NGPRT [APRT]     TIMER [NOTIMER]
                         0               NO
                    ICNVP [CONVERGENCE PLOTS]= 0
          PRINT [NOPRINT]:  POTENT     LIMCEL     OBJDEF     HIDCEL
                              NO          NO        SOME        NO

     7 SURFACE CELLS SPECIFIED FOR I/O:
                    20    28    77    88   129   167   181
          KEYWORDS: [SURFACE CELL], [SURFACE AT], [SURFACE CORNER]

PLOT OPTIONS:  TITLE=NASCAP
          NGPLOT     ICON       REPEAT     ITPART     ITCUR      IROUSP
            0          0          1          0          0          0
          DEST = ELEC
          NCON       NDIR
           6          3
          ADDITIONAL KEYWORDS: TANKCUR TANKTRAJ 3D-VIEW MATVIEW CONTOUR

          CONTOUR PLOTS TABLE
          -------- ------ -----
     DIRECTION      CUT VALUE       NO. GRIDS          MOD
          X              0              1                5                1     9     1     6
          Y              0              1                5                2     9     1     6
          Z              0              1                5                3    17     1     6
          X              0              2                5                1     9     2     6
          Y              0              2                5                2     9     2     6
          Z              0              2                5                3    17     2     6

      NO. OF 3-D PLOT VIEWS =      3

     VECTORS FROM SATELLITE CENTER TOWARD VIEWER ARE
                                                    .5000      .8000      .5000
                                                   -.5000      .8000      .5000
                                                    .2000     -.5000      .5000

        6 MATERIAL PLOT VIEWS REQUESTED:
                    VIEW FROM +X DIRECTION BETWEEN    -8 AND     8
                    VIEW FROM -X DIRECTION BETWEEN    -8 AND     8
                    VIEW FROM +Y DIRECTION BETWEEN    -8 AND     8
                    VIEW FROM -Y DIRECTION BETWEEN    -8 AND     8
                    VIEW FROM +Z DIRECTION BETWEEN   -16 AND    16
                    VIEW FROM -Z DIRECTION BETWEEN   -16 AND    16

PARTICLE TRACKING OPTIONS:
          KEYWORDS: EMITTER, NOEMITTER, SHEATH, SHEATH SELF-CONSISTENT

           NO EMITTERS REQUESTED

MAGNETIC FIELD OPTIONS: KEYWORDS [BFIELD], [DIPOLE]
           CONSTANT MAGNETIC FIELD =(    .00        .00        .00    ) W/M**2.
           NO MAGNETIC DIPOLES
  ASGFIL -- @ASG    2. .


******TRILIN

   OBJECT DEFINITION INFORMATION BEING READ FROM FILE

A SHADOWING TABLE WAS PREVIOUSLY GENERATED
 FOR THIS OBJECT USING THE HIDC OPTION
FLUX DEFINITION SINGLE MAXWELLIAN

                ELECTRON TEMPERATURE =   5.00+003 ELECTRON VOLTS
```

Figure 11.8. (Continued).

```
                ELECTRON DENSITY =        1.20+006 METER**(-3)
                ION TEMPERATURE =         3.00+003 ELECTRON VOLTS
                ION DENSITY =             8.00+005 METER**(-3)
*** RESTART AT NEW CYCLE =   2

  QSUMER FOUND QSUM= -1.98+002 CODE UNITS.
         AFTER SCREENING CORRECTION (SCREENING LENGTH=  2.00+002 M.) QSUM= -1.98+002
                  QSCALE= -1.96+002          CORRECTED TO  -1.97+002
*** QSUMO FROM LAST CYCLE =  -1.9836+002

 *** THE SYSTEM IS NOW AT TIME   5.000+000 SECONDS.     5 CYCLES HAVE BEEN REQUESTED.
                              DELTA=  2.00+002 SECONDS.     DELFAC=  1.00+000.

SURFACE POTENTIALS - ALL  184 CELLS
CELL NO.
   1    -9.765+000 -9.765+000 -9.765+000 -9.767+000 -9.767+000 -9.767+000 -9.767+000 -9.765+000 -9.765+000 -9.765+000    CELL NO.
  11    -9.767+000 -9.767+000 -9.768+000 -9.768+000 -9.767+000 -9.767+000 -9.768+000 -9.767+000 -9.768+000 -9.768+000      10
  21    -9.768+000 -9.767+000 -9.765+000  1.343-001 -9.765+000  1.570+000 -9.767+000  1.570+000 -9.767+000 -9.765+000      20
  31     1.343-001 -9.765+000 -9.768+000 -9.767+000 -9.769+000 -9.769+000 -9.768+000 -9.767+000 -9.770+000 -9.770+000      30
  41    -9.770+000 -9.770+000 -9.768+000  1.569+000  4.441+000  4.441+000 -9.768+000  1.569+000 -9.768+000 -9.768+000      40
  51    -9.769+000 -9.769+000 -9.768+000 -9.768+000 -9.770+000 -9.770+000 -9.767+000 -9.765+000 -9.764+000 -9.770+000      50
  61    -9.770+000 -9.768+000 -9.765+000 -9.763+000 -9.769+000  1.569+000  4.441+000  4.441+000 -9.769+000  1.569+000      60
  71    -9.767+000 -9.765+000 -9.763+000 -9.768+000 -9.768+000 -9.769+000 -9.769+000 -9.768+000 -9.768+000 -9.770+000      70
  81    -9.770+000 -9.768+000 -9.765+000 -9.763+000 -9.770+000 -9.770+000 -9.769+000 -9.763+000 -9.769+000  1.569+000      80
  91     4.441+000  4.441+000 -9.769+000  1.569+000  1.742-001  1.541+000  1.730-001 -9.768+000 -9.767+000 -9.769+000      90
 101    -9.769+000 -9.768+000 -9.767+000 -9.770+000 -9.770+000 -9.767+000 -9.765+000 -9.763+000 -9.770+000 -9.770+000     100
 111     1.743-001  1.541+000  1.730-001 -9.768+000  1.569+000  4.441+000  4.441+000 -9.768+000  1.569+000  3.839+000     110
 121     4.706+000  3.840+000 -9.765+000 -9.765+000  3.040+000 -9.767+000  3.040+000 -9.767+000  3.040+000 -9.765+000     120
 131    -9.765+000  3.040+000 -9.768+000  3.040+000  3.040+000  3.040+000 -9.768+000  3.040+000 -9.768+000  3.040+000     130
 141     3.040+000  3.040+000 -9.768+000  3.040+000 -9.766+000  2.112+000  3.040+000  4.207+000  3.040+000  4.207+000     140
 151     3.040+000 -9.766+000  2.112+000  3.040+000  4.642-001  4.642-001  4.642-001  4.642-001  4.642-001  4.642-001     150
 161     4.642-001  4.642-001  4.642-001  4.642-001  4.642-001  4.642-001  4.642-001  4.642-001  3.418+000  4.027+000     160
 171     3.418+000  4.642-001  4.642-001  4.642-001  3.418+000  4.027+000  3.418+000  4.705+000  5.027+000  4.705+000     170
 181     3.040+000  3.040+000  3.040+000  3.040+000                                                                      180
```

Figure 11.8. (Continued).

```
        BEGIN CYCLE NO.    2          TIME =   5.000+000 SECONDS.

 QSUMER FOUND QSUM= -1.98+002 CODE UNITS.
        AFTER SCREENING CORRECTION (SCREENING LENGTH=  2.00+002 M.) QSUM= -1.98+002
                  QSCALE= -1.96+002          CORRECTED TO  -1.97+002
                  QSUM = -1.9836+002
                  PCOND =  3.040+000   1.726+000
                  QCOND =  7.481+005  -1.168+002

--------------------------------------------------------------------------------

 EXPLICITLY CALCULATED FLUXES FOR CYCLE    2      TIME =  5.000+000 SECONDS.
 DURING THIS TIMESTEP, NASCAP WILL TAKE INTO ACCOUNT SUCH
 ADDITIONAL EFFECTS AS SURFACE CONDUCTIVITY, DISCHARGES, EMITTER OPERATION,
 AND VARIATION OF LIMITING FACTORS FOR LOW-ENERGY EMITTED ELECTRONS.

--------------------------------------------------------------------------------

 SURFACE CELL NO.   20                                    CODE =        004611216003
                                                          LOCATION =     6   9 17
                                                          NORMAL =      -1   0  0
                                                          MATERIAL =  KAPT

                          POTENTIAL = -9.768+000 VOLTS
                          STRESS =  1.009+005 VOLTS/METER
                          EXTERNAL FIELD = -1.505+002 VOLTS/METER
                          LIMITING FACTOR =   1.000+000

  FLUXES IN A/M**2
        INCIDENT ELECTRONS                          2.28-006
             RESULTING SECONDARIES                  9.74-007
             RESULTING BACKSCATTER                  5.99-007
        INCIDENT PROTONS                            2.76-008
             RESULTING SECONDARIES                  4.93-008
        BULK CONDUCTIVITY                           1.01-011
        PHOTOCURRENT                                 .00
                                                   ----------
      NET FLUX                                     -6.25-007

--------------------------------------------------------------------------------

 SURFACE CELL NO.   28                                    CODE =        004612210403
                                                          LOCATION =     6  10 17
                                                          NORMAL =       0   1  0
                                                          MATERIAL =  KAPT

                          POTENTIAL =  1.570+000 VOLTS
                          STRESS =  1.158+004 VOLTS/METER
                          EXTERNAL FIELD =  1.694+002 VOLTS/METER
                          LIMITING FACTOR =   1.837-001

  FLUXES IN A/M**2
        INCIDENT ELECTRONS                          2.28-006
             RESULTING SECONDARIES                  1.79-007      [  9.76-007]
             RESULTING BACKSCATTER                  6.01-007
        INCIDENT PROTONS                            2.75-008
             RESULTING SECONDARIES                  9.02-009      [  4.91-008]
        BULK CONDUCTIVITY                           1.16-012
        PHOTOCURRENT                                2.60-006      [  1.41-005]
                                                   ----------
      NET FLUX                                      1.13-006

--------------------------------------------------------------------------------

 SURFACE CELL NO.   77                                    CODE =        005107211403
                                                          LOCATION =     9   7 17
                                                          NORMAL =       0  -1  0
                                                          MATERIAL =  KAPT

                          POTENTIAL = -9.769+000 VOLTS
                          STRESS =  1.009+005 VOLTS/METER
                          EXTERNAL FIELD = -1.133+002 VOLTS/METER
                          LIMITING FACTOR =   1.000+000

  FLUXES IN A/M**2
        INCIDENT ELECTRONS                          2.28-006
             RESULTING SECONDARIES                  9.74-007
             RESULTING BACKSCATTER                  5.99-007
```

Figure 11.8. (Continued).

```
        INCIDENT PROTONS                          2.76-008
             RESULTING SECONDARIES                4.93-008
        BULK CONDUCTIVITY                         1.01-011
        PHOTOCURRENT                               .00
                                                 ----------
      NET FLUX                                   -6.25-007
-------------------------------------------------------------------------------

  SURFACE CELL NO.   88                                    CODE =       005111270103
                                                           LOCATION =     9  9 23
                                                           NORMAL =       0  0  1
                                                           MATERIAL =   KAPT

                          POTENTIAL = -9.763+000 VOLTS
                          STRESS =  1.008+005 VOLTS/METER
                          EXTERNAL FIELD = -2.943+002 VOLTS/METER
                          LIMITING FACTOR =  1.000+000
   FLUXES IN A/M**2
        INCIDENT ELECTRONS                        2.28-006
             RESULTING SECONDARIES                9.74-007
             RESULTING BACKSCATTER                5.99-007
        INCIDENT PROTONS                          2.76-008
             RESULTING SECONDARIES                4.93-008
        BULK CONDUCTIVITY                         1.01-011
        PHOTOCURRENT                               .00
                                                 ----------
      NET FLUX                                   -6.25-007
-------------------------------------------------------------------------------

  SURFACE CELL NO.  129                                    CODE =       005307212001
                                                           LOCATION =    11  7 17
                                                           NORMAL =       1  0  0
                                                           MATERIAL =   GOLD

                          POTENTIAL =  3.040+000 VOLTS
                          EXTERNAL FIELD =  2.269+002 VOLTS/METER
                          LIMITING FACTOR =  1.034-001
   FLUXES IN A/M**2
        INCIDENT ELECTRONS                        2.28-006
             RESULTING SECONDARIES                1.51-007      [  1.46-006]
             RESULTING BACKSCATTER                1.48-006
        INCIDENT PROTONS                          2.74-008
             RESULTING SECONDARIES                4.59-009      [  4.44-008]
        PHOTOCURRENT                              2.12-006      [  2.05-005]
                                                 ----------
      NET FLUX                                    1.50-006
-------------------------------------------------------------------------------

  SURFACE CELL NO.  167                                    CODE =       011111120302
                                                           LOCATION =     9  9 10
                                                           NORMAL =       0  0 -1
                                                           MATERIAL =   SOLA

                          POTENTIAL =  4.642-001 VOLTS
                          STRESS =  7.047+003 VOLTS/METER
                          EXTERNAL FIELD =  1.402+001 VOLTS/METER
                          LIMITING FACTOR =  7.929-001
   FLUXES IN A/M**2
        INCIDENT ELECTRONS                        2.28-006
             RESULTING SECONDARIES                1.45-006      [  1.83-006]
             RESULTING BACKSCATTER                7.77-007
        INCIDENT PROTONS                          2.75-008
             RESULTING SECONDARIES                2.13-008      [  2.69-008]
        BULK CONDUCTIVITY                         7.05-014
        PHOTOCURRENT                               .00          [   .00     ]
                                                 ----------
      NET FLUX                                   -3.21-009
-------------------------------------------------------------------------------

  BOOM SURFACE CELL NO.  181                               CODE =       000061111123
                                                           LOCATION =     9  9 19    [ 1]
```

Figure 11.8. (Continued).

```
                                                        DIRECTION =   Z
                                                        MATERIAL  =  ALUM
                          POTENTIAL =  3.040+000 VOLTS
                          FIELD     =  5.774+002 VOLTS/METER
                          LIMITING FACTOR =  3.107-003
   FLUXES IN A/M**2
         INCIDENT ELECTRONS                          2.28-006
              RESULTING SECONDARIES                  2.65-009      [  8.53-007]
              RESULTING BACKSCATTER                  8.51-007
         INCIDENT PROTONS                            2.74-008
              RESULTING SECONDARIES                  8.34-011      [  2.68-008]
         PHOTOCURRENT                                3.93-008      [  1.27-005]
                                                    -----------
       NET FLUX                                     -1.36-006

          INITIAL NET CHARGING CURRENT (WITHOUT LIMITING) =  3.60-007 AMPERES.
          INITIAL NET CHARGING CURRENT (WITH    LIMITING) =  5.92-010 AMPERES.

  TOTAL CAPACITANCE TO INFINITY =    49.9 CODE UNITS;    8.83-012 FARADS.

    ICCG --- RDOTR/RDOTR1 =   5.52-022/  7.96+007

  LEAVING ICCG1 -- VCTRI =  -3.707+000 -2.700+000

    ICCG --- RDOTR/RDOTR1 =   5.52-022/  7.96+007

  LEAVING ICCG1 -- VCTRI =  -3.707+000 -2.700+000

    ICCG --- RDOTR/RDOTR1 =   1.03-022/  5.93+007

  LEAVING ICCG1 -- VCTRI =  -3.707+000 -2.323+000

   VFIX ---   59 OUT OF  164 NODES FIXED.
CONDUCTOR   1 FIXED TO     2.26 VOLTS.

    ICCG --- RDOTR/RDOTR1 =   8.16-023/  5.80+007

  LEAVING ICCG1 -- VCTRI =   2.264+000  4.392-001

  NO DISCHARGE ANALYSIS

  NO DISCHARGE ANALYSIS

    ICCG --- RDOTR/RDOTR1 =   1.56-019/  8.60+009

  LEAVING ICCG2 -- VCTRI =   2.361+000  5.127-001

 AVERAGE FLUXES (ONLY AVAILABLE FOR INSULATING CELLS)

AVERAGE FLUX TO CELL    20 IS    -4.658-007 A/M**2
AVERAGE FLUX TO CELL    28 IS     3.114-009 A/M**2
AVERAGE FLUX TO CELL    77 IS    -4.658-007 A/M**2
AVERAGE FLUX TO CELL    88 IS    -4.658-007 A/M**2
AVERAGE FLUX TO CELL   167 IS     1.201-009 A/M**2

NEW CONDUCTOR POTENTIALS

          VNEW                DQ              VOLD        CONDUCTOR
     2.3609+000     2.2498+007      3.0404+000                 1
     5.1266-001    -3.1161-003      1.7256+000                 2

  TOTAL CHANGE IN CHARGE =   -9.724+003 CODE UNITS
                             -1.722-009 COULOMBS

  AVERAGE NET CHARGING CURRENT =   -8.609-012 AMPERES
                                   -4.862+001 CODE UNITS/SEC.

CONDUCTOR CURRENTS (AMPS; POSITIVE INTO CONDUCTORS):

                                  1           2

NET CURRENT(AVG DQ/DT):       1.99-008   -2.76-018
```

Figure 11.8. (Continued).

CONDUCTIVITY CURRENT (NEW) (FROM INSULATING CELLS):	-1.42-011	-2.80-018
PLASMA CURRENT (INITIAL) (TO BARE CELLS):	1.46-008	.00
REMAINDER CURRENT:	5.29-009	4.47-020

Figure 11.8. (Continued).

```
          CONTINUE CYCLE NO.     2 AT UPDATED TIME =   2.050+002 SECONDS.
                   QSUM = -9.9219+003

SURFACE POTENTIALS - ALL  184 CELLS
CELL NO.                                                                                                                                CELL NO.
   1    -3.920+002 -3.920+002 -3.920+002 -3.921+002 -3.921+002 -3.921+002 -3.921+002 -3.920+002 -3.920+002 -3.920+002     10
  11    -3.921+002 -3.921+002 -3.921+002 -3.921+002 -3.921+002 -3.921+002 -3.921+002 -3.921+002 -3.921+002 -3.921+002     20
  21    -3.921+002 -3.921+002 -3.920+002  3.809+000 -3.920+002  3.590+000 -3.920+002  3.442+000 -3.920+002 -3.920+002     30
  31     3.204+000 -3.920+002 -3.921+002 -3.921+002 -3.921+002 -3.921+002 -3.921+002 -3.921+002 -3.922+002 -3.922+002     40
  41    -3.922+002 -3.922+002 -3.921+002  4.334+000  4.312+000  4.461+000 -3.921+002  3.671+000 -3.921+002 -3.921+002     50
  51    -3.922+002 -3.922+002 -3.921+002 -3.921+002 -3.922+002 -3.922+002 -3.921+002 -3.920+002 -3.920+002 -3.922+002     60
  61    -3.922+002 -3.921+002 -3.920+002 -3.920+002 -3.921+002  4.527+000  4.530+000  4.530+000 -3.921+002  4.528+000     70
  71    -3.920+002 -3.920+002 -3.919+002 -3.921+002 -3.921+002 -3.922+002 -3.922+002 -3.921+002 -3.921+002 -3.922+002     80
  81    -3.922+002 -3.921+002 -3.920+002 -3.920+002 -3.922+002 -3.922+002 -3.920+002 -3.919+002 -3.921+002  4.526+000     90
  91     4.529+000  4.529+000 -3.921+002  4.527+000 -1.417+000  2.952+000 -4.895-002 -3.921+002 -3.921+002 -3.921+002    100
 101    -3.921+002 -3.921+002 -3.921+002 -3.922+002 -3.922+002 -3.920+002 -3.920+002 -3.919+002 -3.922+002 -3.922+002    110
 111    -2.143+000  2.743+000 -6.956-002 -3.921+002  4.526+000  4.529+000 -3.921+002  4.527+000  1.393+000 -3.919+002    120
 121     2.690+000  2.238+000 -3.919+002 -3.919+002  2.361+000 -3.920+002  2.361+000 -3.920+002  2.361+000 -3.919+002    130
 131    -3.919+002  2.361+000 -3.920+002  2.361+000  2.361+000  2.361+000 -3.920+002  2.361+000 -3.920+002  2.361+000    140
 141     2.361+000  2.361+000 -3.920+002  2.361+000 -3.919+002  4.527+000  2.361+000  4.529+000  2.361+000  4.529+000    150
 151     2.361+000 -3.919+002  4.528+000  2.361+000 -6.239-001 -2.346+000 -4.097+000 -6.176-002 -1.713+000 -3.517+000    160
 161     5.288-001  4.253-002 -1.581+000 -7.638-002 -1.785+000 -3.786+000  5.287-001 -3.146+000  3.954+000  4.368+000    170
 171     2.380+000  5.289-001 -2.546-001 -2.101+000  3.941+000  4.244+000  1.728+000  5.098+000  5.396+000  4.918+000    180
 181     2.361+000  2.361+000  2.361+000  2.361+000

            16 POTENTIAL ITERATIONS COMPLETED.
               RDOTR/RDRMAX=  1.39+002/  4.62+006
PCOND =     2.3609+000   5.1266-001
QCOND =     2.2608+007  -3.1342+002
  NEXTRA=       0

 EFPREP --     1 GRIDS OUT OF    1 READ IN.
```

Figure 11.8. (Continued).

```
        BEGIN CYCLE NO.    3          TIME =   2.050+002 SECONDS.

 QSUMER FOUND QSUM= -9.99+003 CODE UNITS.
        AFTER SCREENING CORRECTION (SCREENING LENGTH=  2.00+002 M.) QSUM= -9.99+003
                QSCALE= -9.91+003          CORRECTED TO  -9.92+003
                QSUM = -9.9911+003
                PCOND =  2.361+000   5.127-001
                QCOND =  2.261+007  -3.134+002
-------------------------------------------------------------------------------

 EXPLICITLY CALCULATED FLUXES FOR CYCLE    3     TIME =  2.050+002 SECONDS.
 DURING THIS TIMESTEP, NASCAP WILL TAKE INTO ACCOUNT SUCH
 ADDITIONAL EFFECTS AS SURFACE CONDUCTIVITY, DISCHARGES, EMITTER OPERATION,
 AND VARIATION OF LIMITING FACTORS FOR LOW-ENERGY EMITTED ELECTRONS.
-------------------------------------------------------------------------------

 SURFACE CELL NO.   20                                    CODE =       004611216003
                                                          LOCATION =    6  9 17
                                                          NORMAL =     -1  0  0
                                                          MATERIAL =  KAPT
                        POTENTIAL = -3.921+002 VOLTS
                        STRESS =  3.106+006 VOLTS/METER
                        EXTERNAL FIELD = -5.695+003 VOLTS/METER
                        LIMITING FACTOR =   1.000+000
  FLUXES IN A/M**2
       INCIDENT ELECTRONS                          2.11-006
            RESULTING SECONDARIES                  9.02-007
            RESULTING BACKSCATTER                  5.55-007
       INCIDENT PROTONS                            3.11-008
            RESULTING SECONDARIES                  5.59-008
       BULK CONDUCTIVITY                           3.11-010
       PHOTOCURRENT                                 .00
                                                  ----------
     NET FLUX                                     -5.63-007
-------------------------------------------------------------------------------

 SURFACE CELL NO.   28                                    CODE =       004612210403
                                                          LOCATION =    6 10 17
                                                          NORMAL =      0  1  0
                                                          MATERIAL =  KAPT
                        POTENTIAL =  3.442+000 VOLTS
                        STRESS = -8.511+003 VOLTS/METER
                        EXTERNAL FIELD =  6.009+003 VOLTS/METER
                        LIMITING FACTOR =   8.020-027
  FLUXES IN A/M**2
       INCIDENT ELECTRONS                          2.28-006
            RESULTING SECONDARIES                  7.83-033      [  9.76-007]
            RESULTING BACKSCATTER                  6.01-007
       INCIDENT PROTONS                            2.74-008
            RESULTING SECONDARIES                  3.93-034      [  4.90-008]
       BULK CONDUCTIVITY                           -8.51-013
       PHOTOCURRENT                                 1.13-031     [  1.41-005]
                                                  ----------
     NET FLUX                                     -1.65-006
-------------------------------------------------------------------------------

 SURFACE CELL NO.   77                                    CODE =       005107211403
                                                          LOCATION =    9  7 17
                                                          NORMAL =      0 -1  0
                                                          MATERIAL =  KAPT
                        POTENTIAL = -3.922+002 VOLTS
                        STRESS =  3.106+006 VOLTS/METER
                        EXTERNAL FIELD = -4.229+003 VOLTS/METER
                        LIMITING FACTOR =   1.000+000
  FLUXES IN A/M**2
       INCIDENT ELECTRONS                          2.11-006
            RESULTING SECONDARIES                  9.02-007
            RESULTING BACKSCATTER                  5.55-007
```

Figure 11.8. (Continued).

```
      INCIDENT PROTONS                          3.11-008
           RESULTING SECONDARIES                5.60-008
      BULK CONDUCTIVITY                         3.11-010
      PHOTOCURRENT                               .00
                                               ----------
     NET FLUX                                  -5.63-007
-------------------------------------------------------------------------------

 SURFACE CELL NO.   88                                  CODE =       005111270103
                                                        LOCATION =     9  9 23
                                                        NORMAL =       0  0  1
                                                        MATERIAL =   KAPT

                        POTENTIAL = -3.919+002 VOLTS
                        STRESS =  3.104+006 VOLTS/METER
                        EXTERNAL FIELD = -1.102+004 VOLTS/METER
                        LIMITING FACTOR =  1.000+000

  FLUXES IN A/M**2
      INCIDENT ELECTRONS                        2.11-006
           RESULTING SECONDARIES                9.02-007
           RESULTING BACKSCATTER                5.55-007
      INCIDENT PROTONS                          3.10-008
           RESULTING SECONDARIES                5.59-008
      BULK CONDUCTIVITY                         3.10-010
      PHOTOCURRENT                               .00
                                               ----------
     NET FLUX                                  -5.63-007
-------------------------------------------------------------------------------

 SURFACE CELL NO.  129                                  CODE =       005307212001
                                                        LOCATION =    11  7 17
                                                        NORMAL =       1  0  0
                                                        MATERIAL =   GOLD

                        POTENTIAL =  2.361+000 VOLTS
                        EXTERNAL FIELD =  6.014+003 VOLTS/METER
                        LIMITING FACTOR =  7.588-027

  FLUXES IN A/M**2
      INCIDENT ELECTRONS                        2.28-006
           RESULTING SECONDARIES                1.11-032      [  1.46-006]
           RESULTING BACKSCATTER                1.48-006
      INCIDENT PROTONS                          2.75-008
           RESULTING SECONDARIES                3.37-034      [  4.45-008]
      PHOTOCURRENT                              1.56-031      [  2.05-005]
                                               ----------
     NET FLUX                                  -7.76-007
-------------------------------------------------------------------------------

 SURFACE CELL NO.  167                                  CODE =       011111120302
                                                        LOCATION =     9  9 10
                                                        NORMAL =       0  0 -1
                                                        MATERIAL =   SOLA

                        POTENTIAL =  5.287-001 VOLTS
                        STRESS = -8.955+001 VOLTS/METER
                        EXTERNAL FIELD =  1.654+003 VOLTS/METER
                        LIMITING FACTOR =  6.582-008

  FLUXES IN A/M**2
      INCIDENT ELECTRONS                        2.28-006
           RESULTING SECONDARIES                1.20-013      [  1.83-006]
           RESULTING BACKSCATTER                7.77-007
      INCIDENT PROTONS                          2.75-008
           RESULTING SECONDARIES                1.77-015      [  2.69-008]
      BULK CONDUCTIVITY                        -8.95-016
      PHOTOCURRENT                               .00          [   .00     ]
                                               ----------
     NET FLUX                                  -1.48-006
-------------------------------------------------------------------------------

 BOOM SURFACE CELL NO.  181                             CODE =       000061111123
                                                        LOCATION =     9  9 19    ( 1)
```

Figure 11.8. (Continued).

```
                                                          DIRECTION =   Z
                                                          MATERIAL =  ALUM
                          POTENTIAL =  2.361+000 VOLTS
                          FIELD =  1.751+004 VOLTS/METER
                          LIMITING FACTOR =    .000
   FLUXES IN A/M**2
         INCIDENT ELECTRONS                          2.28-006
              RESULTING SECONDARIES                   .00          (  8.53-007)
              RESULTING BACKSCATTER                  8.51-007
         INCIDENT PROTONS                            2.75-008
              RESULTING SECONDARIES                   .00          (  2.68-008)
         PHOTOCURRENT                                 .00          (  1.27-005)
                                                    ----------
       NET FLUX                                     -1.40-006

          INITIAL NET CHARGING CURRENT (WITHOUT LIMITING) =  3.63-007 AMPERES.
          INITIAL NET CHARGING CURRENT (WITH    LIMITING) = -7.05-008 AMPERES.

  TOTAL CAPACITANCE TO INFINITY =    49.9 CODE UNITS;    8.83-012 FARADS.

    ICCG --- RDOTR/RDOTR1 =   7.94-022/  1.21+008

  LEAVING ICCG1 -- VCTR1 =  -1.732+002 -1.313+002

    ICCG --- RDOTR/RDOTR1 =   7.94-022/  1.21+008

  LEAVING ICCG1 -- VCTR1 =  -1.732+002 -1.313+002

    ICCG --- RDOTR/RDOTR1 =   1.69-022/  9.27+007

  LEAVING ICCG1 -- VCTR1 =  -1.732+002 -1.259+002

   VFIX ---   59 OUT OF  164 NODES FIXED.
CONDUCTOR   1 FIXED TO  -166.79 VOLTS.

    ICCG --- RDOTR/RDOTR1 =   1.59-022/  9.08+007

  LEAVING ICCG1 -- VCTR1 =  -1.668+002 -1.226+002

  NO DISCHARGE ANALYSIS

  NO DISCHARGE ANALYSIS

    ICCG --- RDOTR/RDOTR1 =   6.22-018/  5.97+009

  LEAVING ICCG2 -- VCTR1 =  -1.667+002 -1.225+002

 AVERAGE FLUXES (ONLY AVAILABLE FOR INSULATING CELLS)

AVERAGE FLUX TO CELL   20 IS   -3.821-007 A/M**2
AVERAGE FLUX TO CELL   28 IS   -3.371-008 A/M**2
AVERAGE FLUX TO CELL   77 IS   -3.821-007 A/M**2
AVERAGE FLUX TO CELL   88 IS   -3.820-007 A/M**2
AVERAGE FLUX TO CELL  167 IS    6.340-008 A/M**2

NEW CONDUCTOR POTENTIALS

         VNEW              DQ              VOLD        CONDUCTOR
    -1.6670+002     1.8769+007     2.3609+000                1
    -1.2253+002     1.7465-001     5.1266-001                2

  TOTAL CHANGE IN CHARGE =   -1.603+004 CODE UNITS
                             -2.838-009 COULOMBS

  AVERAGE NET CHARGING CURRENT =   -1.419-011 AMPERES
                                   -8.014+001 CODE UNITS/SEC.

CONDUCTOR CURRENTS (AMPS; POSITIVE INTO CONDUCTORS):

                                    1           2

NET CURRENT(AVG DQ/DT):         1.66-008    1.55-016
```

Figure 11.8. (Continued).

CONDUCTIVITY CURRENT (NEW) (FROM INSULATING CELLS):	-2.57-011	7.67-017
PLASMA CURRENT (INITIAL) (TO BARE CELLS):	-5.67-009	.00
REMAINDER CURRENT:	2.23-008	7.79-017

Figure 11.8. (Continued).

```
          CONTINUE CYCLE NO.     3 AT UPDATED TIME =    4.050+002 SECONDS.
                   QSUM = -2.6018+004

SURFACE POTENTIALS - ALL  184 CELLS
CELL NO.                                                                                                                                CELL NO.
   1    -8.740+002 -8.740+002 -8.740+002 -8.741+002 -8.741+002 -8.741+002 -8.741+002 -8.740+002 -8.740+002 -8.740+002                       10
  11    -8.742+002 -8.741+002 -8.742+002 -8.742+002 -8.742+002 -8.742+002 -8.741+002 -8.742+002 -8.742+002 -8.742+002                       20
  21    -8.742+002 -8.741+002 -8.739+002 -2.069+002 -8.738+002 -1.882+002 -8.740+002 -1.932+002 -8.740+002 -8.739+002                       30
  31    -2.274+002 -8.738+002 -8.742+002 -8.741+002 -8.742+002 -8.742+002 -8.742+002 -8.741+002 -8.743+002 -8.743+002                       40
  41    -8.743+002 -8.743+002 -8.741+002 -1.708+002 -1.366+002 -1.417+002 -8.741+002 -1.925+002 -8.742+002 -8.742+002                       50
  51    -8.742+002 -8.742+002 -8.742+002 -8.742+002 -8.743+002 -8.743+002 -8.742+002 -8.740+002 -8.739+002 -8.743+002                       60
  61    -8.743+002 -8.742+002 -8.740+002 -8.739+002 -8.741+002 -1.447+002 -1.042+002 -1.091+002 -8.741+002 -1.672+002                       70
  71    -8.740+002 -8.739+002 -8.738+002 -8.742+002 -8.742+002 -8.742+002 -8.742+002 -8.742+002 -8.742+002 -8.743+002                       80
  81    -8.743+002 -8.742+002 -8.740+002 -8.739+002 -8.744+002 -8.744+002 -8.740+002 -8.736+002 -8.741+002 -1.348+002                       90
  91    -9.470+001 -9.930+001 -8.741+002 -1.553+002 -3.738+002 -1.990+002 -3.207+002 -8.742+002 -8.742+002 -8.742+002                      100
 101    -8.742+002 -8.742+002 -8.742+002 -8.743+002 -8.743+002 -8.740+002 -8.739+002 -8.738+002 -8.743+002 -8.743+002                      110
 111    -3.877+002 -2.081+002 -3.223+002 -8.741+002 -1.260+002 -8.902+001 -9.304+001 -8.741+002 -1.430+002 -2.138+002                      120
 121    -1.688+002 -1.694+002 -8.737+002 -8.737+002 -1.667+002 -8.738+002 -1.667+002 -8.738+002 -1.667+002 -8.737+002                      130
 131    -8.737+002 -1.667+002 -8.739+002 -1.667+002 -1.667+002 -1.667+002 -8.739+002 -1.667+002 -8.739+002 -1.667+002                      140
 141    -1.667+002 -1.667+002 -8.739+002 -1.667+002 -8.736+002 -1.185+002 -1.667+002 -8.934+001 -1.667+002 -9.299+001                      150
 151    -1.667+002 -8.736+002 -1.328+002 -1.667+002 -8.220+001 -1.503+002 -2.233+002 -7.746+001 -1.273+002 -2.197+002                      160
 161    -6.544+001 -1.062+002 -1.586+002 -7.865+001 -1.290+002 -2.301+002 -5.499+001 -2.324+002 -5.682+001 -7.204+001                      170
 171    -1.584+002 -6.896+001 -1.180+002 -1.857+002 -5.931+001 -8.197+001 -1.773+002 -4.892+001 -7.712+001 -1.229+002                      180
 181    -1.667+002 -1.667+002 -1.667+002 -1.667+002

            16 POTENTIAL ITERATIONS COMPLETED.
               RDOTR/RDRMAX=   2.54+002/  6.31+006
PCOND =    -1.6670+002  -1.2253+002
QCOND =     4.0884+007  -4.7210+003
  NEXTRA=       0

 EFPREP --     1 GRIDS OUT OF    1 READ IN.
```

Figure 11.8. (Continued).

```
        BEGIN CYCLE NO.     4          TIME =   4.050+002 SECONDS.

 QSUMER FOUND QSUM= -2.61+004 CODE UNITS.
        AFTER SCREENING CORRECTION (SCREENING LENGTH=  2.00+002 M.) QSUM= -2.61+004
                  QSCALE= -2.60+004          CORRECTED TO  -2.60+004
                  QSUM = -2.6063+004
                  PCOND =  -1.667+002  -1.225+002
                  QCOND =   4.088+007  -4.721+003
-------------------------------------------------------------------------------

 EXPLICITLY CALCULATED FLUXES FOR CYCLE    4      TIME =  4.050+002 SECONDS.
 DURING THIS TIMESTEP, NASCAP WILL TAKE INTO ACCOUNT SUCH
 ADDITIONAL EFFECTS AS SURFACE CONDUCTIVITY, DISCHARGES, EMITTER OPERATION,
 AND VARIATION OF LIMITING FACTORS FOR LOW-ENERGY EMITTED ELECTRONS.
-------------------------------------------------------------------------------

 SURFACE CELL NO.   20                                    CODE =       004611216003
                                                          LOCATION =     6  9 17
                                                          NORMAL =      -1  0  0
                                                          MATERIAL =  KAPT

                          POTENTIAL = -8.742+002 VOLTS
                          STRESS =  5.571+006 VOLTS/METER
                          EXTERNAL FIELD = -1.155+004 VOLTS/METER
                          LIMITING FACTOR =   1.000+000

  FLUXES IN A/M**2
       INCIDENT ELECTRONS                          1.91-006
            RESULTING SECONDARIES                  8.19-007
            RESULTING BACKSCATTER                  5.04-007
       INCIDENT PROTONS                            3.54-008
            RESULTING SECONDARIES                  6.55-008
       BULK CONDUCTIVITY                           5.57-010
       PHOTOCURRENT                                 .00
                                                  ----------
     NET FLUX                                     -4.89-007
-------------------------------------------------------------------------------

 SURFACE CELL NO.   28                                    CODE =       004612210403
                                                          LOCATION =     6 10 17
                                                          NORMAL =       0  1  0
                                                          MATERIAL =  KAPT

                          POTENTIAL = -1.932+002 VOLTS
                          STRESS =  2.083+005 VOLTS/METER
                          EXTERNAL FIELD =  7.927+003 VOLTS/METER
                          LIMITING FACTOR =   3.733-035

  FLUXES IN A/M**2
       INCIDENT ELECTRONS                          2.19-006
            RESULTING SECONDARIES                   .00          [  9.39-007]
            RESULTING BACKSCATTER                  5.78-007
       INCIDENT PROTONS                            2.92-008
            RESULTING SECONDARIES                   .00          [  5.24-008]
       BULK CONDUCTIVITY                           2.08-011
       PHOTOCURRENT                                 .00          [  1.41-005]
                                                  ----------
     NET FLUX                                     -1.59-006
-------------------------------------------------------------------------------

 SURFACE CELL NO.   77                                    CODE =       005107211403
                                                          LOCATION =     9  7 17
                                                          NORMAL =       0 -1  0
                                                          MATERIAL =  KAPT

                          POTENTIAL = -8.742+002 VOLTS
                          STRESS =  5.571+006 VOLTS/METER
                          EXTERNAL FIELD = -8.835+003 VOLTS/METER
                          LIMITING FACTOR =   1.000+000

  FLUXES IN A/M**2
       INCIDENT ELECTRONS                          1.91-006
            RESULTING SECONDARIES                  8.19-007
            RESULTING BACKSCATTER                  5.04-007
```

Figure 11.8. (Continued).

```
        INCIDENT PROTONS                          3.54-008
             RESULTING SECONDARIES                6.55-008
        BULK CONDUCTIVITY                         5.57-010
        PHOTOCURRENT                               .00
                                                 ----------
      NET FLUX                                   -4.89-007
-------------------------------------------------------------------------------

  SURFACE CELL NO.   88                                    CODE =       005111270103
                                                           LOCATION =    9  9 23
                                                           NORMAL =      0  0  1
                                                           MATERIAL =  KAPT
                          POTENTIAL = -8.736+002 VOLTS
                          STRESS =  5.566+006 VOLTS/METER
                          EXTERNAL FIELD = -2.144+004 VOLTS/METER
                          LIMITING FACTOR =  1.000+000
   FLUXES IN A/M**2
        INCIDENT ELECTRONS                        1.91-006
             RESULTING SECONDARIES                8.19-007
             RESULTING BACKSCATTER                5.04-007
        INCIDENT PROTONS                          3.54-008
             RESULTING SECONDARIES                6.55-008
        BULK CONDUCTIVITY                         5.57-010
        PHOTOCURRENT                               .00
                                                 ----------
      NET FLUX                                   -4.89-007
-------------------------------------------------------------------------------

  SURFACE CELL NO.  129                                    CODE =       005307212001
                                                           LOCATION =   11  7 17
                                                           NORMAL =      1  0  0
                                                           MATERIAL =  GOLD
                          POTENTIAL = -1.667+002 VOLTS
                          EXTERNAL FIELD =  9.081+003 VOLTS/METER
                          LIMITING FACTOR =   .000
   FLUXES IN A/M**2
        INCIDENT ELECTRONS                        2.20-006
             RESULTING SECONDARIES                 .00          [  1.42-006]
             RESULTING BACKSCATTER                1.43-006
        INCIDENT PROTONS                          2.90-008
             RESULTING SECONDARIES                 .00          [  9.70-008]
        PHOTOCURRENT                               .00          [  2.05-005]
                                                 ----------
      NET FLUX                                   -7.48-007
-------------------------------------------------------------------------------

  SURFACE CELL NO.  167                                    CODE =       011111120302
                                                           LOCATION =    9  9 10
                                                           NORMAL =      0  0 -1
                                                           MATERIAL =  SOLA
                          POTENTIAL = -5.499+001 VOLTS
                          STRESS = -3.773+005 VOLTS/METER
                          EXTERNAL FIELD =  3.647+003 VOLTS/METER
                          LIMITING FACTOR =  1.448-016
   FLUXES IN A/M**2
        INCIDENT ELECTRONS                        2.25-006
             RESULTING SECONDARIES                2.62-022     [  1.81-006]
             RESULTING BACKSCATTER                7.68-007
        INCIDENT PROTONS                          2.80-008
             RESULTING SECONDARIES                3.96-024     [  2.74-008]
        BULK CONDUCTIVITY                        -3.77-012
        PHOTOCURRENT                               .00          [   .00     ]
                                                 ----------
      NET FLUX                                   -1.46-006
-------------------------------------------------------------------------------

  BOOM SURFACE CELL NO.  181                               CODE =       000061111123
                                                           LOCATION =    9  9 19    ( 1)
```

Figure 11.8. (Continued).

```
                                                        DIRECTION =    Z
                                                        MATERIAL  =  ALUM
                          POTENTIAL = -1.667+002 VOLTS
                          FIELD =  3.150+004 VOLTS/METER
                          LIMITING FACTOR =    .000

 FLUXES IN A/M**2
       INCIDENT ELECTRONS                          2.20-006
            RESULTING SECONDARIES                   .00        (  8.24-007)
            RESULTING BACKSCATTER                  8.23-007
       INCIDENT PROTONS                            2.90-008
            RESULTING SECONDARIES                   .00        (  2.84-008)
       PHOTOCURRENT                                 .00        (  1.27-005)
                                                  ----------
    NET FLUX                                      -1.35-006

       INITIAL NET CHARGING CURRENT (WITHOUT LIMITING) =  3.66-007 AMPERES.
       INITIAL NET CHARGING CURRENT (WITH    LIMITING) = -6.58-008 AMPERES.

 TOTAL CAPACITANCE TO INFINITY =    49.9 CODE UNITS;    8.83-012 FARADS.

   ICCG --- RDOTR/RDOTR1 =   1.06-021/  1.30+008

 LEAVING ICCG1 -- VCTRI =  -4.233+002 -3.291+002

   ICCG --- RDOTR/RDOTR1 =   1.06-021/  1.30+008

 LEAVING ICCG1 -- VCTRI =  -4.233+002 -3.291+002

   ICCG --- RDOTR/RDOTR1 =   1.64-022/  1.03+008

 LEAVING ICCG1 -- VCTRI =  -4.233+002 -3.248+002

  VFIX ---   59 OUT OF  164 NODES FIXED.
CONDUCTOR   1 FIXED TO  -416.40 VOLTS.

   ICCG --- RDOTR/RDOTR1 =   1.53-022/  1.01+008

 LEAVING ICCG1 -- VCTRI =  -4.164+002 -3.214+002

 NO DISCHARGE ANALYSIS

 NO DISCHARGE ANALYSIS

   ICCG --- RDOTR/RDOTR1 =   1.76-017/  4.16+009

 LEAVING ICCG2 -- VCTRI =  -4.163+002 -3.213+002

 AVERAGE FLUXES (ONLY AVAILABLE FOR INSULATING CELLS)

AVERAGE FLUX TO CELL    20 IS    -3.217-007 A/M**2
AVERAGE FLUX TO CELL    28 IS    -1.495-008 A/M**2
AVERAGE FLUX TO CELL    77 IS    -3.217-007 A/M**2
AVERAGE FLUX TO CELL    88 IS    -3.216-007 A/M**2
AVERAGE FLUX TO CELL   167 IS     7.080-008 A/M**2

NEW CONDUCTOR POTENTIALS

          VNEW                DQ                VOLD          CONDUCTOR
    -4.1632+002      1.5449+007     -1.6670+002                    1
    -3.2133+002      3.0019-001     -1.2253+002                    2

   TOTAL CHANGE IN CHARGE =   -1.842+004 CODE UNITS
                              -3.262-009 COULOMBS

   AVERAGE NET CHARGING CURRENT =   -1.631-011 AMPERES
                                    -9.211+001 CODE UNITS/SEC.

 CONDUCTOR CURRENTS (AMPS; POSITIVE INTO CONDUCTORS):

                                    1          2

 NET CURRENT(AVG DQ/DT):        1.37-008   2.66-016
```

Figure 11.8. (Continued).

CONDUCTIVITY CURRENT (NEW) (FROM INSULATING CELLS):	-3.51-011	1.65-016
PLASMA CURRENT (INITIAL) (TO BARE CELLS):	-5.47-009	.00
REMAINDER CURRENT:	1.92-008	1.01-016

Figure 11.8. (Continued).

```
          CONTINUE CYCLE NO.     4 AT UPDATED TIME =   6.050+002 SECONDS.
                   QSUM = -4.4486+004

SURFACE POTENTIALS - ALL  184 CELLS
CELL NO.                                                                                                                                CELL NO.
   1    -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003     10
  11    -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003     20
  21    -1.387+003 -1.387+003 -1.387+003 -4.567+002 -1.387+003 -4.453+002 -1.387+003 -4.549+002 -1.387+003 -1.387+003 -1.387+003     30
  31    -4.915+002 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.388+003 -1.388+003 -1.388+003     40
  41    -1.388+003 -1.388+003 -1.387+003 -4.172+002 -3.039+002 -3.946+002 -1.387+003 -4.565+002 -1.387+003 -1.387+003 -1.387+003     50
  51    -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.388+003 -1.388+003 -1.387+003 -1.387+003 -1.387+003 -1.388+003 -1.388+003     60
  61    -1.388+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -3.783+002 -3.345+002 -3.455+002 -1.387+003 -4.201+002 -1.388+003     70
  71    -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.387+003 -1.388+003 -1.388+003     80
  81    -1.388+003 -1.387+003 -1.387+003 -1.387+003 -1.388+003 -1.388+003 -1.387+003 -1.386+003 -1.387+003 -3.569+002 -1.388+003     90
  91    -3.104+002 -3.211+002 -1.387+003 -3.976+002 -6.336+002 -4.825+002 -5.263+002 -1.387+003 -1.387+003 -1.387+003 -1.387+003    100
 101    -1.387+003 -1.387+003 -1.387+003 -1.388+003 -1.388+003 -1.387+003 -1.387+003 -1.387+003 -1.388+003 -1.388+003 -1.388+003    110
 111    -6.728+002 -4.964+002 -5.283+002 -1.387+003 -3.411+002 -2.981+002 -3.078+002 -1.387+003 -3.773+002 -5.397+002 -1.388+003    120
 121    -4.720+002 -4.576+002 -1.387+003 -1.387+003 -4.163+002 -1.387+003 -4.163+002 -1.387+003 -4.163+002 -1.387+003 -1.387+003    130
 131    -1.387+003 -4.163+002 -1.387+003 -4.163+002 -4.163+002 -4.163+002 -1.387+003 -4.163+002 -1.387+003 -4.163+002 -4.163+002    140
 141    -4.163+002 -4.163+002 -1.387+003 -4.163+002 -1.386+003 -3.268+002 -4.163+002 -2.952+002 -4.163+002 -3.039+002 -4.163+002    150
 151    -4.163+002 -1.386+003 -3.583+002 -4.163+002 -2.456+002 -3.558+002 -5.008+002 -2.302+002 -3.278+002 -5.002+002 -4.163+002    160
 161    -2.110+002 -2.932+002 -3.982+002 -2.333+002 -3.320+002 -5.166+002 -1.783+002 -5.434+002 -1.934+002 -2.367+002 -2.110+002    170
 171    -3.941+002 -2.190+002 -3.124+002 -4.393+002 -1.988+002 -2.555+002 -4.304+002 -1.830+002 -2.504+002 -3.415+002 -3.941+002    180
 181    -4.163+002 -4.163+002 -4.163+002 -4.163+002

            16 POTENTIAL ITERATIONS COMPLETED.
               RDOTR/RDRMAX=  2.71+002/  3.65+006
PCOND =    -4.1632+002  -3.2133+002
QCOND =     5.5913+007  -8.3560+003
  NEXTRA=       0

 EFPREP --     1 GRIDS OUT OF    1 READ IN.
```

Figure 11.8. (Continued)

```
        BEGIN CYCLE NO.    5          TIME =   6.050+002 SECONDS.

 QSUMER FOUND QSUM= -4.46+004 CODE UNITS.
        AFTER SCREENING CORRECTION (SCREENING LENGTH=  2.00+002 M.) QSUM= -4.46+004
                  QSCALE= -4.44+004          CORRECTED TO  -4.45+004
                  QSUM = -4.4583+004
                  PCOND =  -4.163+002  -3.213+002
                  QCOND =   5.591+007  -8.356+003

-------------------------------------------------------------------------------

 EXPLICITLY CALCULATED FLUXES FOR CYCLE    5     TIME =  6.050+002 SECONDS.
 DURING THIS TIMESTEP, NASCAP WILL TAKE INTO ACCOUNT SUCH
 ADDITIONAL EFFECTS AS SURFACE CONDUCTIVITY, DISCHARGES, EMITTER OPERATION,
 AND VARIATION OF LIMITING FACTORS FOR LOW-ENERGY EMITTED ELECTRONS.

-------------------------------------------------------------------------------

 SURFACE CELL NO.   20                                    CODE =       004611216003
                                                          LOCATION =    6  9 17
                                                          NORMAL =     -1  0  0
                                                          MATERIAL =  KAPT
                          POTENTIAL = -1.387+003 VOLTS
                          STRESS =  7.646+006 VOLTS/METER
                          EXTERNAL FIELD = -1.750+004 VOLTS/METER
                          LIMITING FACTOR =  1.000+000
  FLUXES IN A/M**2
       INCIDENT ELECTRONS                          1.73-006
            RESULTING SECONDARIES                  7.39-007
            RESULTING BACKSCATTER                  4.55-007
       INCIDENT PROTONS                            4.01-008
            RESULTING SECONDARIES                  7.69-008
       BULK CONDUCTIVITY                           7.65-010
       PHOTOCURRENT                                 .00
                                                  ----------
     NET FLUX                                     -4.15-007

-------------------------------------------------------------------------------

 SURFACE CELL NO.   28                                    CODE =       004612210403
                                                          LOCATION =    6 10 17
                                                          NORMAL =      0  1  0
                                                          MATERIAL =  KAPT
                          POTENTIAL = -4.549+002 VOLTS
                          STRESS =  3.038+005 VOLTS/METER
                          EXTERNAL FIELD =  8.971+003 VOLTS/METER
                          LIMITING FACTOR =  .000
  FLUXES IN A/M**2
       INCIDENT ELECTRONS                          2.08-006
            RESULTING SECONDARIES                   .00          [  8.91-007]
            RESULTING BACKSCATTER                  5.48-007
       INCIDENT PROTONS                            3.16-008
            RESULTING SECONDARIES                   .00          [  5.71-008]
       BULK CONDUCTIVITY                           3.04-011
       PHOTOCURRENT                                 .00          [  1.41-005]
                                                  ----------
     NET FLUX                                     -1.50-006

-------------------------------------------------------------------------------

 SURFACE CELL NO.   77                                    CODE =       005107211403
                                                          LOCATION =    9  7 17
                                                          NORMAL =      0 -1  0
                                                          MATERIAL =  KAPT
                          POTENTIAL = -1.387+003 VOLTS
                          STRESS =  7.647+006 VOLTS/METER
                          EXTERNAL FIELD = -1.354+004 VOLTS/METER
                          LIMITING FACTOR =  1.000+000
  FLUXES IN A/M**2
       INCIDENT ELECTRONS                          1.73-006
            RESULTING SECONDARIES                  7.39-007
            RESULTING BACKSCATTER                  4.55-007
```

Figure 11.8. (Continued).

```
      INCIDENT PROTONS                          4.01-008
           RESULTING SECONDARIES                7.69-008
      BULK CONDUCTIVITY                         7.65-010
      PHOTOCURRENT                               .00
                                               ----------
    NET FLUX                                   -4.15-007
-------------------------------------------------------------------------------

  SURFACE CELL NO.   88                                  CODE =       005111270103
                                                         LOCATION =     9  9 23
                                                         NORMAL =       0  0  1
                                                         MATERIAL =  KAPT

                          POTENTIAL = -1.386+003 VOLTS
                          STRESS =  7.638+006 VOLTS/METER
                          EXTERNAL FIELD = -3.290+004 VOLTS/METER
                          LIMITING FACTOR =   1.000+000

  FLUXES IN A/M**2
      INCIDENT ELECTRONS                         1.73-006
           RESULTING SECONDARIES                 7.39-007
           RESULTING BACKSCATTER                 4.55-007
      INCIDENT PROTONS                           4.01-008
           RESULTING SECONDARIES                 7.69-008
      BULK CONDUCTIVITY                          7.64-010
      PHOTOCURRENT                                .00
                                                ----------
    NET FLUX                                    -4.15-007
-------------------------------------------------------------------------------

  SURFACE CELL NO.  129                                  CODE =       005307212001
                                                         LOCATION =    11  7 17
                                                         NORMAL =       1  0  0
                                                         MATERIAL =  GOLD

                          POTENTIAL = -4.163+002 VOLTS
                          EXTERNAL FIELD =  1.056+004 VOLTS/METER
                          LIMITING FACTOR =     .000

  FLUXES IN A/M**2
      INCIDENT ELECTRONS                         2.10-006
           RESULTING SECONDARIES                  .00          [  1.35-006]
           RESULTING BACKSCATTER                 1.36-006
      INCIDENT PROTONS                           3.13-008
           RESULTING SECONDARIES                  .00          [  5.11-008]
      PHOTOCURRENT                                .00          [  2.05-005]
                                                ----------
    NET FLUX                                    -7.08-007
-------------------------------------------------------------------------------

  SURFACE CELL NO.  167                                  CODE =       011111120302
                                                         LOCATION =     9  9 10
                                                         NORMAL =       0  0 -1
                                                         MATERIAL =  SOLA

                          POTENTIAL = -1.783+002 VOLTS
                          STRESS = -7.990+005 VOLTS/METER
                          EXTERNAL FIELD =  4.676+003 VOLTS/METER
                          LIMITING FACTOR =  4.908-021

  FLUXES IN A/M**2
      INCIDENT ELECTRONS                         2.20-006
           RESULTING SECONDARIES                 8.67-027     [  1.77-006]
           RESULTING BACKSCATTER                 7.50-007
      INCIDENT PROTONS                           2.91-008
           RESULTING SECONDARIES                 1.40-028     [  2.85-008]
      BULK CONDUCTIVITY                         -7.99-012
      PHOTOCURRENT                                .00          [   .00    ]
                                                ----------
    NET FLUX                                    -1.42-006
-------------------------------------------------------------------------------

  BOOM SURFACE CELL NO.  181                             CODE =       000061111123
                                                         LOCATION =     9  9 19    ( 1)
```

Figure 11.8. (Continued).

```
                                                        DIRECTION =   Z
                                                        MATERIAL  =  ALUM
                          POTENTIAL = -4.163+002 VOLTS
                          FIELD =  4.293+004 VOLTS/METER
                          LIMITING FACTOR =    .000
   FLUXES IN A/M**2
        INCIDENT ELECTRONS                              2.10-006
             RESULTING SECONDARIES                       .00          [  7.84-007]
             RESULTING BACKSCATTER                      7.83-007
        INCIDENT PROTONS                                3.13-008
             RESULTING SECONDARIES                       .00          [  3.09-008]
        PHOTOCURRENT                                     .00          [  1.27-005]
                                                       ----------
      NET FLUX                                        -1.28-006

         INITIAL NET CHARGING CURRENT (WITHOUT LIMITING) =  3.70-007 AMPERES.
         INITIAL NET CHARGING CURRENT (WITH    LIMITING) = -6.06-008 AMPERES.

  TOTAL CAPACITANCE TO INFINITY =    49.9 CODE UNITS;    8.83-012 FARADS.

    ICCG --- RDOTR/RDOTR1 =   9.32-022/  1.21+008

  LEAVING ICCG1 -- VCTRI =  -7.062+002 -5.600+002

    ICCG --- RDOTR/RDOTR1 =   9.32-022/  1.21+008

  LEAVING ICCG1 -- VCTRI =  -7.062+002 -5.600+002

    ICCG --- RDOTR/RDOTR1 =   1.53-022/  9.90+007

  LEAVING ICCG1 -- VCTRI =  -7.062+002 -5.555+002

   VFIX ---   59 OUT OF  164 NODES FIXED.
CONDUCTOR   1 FIXED TO  -698.88 VOLTS.

    ICCG --- RDOTR/RDOTR1 =   1.69-022/  9.67+007

  LEAVING ICCG1 -- VCTRI =  -6.989+002 -5.521+002

  NO DISCHARGE ANALYSIS

  NO DISCHARGE ANALYSIS

    ICCG --- RDOTR/RDOTR1 =   1.94-017/  3.10+009

  LEAVING ICCG2 -- VCTRI =  -6.988+002 -5.521+002

 AVERAGE FLUXES (ONLY AVAILABLE FOR INSULATING CELLS)

AVERAGE FLUX TO CELL    20 IS   -2.747-007 A/M**2
AVERAGE FLUX TO CELL    28 IS   -1.796-008 A/M**2
AVERAGE FLUX TO CELL    77 IS   -2.747-007 A/M**2
AVERAGE FLUX TO CELL    88 IS   -2.746-007 A/M**2
AVERAGE FLUX TO CELL   167 IS    6.788-008 A/M**2

NEW CONDUCTOR POTENTIALS

          VNEW                DQ              VOLD        CONDUCTOR
    -6.9885+002      1.3488+007     -4.1632+002                 1
    -5.5208+002      4.4483-001     -3.2133+002                 2

  TOTAL CHANGE IN CHARGE =   -1.924+004 CODE UNITS
                             -3.408-009 COULOMBS

  AVERAGE NET CHARGING CURRENT =   -1.704-011 AMPERES
                                   -9.622+001 CODE UNITS/SEC.

CONDUCTOR CURRENTS (AMPS; POSITIVE INTO CONDUCTORS):

                                  1           2

NET CURRENT(AVG DQ/DT):       1.19-008    3.94-016
```

Figure 11.8. (Continued).

CONDUCTIVITY CURRENT (NEW) (FROM INSULATING CELLS):	-4.33-011	2.54-016
PLASMA CURRENT (INITIAL) (TO BARE CELLS):	-5.18-009	.00
REMAINDER CURRENT:	1.72-008	1.40-016

Figure 11.8. (Continued).

```
          CONTINUE CYCLE NO.     5 AT UPDATED TIME =    8.050+002 SECONDS.
                   QSUM = -6.3827+004
SURFACE POTENTIALS - ALL  184 CELLS
CELL NO.
   1   -1.894+003 -1.894+003 -1.894+003 -1.895+003 -1.895+003 -1.895+003 -1.895+003 -1.894+003 -1.894+003 -1.894+003   CELL NO.
  11   -1.895+003 -1.895+003 -1.895+003 -1.895+003 -1.895+003 -1.895+003 -1.895+003 -1.895+003 -1.895+003 -1.894+003    10
  21   -1.895+003 -1.895+003 -1.894+003 -7.559+002 -1.894+003 -7.393+002 -1.894+003 -7.520+002 -1.894+003 -1.894+003    20
  31   -8.028+002 -1.894+003 -1.895+003 -1.895+003 -1.895+003 -1.895+003 -1.895+003 -1.895+003 -1.895+003 -1.895+003    30
  41   -1.895+003 -1.895+003 -1.895+003 -7.064+002 -6.614+002 -6.751+002 -1.895+003 -7.585+002 -1.895+003 -1.895+003    40
  51   -1.895+003 -1.895+003 -1.895+003 -1.895+003 -1.895+003 -1.895+003 -1.894+003 -1.894+003 -1.895+003 -1.895+003    50
  61   -1.894+003 -1.894+003 -1.894+003 -1.894+003 -1.895+003 -6.577+002 -5.972+002 -6.117+002 -1.895+003 -1.895+003    60
  71   -1.895+003 -1.895+003 -1.894+003 -1.895+003 -1.895+003 -1.895+003 -1.895+003 -1.895+003 -7.130+002 -1.895+003    70
  81   -5.684+002 -5.824+002 -1.895+003 -6.844+002 -1.066+003 -7.468+002 -9.190+002 -1.895+003 -1.895+003 -6.318+002    80
  91   -1.895+003 -1.895+003 -1.895+003 -1.895+003 -1.895+003 -1.894+003 -1.894+003 -1.895+003 -1.895+003 -1.895+003    90
 101   -1.104+003 -7.685+002 -9.225+002 -1.895+003 -6.068+002 -5.488+002 -5.614+002 -1.895+003 -6.533+002 -8.306+002   100
 111   -7.087+002 -6.768+002 -1.894+003 -1.894+003 -6.988+002 -1.894+003 -6.988+002 -1.894+003 -6.988+002 -1.894+003   110
 121   -1.894+003 -6.988+002 -1.894+003 -6.988+002 -6.988+002 -6.988+002 -1.894+003 -6.988+002 -1.894+003 -6.988+002   120
 131   -6.988+002 -6.988+002 -1.894+003 -6.988+002 -1.893+003 -5.707+002 -6.988+002 -5.361+002 -6.988+002 -5.473+002   130
 141   -6.988+002 -1.893+003 -6.187+002 -6.988+002 -4.305+002 -6.036+002 -8.148+002 -5.573+002 -8.161+002 -4.319+002   140
 151   -3.868+002 -5.069+002 -6.713+002 -4.123+002 -5.616+002 -8.382+002 -3.367+002 -9.001+002 -3.630+002 -4.460+002   150
 161   -6.699+002 -3.971+002 -5.346+002 -7.294+002 -3.701+002 -4.586+002 -7.193+002 -3.515+002 -4.460+002 -5.944+002   160
 171   -6.988+002 -6.988+002 -6.988+002 -6.988+002                                                                   170
 181                                                                                                                   180

          16 POTENTIAL ITERATIONS COMPLETED.
             RDOTR/RDRMAX=   1.70+002/  2.24+006
PCOND =    -6.9885+002  -5.5208+002
QCOND =     6.9044+007  -1.2293+004
  NEXTRA=       0

 EFPREP --     1 GRIDS OUT OF    1 READ IN.
```

Figure 11.8. (Continued).

```
        BEGIN CYCLE NO.    6          TIME =   8.050+002 SECONDS.

 QSUMER FOUND QSUM= -6.39+004 CODE UNITS.
        AFTER SCREENING CORRECTION (SCREENING LENGTH=  2.00+002 M.) QSUM= -6.39+004
                  QSCALE= -6.37+004          CORRECTED TO  -6.38+004
                  QSUM = -6.3875+004
                  PCOND = -6.988+002  -5.521+002
                  QCOND =  6.904+007  -1.229+004

-------------------------------------------------------------------------------

 EXPLICITLY CALCULATED FLUXES FOR CYCLE   6     TIME =  8.050+002 SECONDS.
 DURING THIS TIMESTEP, NASCAP WILL TAKE INTO ACCOUNT SUCH
 ADDITIONAL EFFECTS AS SURFACE CONDUCTIVITY, DISCHARGES, EMITTER OPERATION,
 AND VARIATION OF LIMITING FACTORS FOR LOW-ENERGY EMITTED ELECTRONS.

-------------------------------------------------------------------------------

 SURFACE CELL NO.   20                                    CODE =       004611216003
                                                          LOCATION =    6  9 17
                                                          NORMAL =     -1  0  0
                                                          MATERIAL =  KAPT
                          POTENTIAL = -1.895+003 VOLTS
                          STRESS =  9.418+006 VOLTS/METER
                          EXTERNAL FIELD = -2.310+004 VOLTS/METER
                          LIMITING FACTOR =   1.000+000
  FLUXES IN A/M**2
       INCIDENT ELECTRONS                          1.56-006
            RESULTING SECONDARIES                  6.68-007
            RESULTING BACKSCATTER                  4.11-007
       INCIDENT PROTONS                            4.48-008
            RESULTING SECONDARIES                  8.91-008
       BULK CONDUCTIVITY                           9.42-010
       PHOTOCURRENT                                 .00
                                                  ----------
    NET FLUX                                      -3.47-007

-------------------------------------------------------------------------------

 SURFACE CELL NO.   28                                    CODE =       004612210403
                                                          LOCATION =    6 10 17
                                                          NORMAL =      0  1  0
                                                          MATERIAL =  KAPT
                          POTENTIAL = -7.520+002 VOLTS
                          STRESS =  4.185+005 VOLTS/METER
                          EXTERNAL FIELD =  9.151+003 VOLTS/METER
                          LIMITING FACTOR =    .000
  FLUXES IN A/M**2
       INCIDENT ELECTRONS                          1.96-006
            RESULTING SECONDARIES                   .00          [  8.39-007]
            RESULTING BACKSCATTER                  5.17-007
       INCIDENT PROTONS                            3.43-008
            RESULTING SECONDARIES                   .00          [  6.30-008]
       BULK CONDUCTIVITY                           4.19-011
       PHOTOCURRENT                                 .00          [  1.41-005]
                                                  ----------
    NET FLUX                                      -1.41-006

-------------------------------------------------------------------------------

 SURFACE CELL NO.   77                                    CODE =       005107211403
                                                          LOCATION =    9  7 17
                                                          NORMAL =      0 -1  0
                                                          MATERIAL =  KAPT
                          POTENTIAL = -1.895+003 VOLTS
                          STRESS =  9.418+006 VOLTS/METER
                          EXTERNAL FIELD = -1.803+004 VOLTS/METER
                          LIMITING FACTOR =   1.000+000
  FLUXES IN A/M**2
       INCIDENT ELECTRONS                          1.56-006
            RESULTING SECONDARIES                  6.68-007
            RESULTING BACKSCATTER                  4.11-007
```

Figure 11.8. (Continued).

```
        INCIDENT PROTONS                          9.48-008
             RESULTING SECONDARIES                8.91-008
        BULK CONDUCTIVITY                         9.42-010
        PHOTOCURRENT                               .00
                                                 ----------
      NET FLUX                                   -3.47-007
-------------------------------------------------------------------------------

  SURFACE CELL NO.   88                                    CODE =       005111270103
                                                           LOCATION =     9  9 23
                                                           NORMAL =       0  0  1
                                                           MATERIAL =   KAPT
                          POTENTIAL = -1.894+003 VOLTS
                          STRESS =  9.407+006 VOLTS/METER
                          EXTERNAL FIELD = -4.309+004 VOLTS/METER
                          LIMITING FACTOR =   1.000+000
   FLUXES IN A/M**2
        INCIDENT ELECTRONS                        1.56-006
             RESULTING SECONDARIES                6.68-007
             RESULTING BACKSCATTER                4.11-007
        INCIDENT PROTONS                          4.47-008
             RESULTING SECONDARIES                8.91-008
        BULK CONDUCTIVITY                         9.41-010
        PHOTOCURRENT                               .00
                                                 ----------
      NET FLUX                                   -3.47-007
-------------------------------------------------------------------------------

  SURFACE CELL NO.  129                                    CODE =       005307212001
                                                           LOCATION =    11  7 17
                                                           NORMAL =       1  0  0
                                                           MATERIAL =   GOLD
                          POTENTIAL = -6.988+002 VOLTS
                          EXTERNAL FIELD =  1.117+004 VOLTS/METER
                          LIMITING FACTOR =    .000
   FLUXES IN A/M**2
        INCIDENT ELECTRONS                        1.98-006
             RESULTING SECONDARIES                 .00          [  1.27-006]
             RESULTING BACKSCATTER                1.28-006
        INCIDENT PROTONS                          3.38-008
             RESULTING SECONDARIES                 .00          [  5.61-008]
        PHOTOCURRENT                               .00          [  2.05-005]
                                                 ----------
      NET FLUX                                   -6.64-007
-------------------------------------------------------------------------------

  SURFACE CELL NO.  167                                    CODE =       011111120302
                                                           LOCATION =     9  9 10
                                                           NORMAL =       0  0 -1
                                                           MATERIAL =   SOLA
                          POTENTIAL = -3.367+002 VOLTS
                          STRESS = -1.204+006 VOLTS/METER
                          EXTERNAL FIELD =  4.873+003 VOLTS/METER
                          LIMITING FACTOR =  6.865-022
   FLUXES IN A/M**2
        INCIDENT ELECTRONS                        2.13-006
             RESULTING SECONDARIES                1.17-027     [  1.71-006]
             RESULTING BACKSCATTER                7.26-007
        INCIDENT PROTONS                          3.05-008
             RESULTING SECONDARIES                2.06-029     [  3.01-008]
        BULK CONDUCTIVITY                        -1.20-011
        PHOTOCURRENT                               .00         [   .00     ]
                                                 ----------
      NET FLUX                                   -1.37-006
-------------------------------------------------------------------------------

  BOOM SURFACE CELL NO.  181                               CODE =       000061111123
                                                           LOCATION =     9  9 19    ( 1)
```

Figure 11.8. (Continued).

```
                                                        DIRECTION =    Z
                                                        MATERIAL  =  ALUM
                          POTENTIAL = -6.988+002 VOLTS
                          FIELD =  5.277+004 VOLTS/METER
                          LIMITING FACTOR =    .000
  FLUXES IN A/M**2
       INCIDENT ELECTRONS                              1.98-006
            RESULTING SECONDARIES                       .00          (  7.41-007)
            RESULTING BACKSCATTER                      7.40-007
       INCIDENT PROTONS                                3.38-008
            RESULTING SECONDARIES                       .00          (  3.39-008)
       PHOTOCURRENT                                     .00          (  1.27-005)
                                                      ----------
     NET FLUX                                         -1.21-006

        INITIAL NET CHARGING CURRENT (WITHOUT LIMITING) =  3.73-007 AMPERES.
        INITIAL NET CHARGING CURRENT (WITH    LIMITING) = -5.53-008 AMPERES.

  TOTAL CAPACITANCE TO INFINITY =    49.9 CODE UNITS;    8.83-012 FARADS.

    ICCG --- RDOTR/RDOTR1 =   8.90-022/  1.04+008

  LEAVING ICCG1 -- VCTRI =  -9.964+002 -7.989+002

    ICCG --- RDOTR/RDOTR1 =   8.90-022/  1.04+008

  LEAVING ICCG1 -- VCTRI =  -9.964+002 -7.989+002

    ICCG --- RDOTR/RDOTR1 =   1.50-022/  8.77+007

  LEAVING ICCG1 -- VCTRI =  -9.964+002 -7.949+002

   VFIX ---   59 OUT OF  164 NODES FIXED.
CONDUCTOR   1 FIXED TO  -988.58 VOLTS.

    ICCG --- RDOTR/RDOTR1 =   1.46-022/  8.54+007

  LEAVING ICCG1 -- VCTRI =  -9.886+002 -7.914+002

  NO DISCHARGE ANALYSIS

  NO DISCHARGE ANALYSIS

    ICCG --- RDOTR/RDOTR1 =   1.97-017/  2.25+009

  LEAVING ICCG2 -- VCTRI =  -9.885+002 -7.914+002

 AVERAGE FLUXES (ONLY AVAILABLE FOR INSULATING CELLS)

AVERAGE FLUX TO CELL    20 IS    -2.353-007 A/M**2
AVERAGE FLUX TO CELL    28 IS    -1.641-008 A/M**2
AVERAGE FLUX TO CELL    77 IS    -2.352-007 A/M**2
AVERAGE FLUX TO CELL    88 IS    -2.350-007 A/M**2
AVERAGE FLUX TO CELL   167 IS     6.964-008 A/M**2

NEW CONDUCTOR POTENTIALS

          VNEW                 DQ                VOLD          CONDUCTOR
    -9.8851+002      1.1296+007     -6.9885+002                     1
    -7.9138+002      6.4145-001     -5.5208+002                     2

  TOTAL CHANGE IN CHARGE =   -1.858+004 CODE UNITS
                             -3.291-009 COULOMBS

  AVERAGE NET CHARGING CURRENT =   -1.645-011 AMPERES
                                   -9.292+001 CODE UNITS/SEC.

CONDUCTOR CURRENTS (AMPS; POSITIVE INTO CONDUCTORS):

                                    1           2

NET CURRENT(AVG DQ/DT):         1.00-008    5.68-016
```


Figure 11.8. (Continued).

CONDUCTIVITY CURRENT (NEW) (FROM INSULATING CELLS):	-5.02-011	3.41-016
PLASMA CURRENT (INITIAL) (TO BARE CELLS):	-4.86-009	.00
REMAINDER CURRENT:	1.49-008	2.27-016

Figure 11.8. (Continued).

```
          CONTINUE CYCLE NO.     6 AT UPDATED TIME =    1.005+003 SECONDS.
                   QSUM = -8.2459+004

SURFACE POTENTIALS - ALL  184 CELLS
CELL NO.                                                                                                                                CELL NO.
   1    -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003      10
  11    -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003      20
  21    -2.377+003 -2.377+003 -2.376+003 -1.049+003 -2.376+003 -1.039+003 -2.376+003 -1.055+003 -2.376+003 -2.376+003 -2.376+003      30
  31    -1.108+003 -2.376+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003      40
  41    -2.377+003 -2.377+003 -2.377+003 -1.001+003 -9.555+002 -9.734+002 -2.377+003 -1.067+003 -2.377+003 -2.377+003 -2.378+003      50
  51    -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.378+003 -2.378+003 -2.377+003 -2.377+003 -2.376+003 -2.378+003 -2.378+003      60
  61    -2.378+003 -2.377+003 -2.377+003 -2.376+003 -2.377+003 -9.446+002 -8.813+002 -8.999+002 -2.377+003 -1.015+003 -2.378+003      70
  71    -2.377+003 -2.376+003 -2.376+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.375+003 -2.377+003 -9.107+002 -2.378+003      80
  81    -2.378+003 -2.377+003 -2.377+003 -2.376+003 -2.378+003 -2.378+003 -2.377+003 -2.377+003 -2.377+003 -2.377+003 -2.378+003      90
  91    -8.430+002 -8.611+002 -2.377+003 -9.790+002 -1.371+003 -1.057+003 -1.120+003 -2.377+003 -2.376+003 -2.378+003 -2.378+003     100
 101    -2.377+003 -2.377+003 -2.377+003 -2.378+003 -2.378+003 -2.377+003 -2.376+003 -2.376+003 -2.378+003 -2.378+003 -2.378+003     110
 111    -1.430+003 -1.002+003 -1.124+003 -2.377+003 -8.703+002 -8.163+002 -8.327+002 -2.377+003 -9.391+002 -1.184+003 -2.378+003     120
 121    -1.037+003 -9.901+002 -2.376+003 -2.376+003 -9.885+002 -2.376+003 -9.885+002 -2.376+003 -9.885+002 -2.376+003 -2.378+003     130
 131    -2.376+003 -9.885+002 -2.376+003 -9.885+002 -9.885+002 -9.885+002 -2.376+003 -9.885+002 -2.376+003 -9.885+002 -2.378+003     140
 141    -9.885+002 -9.885+002 -2.376+003 -9.885+002 -2.375+003 -8.382+002 -9.885+002 -7.946+002 -9.885+002 -8.092+002 -2.378+003     150
 151    -9.885+002 -2.375+003 -8.909+002 -9.885+002 -6.328+002 -8.442+002 -1.130+003 -6.012+002 -7.968+002 -1.134+003 -2.378+003     160
 161    -5.733+002 -7.360+002 -9.549+002 -6.061+002 -8.018+002 -1.160+003 -5.017+002 -1.263+003 -5.386+002 -6.392+002 -2.378+003     170
 171    -9.482+002 -5.868+002 -7.681+002 -1.025+003 -5.481+002 -6.729+002 -1.014+003 -5.276+002 -6.639+002 -8.584+002 -2.378+003     180
 181    -9.885+002 -9.885+002 -9.885+002 -9.885+002

             16 POTENTIAL ITERATIONS COMPLETED.
                RDOTR/RDRMAX=  1.34+002/  1.57+006
PCOND =   -9.8851+002  -7.9138+002
QCOND =    8.0033+007  -1.5910+004
  NEXTRA=      0

 EFPREP --     1 GRIDS OUT OF    1 READ IN.

IP = 14  IR = 12  IU = 13  ISPARE = 10  IPSAVE = 10

LAST CYCLE COMPLETED IS    6.

IP = 10  IR = 12  IU = 13  ISPARE = 14  IPSAVE = 10


******END

CEND NASCAP]

@ASG,A NASCAP*PLOTREAD.

@XQT NASCAP*PLOTREAD.
DEVICE OPTION =  3.
```


Figure 11.8. (Concluded).

By the end of the run we note that neither the change in conductor potential per timestep (~250 V) nor the average net charging current (~10^{-11} A) has changed substantially. Therefore, we decide to perform a third run to continue the simulation with the same parameters for an additional 5 cycles.

A potential contour plot for cycle 6 is shown in Figure 11.9. Note the appearance of a saddle point at the right of the figure.

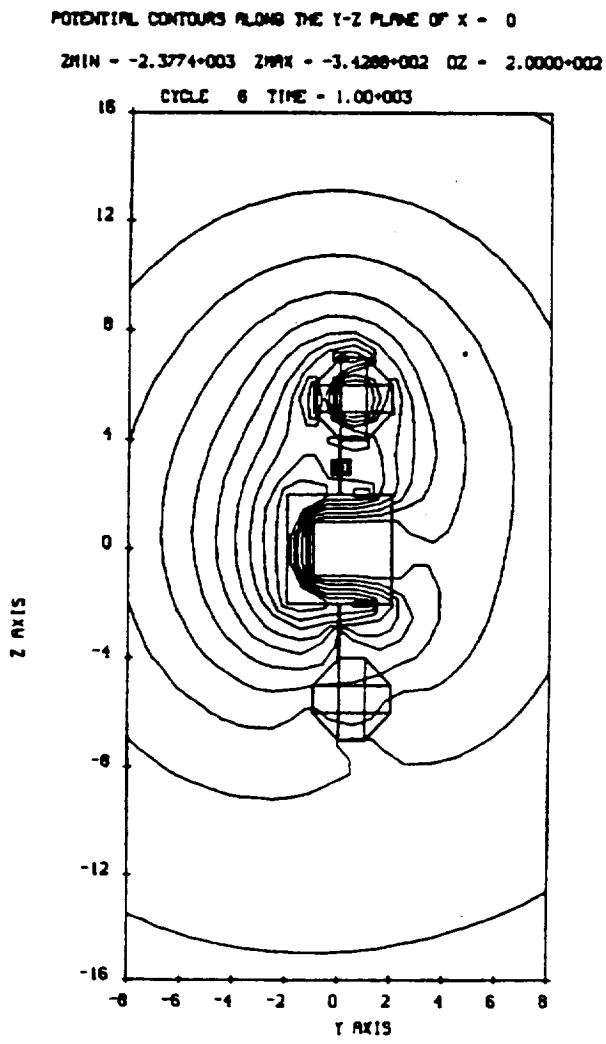


Figure 11.9. Potential contour plots (second run).

11.8 THE THIRD RUN

This run is carried out with the same parameters as the second run, extending the number of cycles out to 11. The printed output and contour plots for cycle 11 are shown in Figure 11.10. The conductor potential has reached -2.1 kV and the KAPTON -4.1 kV. the current breakdown for KAPTON shows that the net current is decreasing as equilibrium approaches. In the next run we increase the timestep and dvlim, to hasten the attainment of equilibrium.

```
        BEGIN CYCLE NO.   11          TIME =   1.805+003 SECONDS.

 QSUMER FOUND QSUM= -1.43+005 CODE UNITS.
        AFTER SCREENING CORRECTION (SCREENING LENGTH=  2.00+002 M.) QSUM= -1.43+005
                  QSCALE= -1.43+005          CORRECTED TO  -1.43+005
                  QSUM  = -1.4312+005
                  PCOND =  -1.980+003  -1.621+003
                  QCOND =   1.098+008  -2.753+004

-------------------------------------------------------------------------------

 EXPLICITLY CALCULATED FLUXES FOR CYCLE  11     TIME =  1.805+003 SECONDS.
 DURING THIS TIMESTEP, NASCAP WILL TAKE INTO ACCOUNT SUCH
 ADDITIONAL EFFECTS AS SURFACE CONDUCTIVITY, DISCHARGES, EMITTER OPERATION,
 AND VARIATION OF LIMITING FACTORS FOR LOW-ENERGY EMITTED ELECTRONS.

-------------------------------------------------------------------------------

 SURFACE CELL NO.   20                                        CODE =       004611216003
                                                              LOCATION =     6  9 17
                                                              NORMAL =      -1  0  0
                                                              MATERIAL =  KAPT
                          POTENTIAL = -3.883+003 VOLTS
                          STRESS =  1.499+007 VOLTS/METER
                          EXTERNAL FIELD = -4.412+004 VOLTS/METER
                          LIMITING FACTOR =   1.000+000
  FLUXES IN A/M**2
        INCIDENT ELECTRONS                          1.05-006
             RESULTING SECONDARIES                  4.49-007
             RESULTING BACKSCATTER                  2.76-007
        INCIDENT PROTONS                            6.29-008
             RESULTING SECONDARIES                  1.44-007
        BULK CONDUCTIVITY                           1.50-009
        PHOTOCURRENT                                  .00
                                                   ----------
      NET FLUX                                     -1.15-007

-------------------------------------------------------------------------------

 SURFACE CELL NO.   28                                        CODE =       004612210403
                                                              LOCATION =     6 10 17
                                                              NORMAL =       0  1  0
                                                              MATERIAL =  KAPT
                          POTENTIAL = -2.086+003 VOLTS
                          STRESS =  8.419+005 VOLTS/METER
                          EXTERNAL FIELD =  5.895+003 VOLTS/METER
                          LIMITING FACTOR =   2.512-026
  FLUXES IN A/M**2
        INCIDENT ELECTRONS                          1.50-006
             RESULTING SECONDARIES                  1.61-032      [  6.43-007]
             RESULTING BACKSCATTER                  3.96-007
        INCIDENT PROTONS                            4.65-008
             RESULTING SECONDARIES                  2.36-033      [  9.39-008]
        BULK CONDUCTIVITY                           8.42-011
        PHOTOCURRENT                                3.55-031      [  1.41-005]
                                                   ----------
      NET FLUX                                     -1.06-006

-------------------------------------------------------------------------------

 SURFACE CELL NO.   77                                        CODE =       005107211403
                                                              LOCATION =     9  7 17
                                                              NORMAL =       0 -1  0
                                                              MATERIAL =  KAPT
                          POTENTIAL = -3.883+003 VOLTS
                          STRESS =  1.499+007 VOLTS/METER
                          EXTERNAL FIELD = -3.512+004 VOLTS/METER
                          LIMITING FACTOR =   1.000+000
  FLUXES IN A/M**2
        INCIDENT ELECTRONS                          1.05-006
             RESULTING SECONDARIES                  4.49-007
             RESULTING BACKSCATTER                  2.76-007
```

Figure 11.10a. Trilin Output for cycle 11.

```
                                                        DIRECTION =   Z
                                                        MATERIAL  =  ALUM

                          POTENTIAL = -1.980+003 VOLTS
                          FIELD =  8.294+004 VOLTS/METER
                          LIMITING FACTOR =    .000

 FLUXES IN A/M**2
      INCIDENT ELECTRONS                              1.53-006
           RESULTING SECONDARIES                       .00          [  5.74-007]
           RESULTING BACKSCATTER                      5.73-007
      INCIDENT PROTONS                                4.55-008
           RESULTING SECONDARIES                       .00          [  5.00-008]
      PHOTOCURRENT                                      .00          [  1.27-005]
                                                     -----------
     NET FLUX                                        -9.16-007

        INITIAL NET CHARGING CURRENT (WITHOUT LIMITING) =  3.84-007 AMPERES.
        INITIAL NET CHARGING CURRENT (WITH    LIMITING) =  1.56-008 AMPERES.

  TOTAL CAPACITANCE TO INFINITY =    49.9 CODE UNITS;    8.83-012 FARADS.

    ICCG --- RDOTR/RDOTR1 =   2.29-022/  2.63+007

  LEAVING ICCG1 -- VCTRI =  -2.174+003 -1.783+003

    ICCG --- RDOTR/RDOTR1 =   2.29-022/  2.63+007

  LEAVING ICCG1 -- VCTRI =  -2.174+003 -1.783+003

    ICCG --- RDOTR/RDOTR1 =   1.10-022/  2.43+007

  LEAVING ICCG1 -- VCTRI =  -2.174+003 -1.780+003

   VFIX ---   59 OUT OF  164 NODES FIXED.
CONDUCTOR   1 FIXED TO -2164.04 VOLTS.

    ICCG --- RDOTR/RDOTR1 =   8.64-023/  2.27+007

  LEAVING ICCG1 -- VCTRI =  -2.164+003 -1.777+003

  NO DISCHARGE ANALYSIS

  NO DISCHARGE ANALYSIS

    ICCG --- RDOTR/RDOTR1 =   1.24-018/  3.35+008

  LEAVING ICCG2 -- VCTRI =  -2.164+003 -1.776+003

 AVERAGE FLUXES (ONLY AVAILABLE FOR INSULATING CELLS)

AVERAGE FLUX TO CELL    20 IS    -8.849-008 A/M**2
AVERAGE FLUX TO CELL    28 IS    -8.589-009 A/M**2
AVERAGE FLUX TO CELL    77 IS    -8.848-008 A/M**2
AVERAGE FLUX TO CELL    88 IS    -8.805-008 A/M**2
AVERAGE FLUX TO CELL   167 IS     3.968-008 A/M**2

NEW CONDUCTOR POTENTIALS

          VNEW                DQ                VOLD          CONDUCTOR
    -2.1640+003      4.3728+006     -1.9796+003                   1
    -1.7765+003      1.0534+000     -1.6207+003                   2

  TOTAL CHANGE IN CHARGE =    -1.069+004 CODE UNITS
                              -1.893-009 COULOMBS

  AVERAGE NET CHARGING CURRENT =    -9.465-012 AMPERES
                                    -5.345+001 CODE UNITS/SEC.

CONDUCTOR CURRENTS (AMPS; POSITIVE INTO CONDUCTORS):

                                    1           2

NET CURRENT(AVG DQ/DT):         3.87-009    9.33-016
```

Figure 11.10a. (Continued).

```
      INCIDENT PROTONS                          6.29-008
           RESULTING SECONDARIES                1.44-007
      BULK CONDUCTIVITY                         1.50-009
      PHOTOCURRENT                               .00
                                               ----------
     NET FLUX                                  -1.15-007
-------------------------------------------------------------------------------

  SURFACE CELL NO.   88                                  CODE =       005111270103
                                                         LOCATION =     9  9 23
                                                         NORMAL =       0  0  1
                                                         MATERIAL =   KAPT
                          POTENTIAL = -3.879+003 VOLTS
                          STRESS =  1.496+007 VOLTS/METER
                          EXTERNAL FIELD = -8.349+004 VOLTS/METER
                          LIMITING FACTOR =  1.000+000
   FLUXES IN A/M**2
      INCIDENT ELECTRONS                        1.05-006
           RESULTING SECONDARIES                8.49-007
           RESULTING BACKSCATTER                2.76-007
      INCIDENT PROTONS                          6.28-008
           RESULTING SECONDARIES                1.44-007
      BULK CONDUCTIVITY                         1.50-009
      PHOTOCURRENT                               .00
                                               ----------
     NET FLUX                                  -1.15-007
-------------------------------------------------------------------------------

  SURFACE CELL NO.  129                                  CODE =       005307212001
                                                         LOCATION =    11  7 17
                                                         NORMAL =       1  0  0
                                                         MATERIAL =   GOLD
                          POTENTIAL = -1.980+003 VOLTS
                          EXTERNAL FIELD =  9.100+003 VOLTS/METER
                          LIMITING FACTOR =   .000
   FLUXES IN A/M**2
      INCIDENT ELECTRONS                        1.53-006
           RESULTING SECONDARIES                 .00          [  9.85-007]
           RESULTING BACKSCATTER                9.94-007
      INCIDENT PROTONS                          4.55-008
           RESULTING SECONDARIES                 .00          [  8.26-008]
      PHOTOCURRENT                               .00          [  2.05-005]
                                               ----------
     NET FLUX                                  -4.95-007
-------------------------------------------------------------------------------

  SURFACE CELL NO.  167                                  CODE =       011111120302
                                                         LOCATION =     9  9 10
                                                         NORMAL =       0  0 -1
                                                         MATERIAL =   SOLA
                          POTENTIAL = -1.097+003 VOLTS
                          STRESS = -2.927+006 VOLTS/METER
                          EXTERNAL FIELD =  3.360+003 VOLTS/METER
                          LIMITING FACTOR =  2.557-015
   FLUXES IN A/M**2
      INCIDENT ELECTRONS                        1.83-006
           RESULTING SECONDARIES                3.76-021     [  1.47-006]
           RESULTING BACKSCATTER                6.24-007
      INCIDENT PROTONS                          3.75-008
           RESULTING SECONDARIES                9.84-023     [  3.85-008]
      BULK CONDUCTIVITY                        -2.93-011
      PHOTOCURRENT                               .00          [   .00     ]
                                               ----------
     NET FLUX                                  -1.17-006
-------------------------------------------------------------------------------

  BOOM SURFACE CELL NO.  181                             CODE =       000061111123
                                                         LOCATION =     9  9 19    [ 11
```

Figure 11.10a. (Continued).

```
CONDUCTIVITY CURRENT (NEW)
 (FROM INSULATING CELLS):      -7.16-011     6.70-016

PLASMA CURRENT (INITIAL)
 (TO BARE CELLS):              -3.63-009      .00

REMAINDER CURRENT:              7.57-009     2.63-016
```

```
          CONTINUE CYCLE NO.   11 AT UPDATED TIME =   2.005+003 SECONDS.
                   QSUM = -1.5381+005

SURFACE POTENTIALS - ALL  184 CELLS
CELL NO.
   1   -4.139+003 -4.139+003 -4.139+003 -4.139+003 -4.139+003 -4.139+003 -4.139+003 -4.139+003 -4.139+003 -4.139+003                CELL NO.
  11   -4.140+003 -4.139+003 -4.140+003 -4.140+003 -4.140+003 -4.139+003 -4.140+003 -4.139+003 -4.140+003 -4.140+003    10
  21   -4.140+003 -4.139+003 -4.137+003 -2.247+003 -4.137+003 -2.252+003 -4.138+003 -2.278+003 -4.138+003 -4.138+003    20
  31   -2.341+003 -4.137+003 -4.140+003 -4.140+003 -4.140+003 -4.140+003 -4.140+003 -4.140+003 -4.140+003 -4.140+003    30
  41   -4.140+003 -4.140+003 -4.138+003 -2.208+003 -2.160+003 -2.189+003 -4.138+003 -2.314+003 -4.140+003 -4.140+003    40
  51   -4.140+003 -4.140+003 -4.140+003 -4.140+003 -4.140+003 -4.140+003 -4.140+003 -4.139+003 -4.139+003 -4.140+003    50
  61   -4.140+003 -4.140+003 -4.139+003 -4.139+003 -4.138+003 -2.137+003 -2.060+003 -2.091+003 -4.138+003 -2.249+003    60
  71   -4.138+003 -4.138+003 -4.137+003 -4.140+003 -4.140+003 -4.140+003 -4.140+003 -4.140+003 -4.140+003 -4.140+003    70
  81   -4.140+003 -4.140+003 -4.139+003 -4.139+003 -4.140+003 -4.140+003 -4.138+003 -4.135+003 -4.138+003 -2.085+003    80
  91   -2.001+003 -2.031+003 -4.138+003 -2.195+003 -2.806+003 -2.175+003 -2.354+003 -4.140+003 -4.140+003 -4.140+003    90
 101   -4.140+003 -4.140+003 -4.140+003 -4.140+003 -4.140+003 -4.138+003 -4.138+003 -4.137+003 -4.140+003 -4.140+003   100
 111   -2.890+003 -2.220+003 -2.361+003 -4.138+003 -2.021+003 -1.945+003 -1.972+003 -4.138+003 -2.119+003 -2.451+003   110
 121   -2.128+003 -2.020+003 -4.136+003 -4.136+003 -2.164+003 -4.136+003 -2.164+003 -4.136+003 -2.164+003 -4.136+003   120
 131   -4.136+003 -2.164+003 -4.136+003 -2.164+003 -2.164+003 -2.164+003 -4.136+003 -2.164+003 -4.136+003 -2.164+003   130
 141   -2.164+003 -2.164+003 -4.136+003 -2.164+003 -4.134+003 -1.924+003 -2.164+003 -1.876+003 -2.164+003 -1.900+003   140
 151   -2.164+003 -4.134+003 -2.009+003 -2.164+003 -1.459+003 -1.860+003 -2.400+003 -1.393+003 -1.777+003 -2.413+003   150
 161   -1.362+003 -1.666+003 -2.111+003 -1.397+003 -1.780+003 -2.451+003 -1.210+003 -2.739+003 -1.299+003 -1.511+003   160
 171   -2.104+003 -1.384+003 -1.721+003 -2.225+003 -1.314+003 -1.569+003 -2.210+003 -1.286+003 -1.541+003 -1.950+003   170
 181   -2.164+003 -2.164+003 -2.164+003 -2.164+003                                                                   180

            16 POTENTIAL ITERATIONS COMPLETED.
               RDOTR/RDRMAX=  2.10+001/  2.82+005
PCOND =    -2.1640+003  -1.7765+003
QCOND =     1.1409+008  -2.9614+004
  NEXTRA=       0

 EFPREP --     1 GRIDS OUT OF    1 READ IN.

IP = 14  IR = 12  IU = 13  ISPARE = 10  IPSAVE = 10

LAST CYCLE COMPLETED IS  11.

IP = 10  IR = 12  IU = 13  ISPARE = 14  IPSAVE = 10
```

Figure 11.10a. (Concluded).

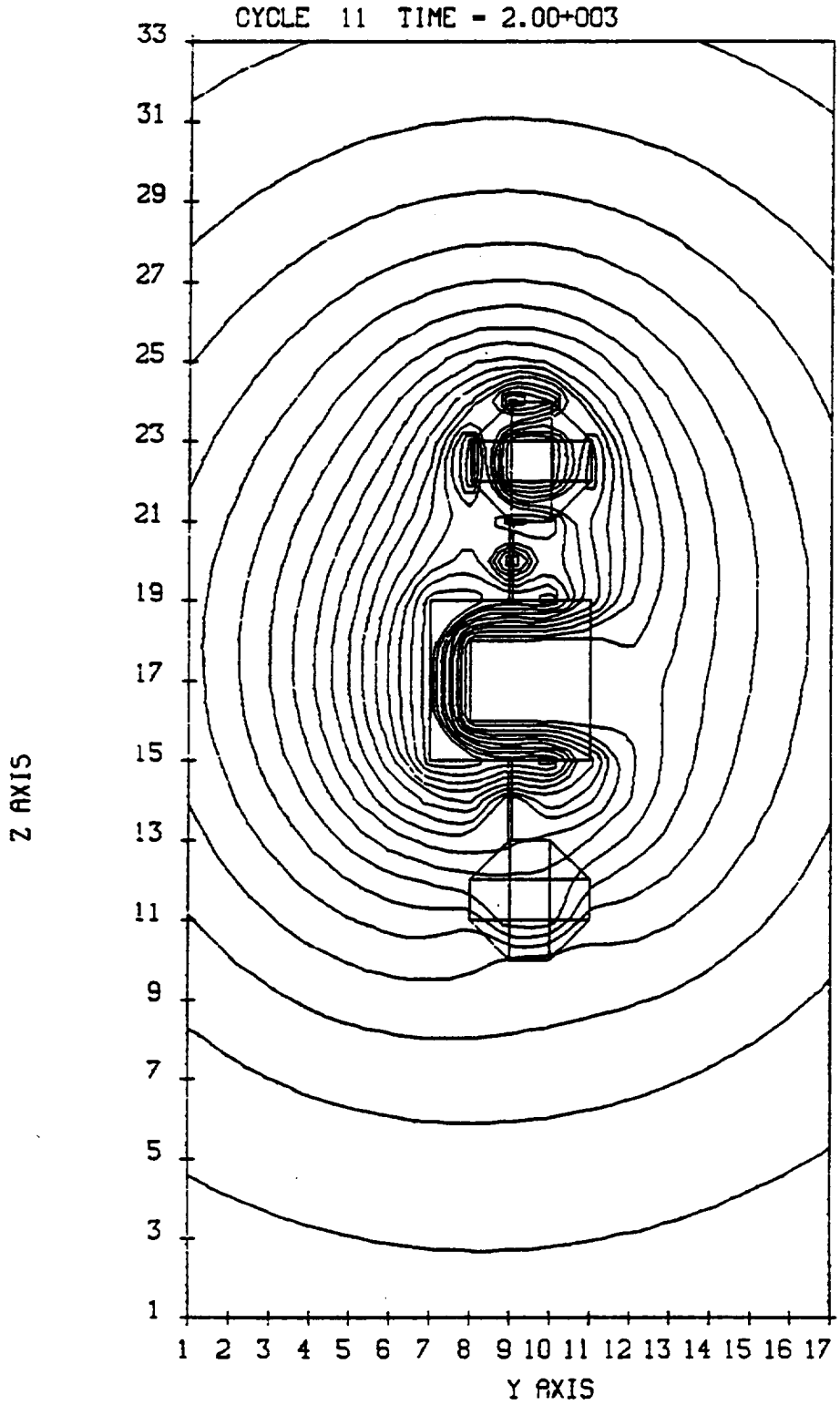


Figure 11.10b. Potential contours for cycle 11.

11.9 EQUILIBRIUM

Two more runs are carried out, adding a further 10 cycles. In each run DELTA is increased to 500s and dvlim to 1000.

```
DELTA 500s
LONGTIMESTEP 1000
```

The printed output and contour plot for the final cycle is shown in Figure 11.11 and Figure 11.12.

The potentials remains steady for cycles 18-21, showing the equilibrium has been achieved. The final equilibrium potentials are as follows:

Type of cell	Potential (kv)
Shaded KAPTON	- 5.1
Sunlit KAPTON	$\sim$ -3
GOLD	$\sim$ -3
SOLAR sphere	$\sim$ -2 $\rightarrow$ -3

From these results we draw the following conclusions:

1. The spacecraft will charge considerably in the given environment, but only on a differential charging (long) timescale. Charging is driven by the shaded KAPTON, whose electric field suppresses emission from the other, initially non-charging, surfaces.

2. Differential potentials in the 2 $\rightarrow$ 3 kV range are likely.

```
        BEGIN CYCLE NO.   21          TIME =   6.505+003 SECONDS.

 QSUMER FOUND QSUM= -1.96+005 CODE UNITS.
        AFTER SCREENING CORRECTION (SCREENING LENGTH=  2.00+002 M.) QSUM= -1.96+005
                  QSCALE= -1.96+005          CORRECTED TO  -1.96+005
                  QSUM = -1.9585+005
                  PCOND = -2.930+003  -2.432+003
                  QCOND =  1.261+008  -3.745+004
-------------------------------------------------------------------------------

 EXPLICITLY CALCULATED FLUXES FOR CYCLE  21     TIME =  6.505+003 SECONDS.
 DURING THIS TIMESTEP, NASCAP WILL TAKE INTO ACCOUNT SUCH
 ADDITIONAL EFFECTS AS SURFACE CONDUCTIVITY, DISCHARGES, EMITTER OPERATION,
 AND VARIATION OF LIMITING FACTORS FOR LOW-ENERGY EMITTED ELECTRONS.

-------------------------------------------------------------------------------

 SURFACE CELL NO.   20                                    CODE =       004611216003
                                                          LOCATION =     6  9 17
                                                          NORMAL =      -1  0  0
                                                          MATERIAL =  KAPT
                        POTENTIAL = -5.113+003 VOLTS
                        STRESS =  1.719+007 VOLTS/METER
                        EXTERNAL FIELD = -5.619+004 VOLTS/METER
                        LIMITING FACTOR =   1.000+000
  FLUXES IN A/M**2
       INCIDENT ELECTRONS                    8.20-007
            RESULTING SECONDARIES            3.51-007
            RESULTING BACKSCATTER            2.16-007
       INCIDENT PROTONS                      7.41-008
            RESULTING SECONDARIES            1.83-007
       BULK CONDUCTIVITY                     1.72-009
       PHOTOCURRENT                           .00
                                            ----------
     NET FLUX                                6.07-009
-------------------------------------------------------------------------------

 SURFACE CELL NO.   28                                    CODE =       004612210403
                                                          LOCATION =     6 10 17
                                                          NORMAL =       0  1  0
                                                          MATERIAL =  KAPT
                        POTENTIAL = -3.071+003 VOLTS
                        STRESS =  1.114+006 VOLTS/METER
                        EXTERNAL FIELD =  2.344+002 VOLTS/METER
                        LIMITING FACTOR =   9.598-002
  FLUXES IN A/M**2
       INCIDENT ELECTRONS                    1.23-006
            RESULTING SECONDARIES            5.07-008      [  5.28-007]
            RESULTING BACKSCATTER            3.25-007
       INCIDENT PROTONS                      5.55-008
            RESULTING SECONDARIES            1.16-008      [  1.21-007]
       BULK CONDUCTIVITY                     1.11-010
       PHOTOCURRENT                          1.36-006      [  1.41-005]
                                            ----------
     NET FLUX                                5.67-007
-------------------------------------------------------------------------------

 SURFACE CELL NO.   77                                    CODE =       005107211403
                                                          LOCATION =     9  7 17
                                                          NORMAL =       0 -1  0
                                                          MATERIAL =  KAPT
                        POTENTIAL = -5.113+003 VOLTS
                        STRESS =  1.719+007 VOLTS/METER
                        EXTERNAL FIELD = -4.516+004 VOLTS/METER
                        LIMITING FACTOR =   1.000+000
  FLUXES IN A/M**2
       INCIDENT ELECTRONS                    8.20-007
            RESULTING SECONDARIES            3.51-007
            RESULTING BACKSCATTER            2.16-007
```

Figure 11.11. Trilin output for cycle 21.

```
        INCIDENT PROTONS                          7.41-008
             RESULTING SECONDARIES                1.83-007
        BULK CONDUCTIVITY                         1.72-009
        PHOTOCURRENT                               .00
                                                 ----------
      NET FLUX                                    6.08-009
-------------------------------------------------------------------------------

  SURFACE CELL NO.   88                                    CODE =       005111270103
                                                           LOCATION =     9  9 23
                                                           NORMAL =       0  0  1
                                                           MATERIAL =   KAPT
                          POTENTIAL = -5.104+003 VOLTS
                          STRESS =  1.712+007 VOLTS/METER
                          EXTERNAL FIELD = -1.064+005 VOLTS/METER
                          LIMITING FACTOR =   1.000+000
   FLUXES IN A/M**2
        INCIDENT ELECTRONS                        8.21-007
             RESULTING SECONDARIES                3.52-007
             RESULTING BACKSCATTER                2.16-007
        INCIDENT PROTONS                          7.40-008
             RESULTING SECONDARIES                1.83-007
        BULK CONDUCTIVITY                         1.71-009
        PHOTOCURRENT                               .00
                                                 ----------
      NET FLUX                                    5.17-009
-------------------------------------------------------------------------------

  SURFACE CELL NO.  129                                    CODE =       005307212001
                                                           LOCATION =    11  7 17
                                                           NORMAL =       1  0  0
                                                           MATERIAL =   GOLD
                          POTENTIAL = -2.930+003 VOLTS
                          EXTERNAL FIELD =  3.835+003 VOLTS/METER
                          LIMITING FACTOR =   2.219-017
   FLUXES IN A/M**2
        INCIDENT ELECTRONS                        1.27-006
             RESULTING SECONDARIES                1.81-023      [  8.14-007]
             RESULTING BACKSCATTER                8.22-007
        INCIDENT PROTONS                          5.42-008
             RESULTING SECONDARIES                2.34-024      [  1.06-007]
        PHOTOCURRENT                              4.55-022      [  2.05-005]
                                                 ----------
      NET FLUX                                   -3.93-007
-------------------------------------------------------------------------------

  SURFACE CELL NO.  167                                    CODE =       011111120302
                                                           LOCATION =     9  9 10
                                                           NORMAL =       0  0 -1
                                                           MATERIAL =   SOLA
                          POTENTIAL = -1.700+003 VOLTS
                          STRESS = -4.087+006 VOLTS/METER
                          EXTERNAL FIELD =  5.624+001 VOLTS/METER
                          LIMITING FACTOR =   5.698-001
   FLUXES IN A/M**2
        INCIDENT ELECTRONS                        1.62-006
             RESULTING SECONDARIES                7.42-007      [  1.30-006]
             RESULTING BACKSCATTER                5.53-007
        INCIDENT PROTONS                          4.30-008
             RESULTING SECONDARIES                2.63-008      [  4.62-008]
        BULK CONDUCTIVITY                        -4.09-011
        PHOTOCURRENT                               .00          [   .00     ]
                                                 ----------
      NET FLUX                                   -2.58-007
-------------------------------------------------------------------------------

  BOOM SURFACE CELL NO.  181                               CODE =       000061111123
                                                           LOCATION =     9  9 19   ( 1)
```

Figure 11.11. (Continued).

```
                                                    DIRECTION =    Z
                                                    MATERIAL  =  ALUM

                          POTENTIAL = -2.930+003 VOLTS
                          FIELD =  9.436+004 VOLTS/METER
                          LIMITING FACTOR =     .000

 FLUXES IN A/M**2
      INCIDENT ELECTRONS                          1.27-006
           RESULTING SECONDARIES                   .00          [  4.74-007]
           RESULTING BACKSCATTER                  4.74-007
      INCIDENT PROTONS                            5.42-008
           RESULTING SECONDARIES                   .00          [  6.39-008]
      PHOTOCURRENT                                 .00          [  1.27-005]
                                                 ----------
    NET FLUX                                     -7.41-007

       INITIAL NET CHARGING CURRENT (WITHOUT LIMITING) =  3.91-007 AMPERES.
       INITIAL NET CHARGING CURRENT (WITH    LIMITING) =  8.94-008 AMPERES.

 TOTAL CAPACITANCE TO INFINITY =    49.9 CODE UNITS;    8.83-012 FARADS.

   ICCG --- RDOTR/RDOTR1 =   1.35-024/  3.57+006

 LEAVING ICCG1 -- VCTR1 =  -2.942+003 -2.257+003

   ICCG --- RDOTR/RDOTR1 =   1.15-025/  4.06+002

 LEAVING ICCG1 -- VCTR1 =  -2.942+003 -2.435+003

   ICCG --- RDOTR/RDOTR1 =   1.18-025/  3.17+002

 LEAVING ICCG1 -- VCTR1 =  -2.942+003 -2.435+003

  VFIX ---    59 OUT OF  164 NODES FIXED.
CONDUCTOR   1 FIXED TO -2928.48 VOLTS.

   ICCG --- RDOTR/RDOTR1 =   1.49-022/  2.24+004

 LEAVING ICCG1 -- VCTR1 =  -2.928+003 -2.431+003

 NO DISCHARGE ANALYSIS

 NO DISCHARGE ANALYSIS

   ICCG --- RDOTR/RDOTR1 =   5.48-020/  9.18+006

 LEAVING ICCG2 -- VCTR1 =  -2.928+003 -2.431+003

 AVERAGE FLUXES (ONLY AVAILABLE FOR INSULATING CELLS)

AVERAGE FLUX TO CELL   20 IS    6.039-009 A/M**2
AVERAGE FLUX TO CELL   28 IS   -1.092-011 A/M**2
AVERAGE FLUX TO CELL   77 IS    6.043-009 A/M**2
AVERAGE FLUX TO CELL   88 IS    6.150-009 A/M**2
AVERAGE FLUX TO CELL  167 IS   -4.000-010 A/M**2

NEW CONDUCTOR POTENTIALS

        VNEW                 DQ              VOLD          CONDUCTOR
   -2.9285+003     -7.2313+005     -2.9298+003                  1
   -2.4314+003      2.1257+000     -2.4315+003                  2

  TOTAL CHANGE IN CHARGE =     3.648+002 CODE UNITS
                               6.461-011 COULOMBS

  AVERAGE NET CHARGING CURRENT =     1.292-013 AMPERES
                                     7.297-001 CODE UNITS/SEC.

CONDUCTOR CURRENTS (AMPS; POSITIVE INTO CONDUCTORS):

                                    1           2

NET CURRENT(AVG DQ/DT):        -2.56-010    7.53-016
```

Figure 11.11. (Continued).

```
:ONDUCTIVITY CURRENT (NEW)
 (FROM INSULATING CELLS):     -7.87-011     8.58-016

'LASMA CURRENT (INITIAL)
 (TO BARE CELLS):              1.06-009      .00

(EMAINDER CURRENT:            -1.23-009    -1.05-016
```

```
          CONTINUE CYCLE NO.    21 AT UPDATED TIME =   7.005+003 SECONDS.
                   QSUM = -1.9549+005

;URFACE POTENTIALS - ALL  184 CELLS
:ELL NO.
   1   -5.099+003 -5.099+003 -5.099+003 -5.099+003 -5.099+003 -5.099+003 -5.099+003 -5.099+003 -5.099+003 -5.099+003 -5.099+003   CELL NO.
  11   -5.099+003 -5.099+003 -5.100+003 -5.100+003 -5.099+003 -5.099+003 -5.099+003 -5.099+003 -5.100+003 -5.100+003 -5.099+003     10
  21   -5.099+003 -5.099+003 -5.099+003 -5.099+003 -5.099+003 -5.099+003 -5.099+003 -5.095+003 -5.095+003 -5.095+003 -5.100+003     20
  31   -3.127+003 -5.095+003 -5.100+003 -5.099+003 -5.100+003 -5.100+003 -5.100+003 -3.070+003 -5.095+003 -5.100+003 -5.100+003     30
  41   -5.100+003 -5.100+003 -5.095+003 -3.001+003 -2.966+003 -3.000+003 -5.095+003 -3.125+003 -5.100+003 -5.100+003 -5.100+003     40
  51   -5.100+003 -5.100+003 -5.100+003 -5.099+003 -5.099+003 -5.094+003 -3.032+003 -2.863+003 -2.899+003 -5.095+003 -3.064+003     50
  61   -5.100+003 -5.099+003 -5.100+003 -5.100+003 -5.100+003 -5.100+003 -5.100+003 -5.100+003 -5.100+003 -5.100+003 -5.100+003     60
  71   -5.095+003 -5.096+003 -5.094+003 -5.100+003 -5.100+003 -5.100+003 -5.100+003 -5.093+003 -5.090+003 -5.100+003 -5.100+003     70
  81   -5.100+003 -5.099+003 -5.099+003 -5.099+003 -5.100+003 -5.100+003 -5.100+003 -5.100+003 -5.094+003 -2.874+003     80
  91   -2.796+003 -2.831+003 -5.095+003 -3.002+003 -3.655+003 -2.898+003 -3.039+003 -5.100+003 -5.099+003 -5.100+003     90
 101   -5.100+003 -5.100+003 -5.099+003 -5.100+003 -5.100+003 -5.096+003 -5.096+003 -5.094+003 -5.100+003 -5.100+003    100
 111   -3.755+003 -2.951+003 -3.048+003 -5.094+003 -2.790+003 -2.721+003 -2.753+003 -5.094+003 -2.905+003 -3.266+003    110
 121   -2.855+003 -2.704+003 -5.089+003 -5.089+003 -2.928+003 -5.089+003 -2.928+003 -5.089+003 -2.928+003 -5.089+003    120
 131   -5.089+003 -2.928+003 -5.089+003 -2.928+003 -2.928+003 -2.928+003 -5.089+003 -2.928+003 -5.089+003 -2.928+003    130
 141   -2.928+003 -2.928+003 -5.089+003 -2.928+003 -5.083+003 -2.653+003 -2.928+003 -2.614+003 -2.928+003 -2.642+003    140
 151   -2.928+003 -5.084+003 -2.753+003 -2.928+003 -2.020+003 -2.519+003 -3.211+003 -1.936+003 -2.826+003 -3.231+003    150
 161   -1.903+003 -2.297+003 -2.873+003 -1.942+003 -2.427+003 -3.271+003 -1.701+003 -3.698+003 -1.815+003 -2.107+003    160
 171   -2.862+003 -1.928+003 -2.357+003 -3.005+003 -1.834+003 -2.176+003 -2.988+003 -1.813+003 -2.148+003 -2.679+003    170
 181   -2.928+003 -2.928+003 -2.928+003 -2.928+003                                                                    180

            16 POTENTIAL ITERATIONS COMPLETED.
               RDOTR/RDRMAX=   3.75-001/  3.91+003
'COND =    -2.9285+003   -2.4314+003
ICOND =     1.2544+008   -3.7362+004
  NEXTRA=        0

 EFPREP --     1 GRIDS OUT OF    1 READ IN.

:P = 14  IR = 12  IU = 13  ISPARE = 10  IPSAVE = 10

.AST CYCLE COMPLETED IS  21.

:P = 10  IR = 12  IU = 13  ISPARE = 14  IPSAVE = 10
```

Figure 11.11. (Concluded).

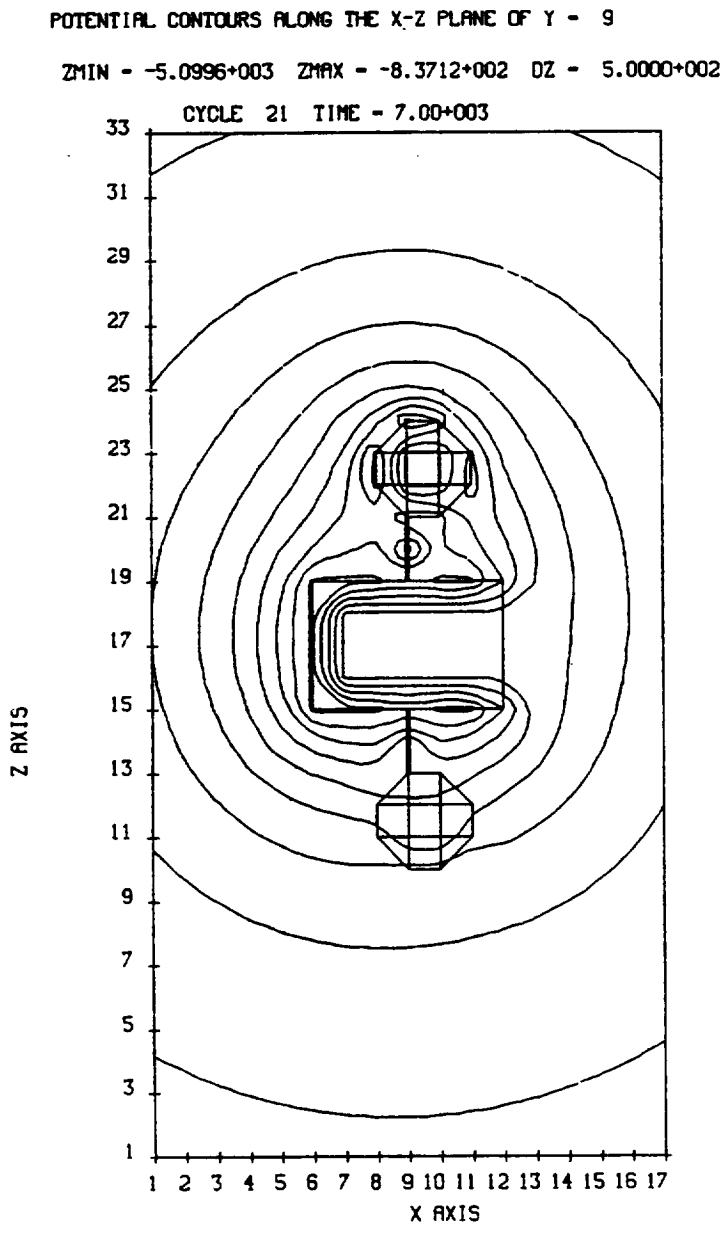


Figure 11.12. Potential contours for cycle 21.

11.10 THE DETECTOR

The question that remains to be answered is, how does this charging affect the operation of an on-board particle detector? Suppose an ion detector is mounted on the shaded side of the SOLAR sphere, looking towards the KAPTON sphere. Will the electric field of the negatively charged KAPTON deflect incoming ions, and affect the sampling of the detector? We can simulate the operation of a detector with a new run using the DETECT module.

11.11 THE DETECT RUN

We choose the spare file number 23 for the detector input file. This is shown in Figure 11.13.

Cell 170 is chosen as the site for the detector, which looks out in the positive y direction. ø is set to zero. The energy range chosen is 1 - 10,000 eV and the angle theta is scanned over the ZY plane from -88° to + 88°. The cone collecting particles is defined to have a half-angle of 1°. If theta were scanned from -90° to 90° some of the particles would have been emitted towards the object (with an angle 91°!) This causes an execution error.

The energy range is sampled with 12 particles. The cone is so narrow that only one angle sample is used (the default).

```
 1:DETECT
 2:ICELL 170
 3:ENERGY 1
 4:DEK 1000000
 5:THETA -88
 6:DTH 1
 7:PHI 0
 8:NE 12
 9:AUTOS
10:INDVAR=THETA
11:FINALV 88
12:N 40
13:PLPART
14:NGBND 1
15:LIMGRD 2
16:END
EOF:16
0:>
```

Figure 11.13. DETECT input file (MANUAL23).

The NASCAP runstream executing the run is shown in Figure 11.14. The energy flux density plot is chosen to be plotted against theta. The plot is shown in Figure 11.15. A dropout in proton flux occurs at angles of less than about -70°. Inspection of the YZ plane particle trajectories (Figure 11.16) show that this is due to the charged KAPTON sphere capturing the protons coming from this direction. The flux dropout corresponds to particles originating on the KAPTON sphere (which do not, in reality, originate at all).

The electron flux is apparently unaffected. The trajectory plots show however that particles that are apparently arriving at grazing angles < -70°, originally approached at much more normal angles. The detector therefore sees a distorted angular distribution. To be sure of this interpretation, we must compare results with these for an uncharged spacecraft.

```
          1:@RUN,M/R PRS,11182-00,STANNARD-P,45,500  .  NASCAP RUN STREAM
          2:@HDG,N .B,B .M,88,8,8
          3:@BIG-NAME,N
          4:MANUAL
          5:BOX 19
          6:@ASG,T TPF8.,F///1000
          7:@ASG,T 2.
          8:@ASG,T 10.
          9:@ASG,T 11.
         10:@ASG,T 12.
         11:@ASG,T 13.
         12:@ASG,T 14.
         13:@ASG,T 15.
         14:@ASG,T 16.
         15:@ASG,T 17.
         16:@ASG,T 20.
         17:@ASG,T 21.
         18:@ASG,T 22.
         19:@ASG,T 23.
         20:@ASG,T 25.
         21:@ASG,T 26.
         22:@ASG,T 27.
         23:@COPY MANUALOBJ.,20.
         24:@COPY MANUALFLX.,22.
         25:@COPY MANUALOPT.,26.
         26:@COPY MANUAL10.,10.
         27:@COPY MANUAL15.,15.
         28:@COPY MANUAL16.,16.
         29:@COPY MANUAL17.,17.
         30:@COPY MANUAL21.,21.
         31:@COPY MANUAL23.,23.
         32:@COPY MANUAL27.,27.
         33:@ASG,A NASCAP%NPROG.
         34:@COPY,A NASCAP%NPROG.NASCAP
         35:@FREE NASCAP%NPROG.
         36:@XQT
         37:RDOPT
         38:DETECT 23
         39:END
         40:@PMD,EL
         41:@COPY 10.,MANUAL10.
         42:@COPY 15.,MANUAL15.
         43:@COPY 16.,MANUAL16.
         44:@COPY 17.,MANUAL17.
         45:@COPY 21.,MANUAL21.
         46:@COPY 27.,MANUAL27.
         47:@BIG-NAME,N
         48:END
         49:BOX 19
         50:@FIN
EOF:50
0:)
```

Figure 11.14. DETECT runstream.

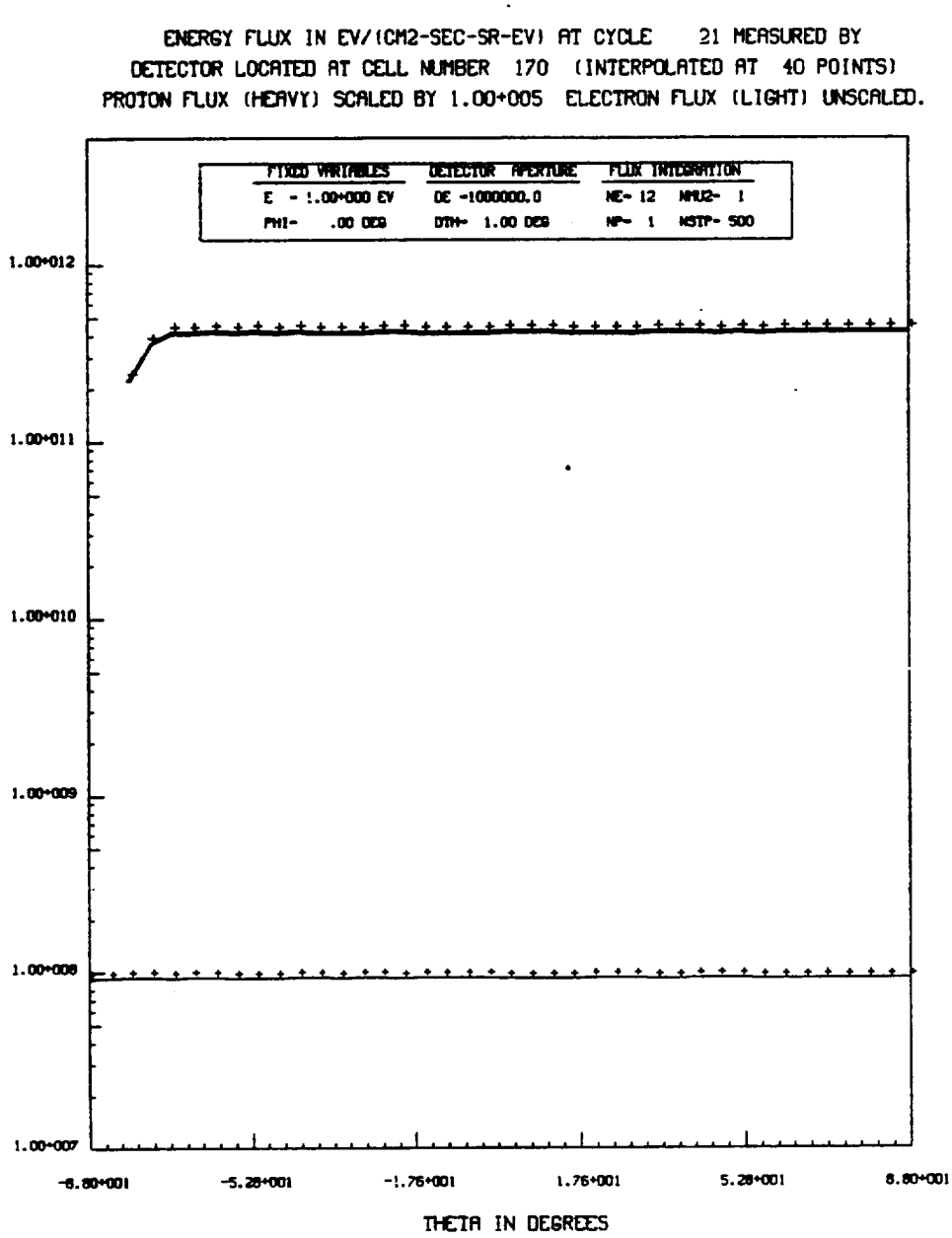


Figure 11.15. Detector plot for charged spacecraft.

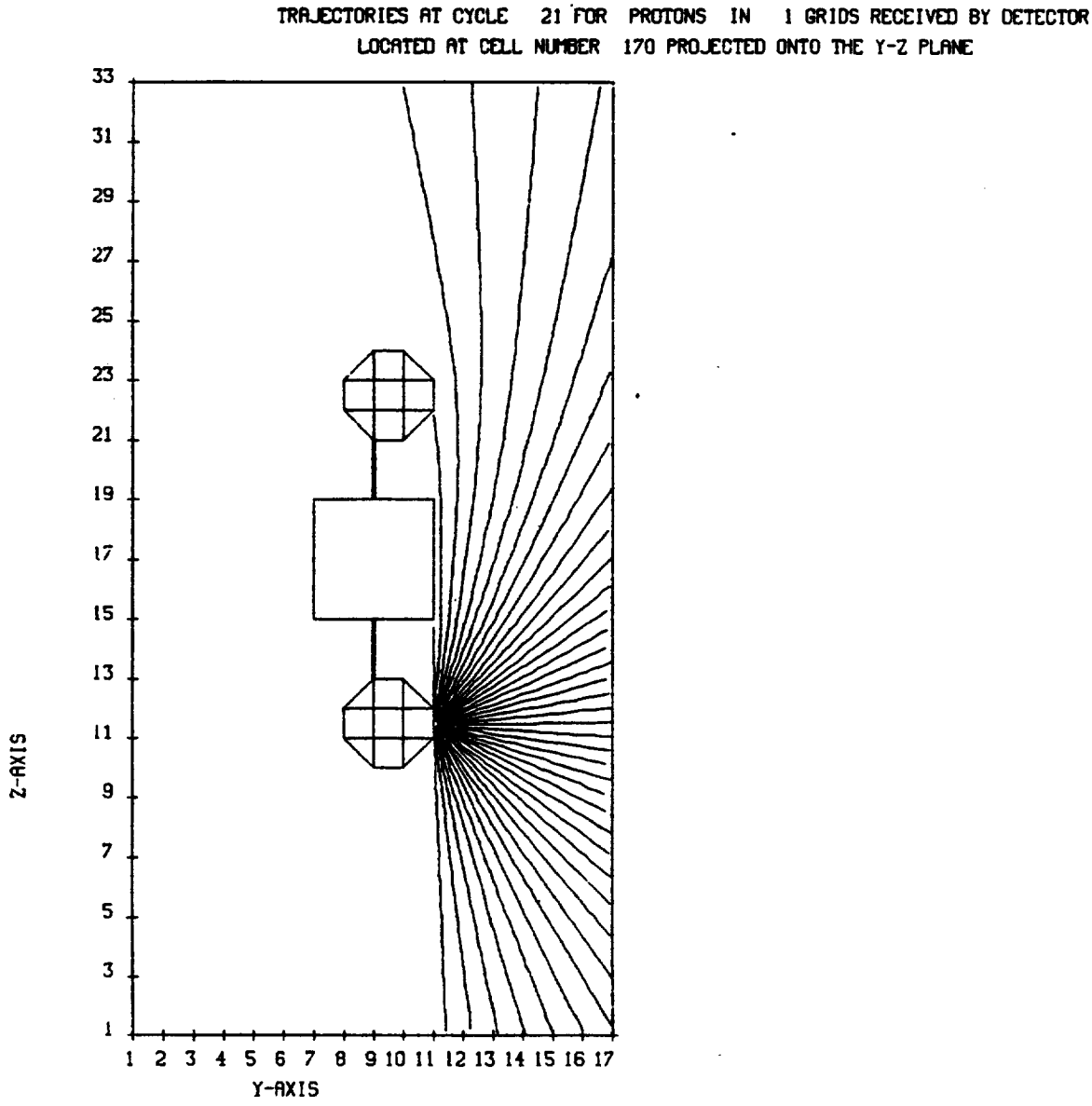


Figure 11.16a. Trajectory plots for charged spacecraft.

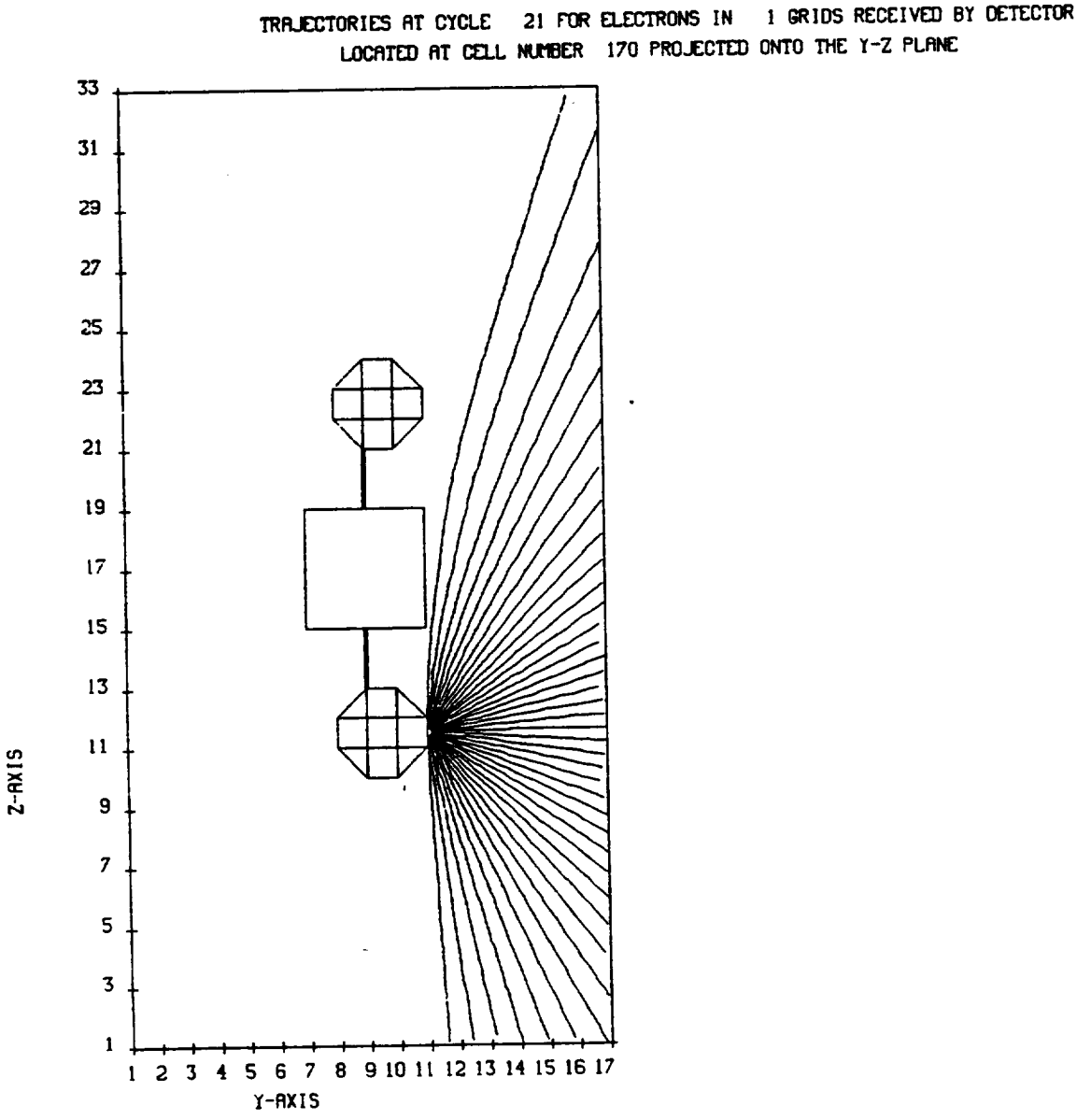


Figure 11.16b. Trajectory plots for charged spacecraft.

11.12 A DETECTOR ON AN UNCHARGED SPACECRAFT

We can zero the potential on the object using the IPS module. If no parameter cards are included as input this module sets all potentials in accordance with the run options.

The results are shown in Figures 11.17 and 11.18. The trajectory plots show no deflection, and there is no proton flux dropout. The actual magnitudes of the electron and proton energy fluxes are smaller and greater respectively for the charged object compared with the neutral object. This is a reflection of their deceleration and acceleration respectively by the satellite electric field.

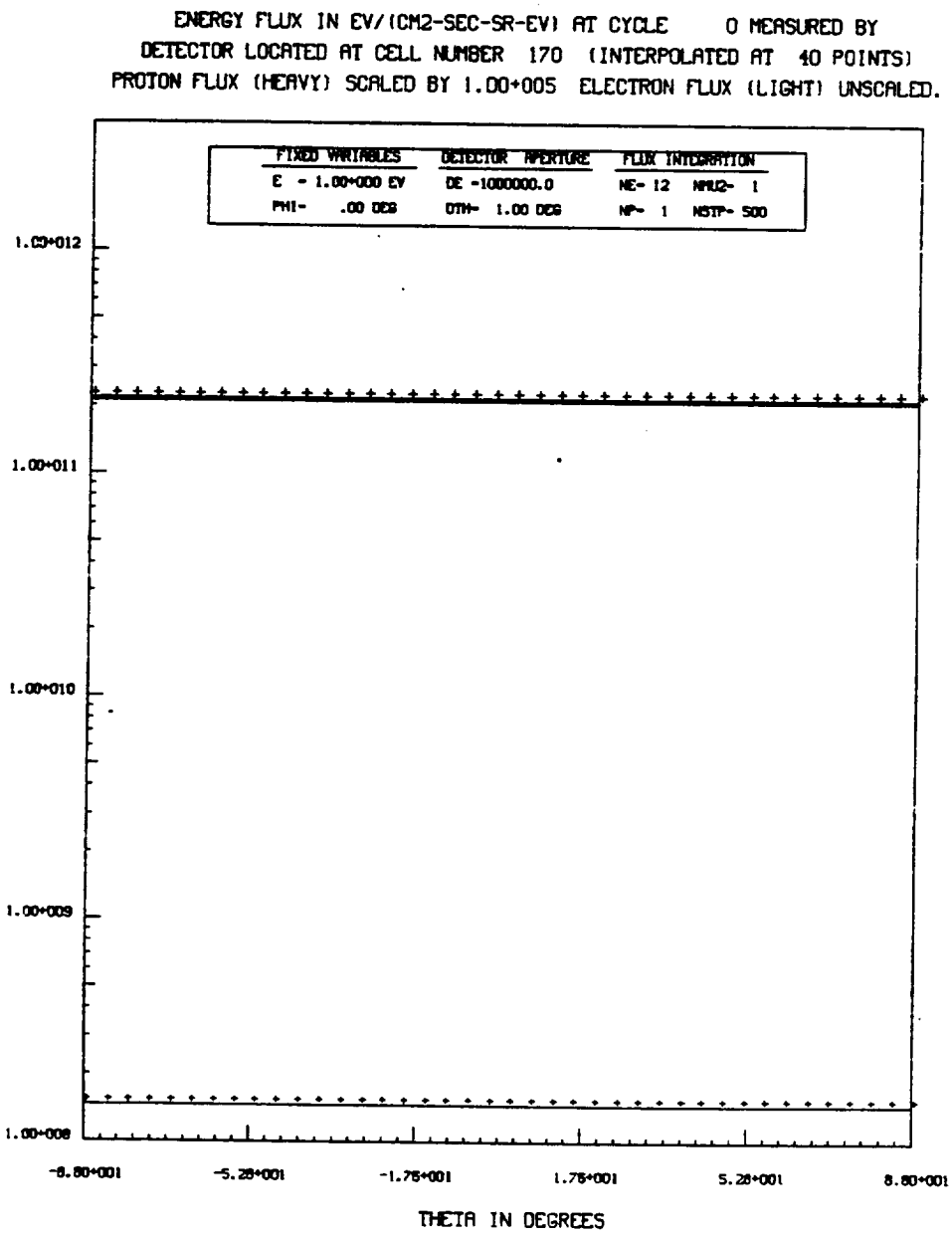


Figure 11.17. Trajectory plots for uncharged spacecraft.

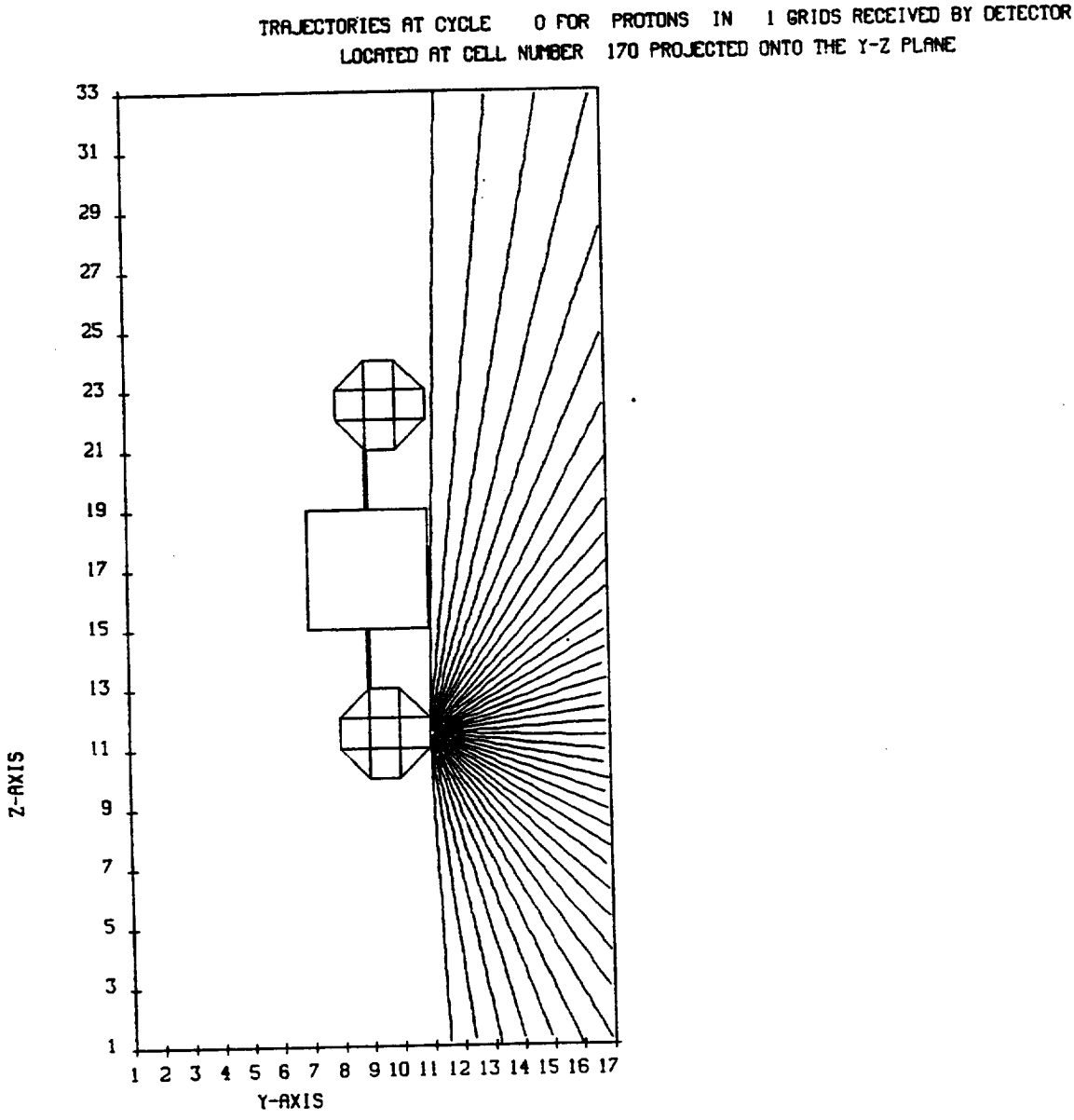


Figure 11.18a. Trajectory plots for uncharged spacecraft.

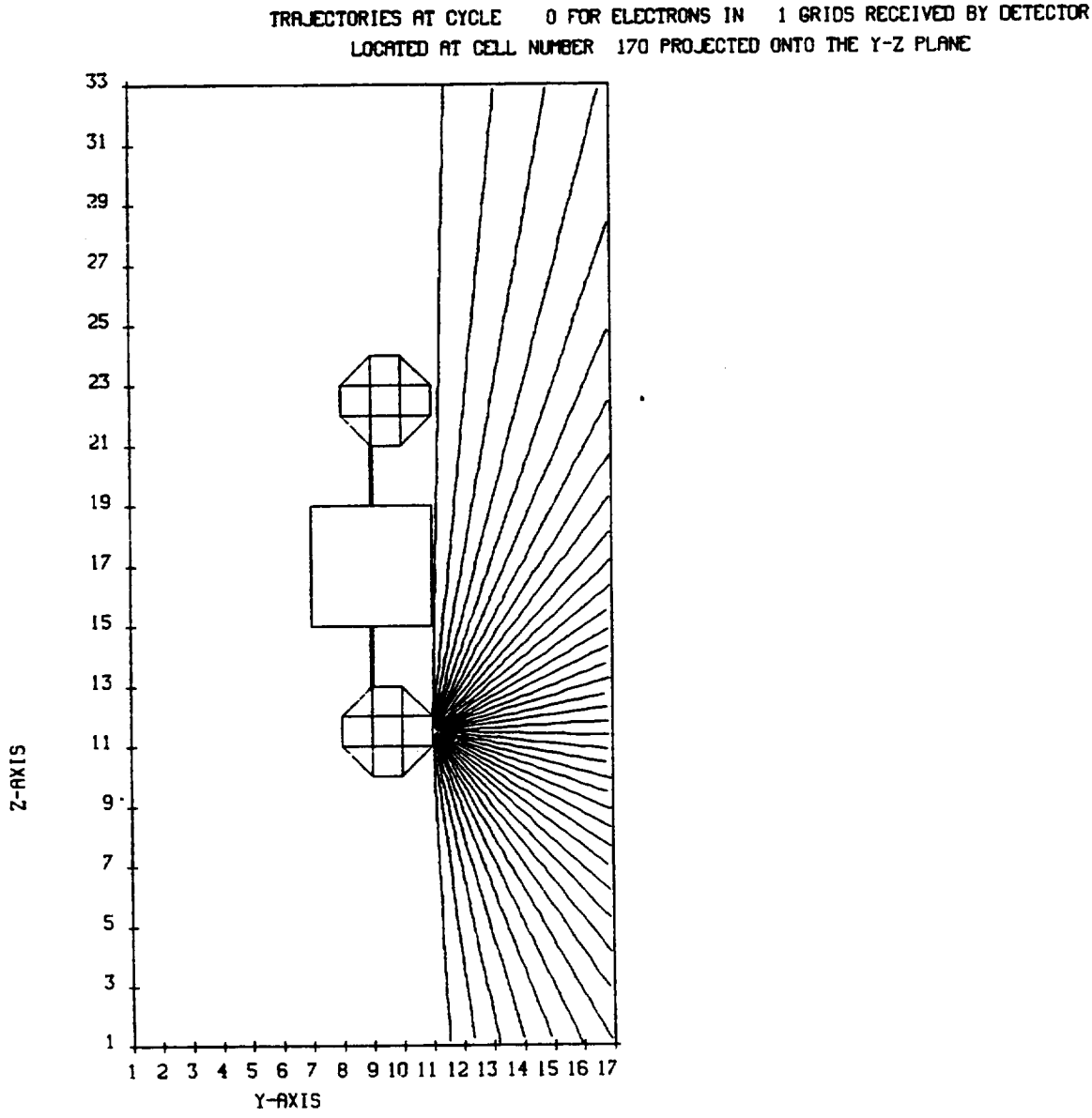


Figure 11.18b. Trajectory plots for uncharged spacecraft.

11.13 SUMMARY

As a result of these simulations we have learned the following:

1. In the environment given the object charges negatively with differential potentials of up to 3 kV.

2. The differential potentials affect the operation of a particle detector. In particular, a detector looking at a more negative piece of the spacecraft will underestimate the ambient proton energy flux and see a distorted angular distribution for the electron flux.

APPENDIX A

SUBROUTINE PRECIS

SUBROUTINE ADBOOM
Generates polygons for boom cells to be used for shadowing and hidden line satellite plots. Represents booms as square cross sectioned rods for graphical purposes only.

SUBROUTINE ADDA1
Adds a subdived surface cell polygon to the list of surface polygons. The polygons can be subdivided as part of the shadowing calculations.

SUBROUTINE ADDCND
Adds one matrix element between conductor nodes. This is done during the ICCG matrix setup.

SUBROUTINE ADDME
Adds a matrix element to the sparse matrix being set up for ICCG.

SUBROUTINE ADDVXB
Adds vector cross product to another vector. Used to push particles in a magnetic field.

SUBROUTINE ADEMIT
Adds emitter fluxes to the net currents of individual surface cells. Also accounts for the charge which returned to the satellite.

SUBROUTINE ADF
Advances to the next plot frame.

SUBROUTINE ADJRE
Adjusts plot co-ordinates for plots of quantities over more than one grid. Used for potential contour plots.

SUBROUTINE ADJUST
Calculates total emitted beam current to adjust return emitter currents.

SUBROUTINE ANGAVG
Averages shadowing of surface cells over several angles of rotation. Used for the SPIN option.

SUBROUTINE ANTERP
Performs linear interpolation to determine anisotropy for given energy and species.

SUBROUTINE APRNTV
Prints character string labels on plots. Labels can be horizontal or vertical.

SUBROUTINE APRT
Utility routine to print out information in a file. RDOPT keyword APRT governs usage.

FUNCTION AREA
Calculates surface area of a polygon. Used during shadowing calculations.

SUBROUTINE ASGFIL
Assigns mass storage files to be used during a NASCAP run.

SUBROUTINE ASUNDR
Converts 10 character CDC words to 4 character words. Complements TOGETH.

SUBROUTINE AXISXV
Plot routine to draw line parallel to the X-axis.

SUBROUTINE AXISYV
Plot routine to draw line parallel to the Y-axis.

SUBROUTINE A1COMP
Compresses the surface cell polygon list to remove those which are completely obscured from view.

SUBROUTINE A1GEN
Generates the 3-D co-ordinates of the surface cells for a given perspective. Used for shadowing and satellite plotting.

SUBROUTINE A2GEN
Generates 3-D and 2-D vertices of object building blocks for use in shadowing and satellite plotting routines.

SUBROUTINE A2PLOT
Non-hidden line plots of the building block faces. These are diagnostic plots used during object definition.

SUBROUTINE BADCEL
Find cells where electric fields limit low energy electrons. Part of LONGTIMESTEP algorithm.

SUBROUTINE BADCOND
Determines which conductors have electric fields which prevent their low energy photo and secondary electrons from escaping.

SUBROUTINE BADEMT
Sets trial potentials for conductors having ion or electron emitters. Magnitude of charge is determined taking into account whether the environment is charging in the same or opposite direction as the emitter.

SUBROUTINE BADTRI
Estimates the potentials of cells whose low energy electron emission (e.g. photo emission) is electric field limited. Assumes the potential exterior to a cell changes half as rapidly as the cell potential.

SUBROUTINE BAXSET
Sets maximum plot dimensions for SILHOU to take into account the booms.

SUBROUTINE BDQTRI
Gets trial changes in the charges, DQ's, for boom cells.

SUBROUTINE BFIELD
Calculates the magnetic field vector for a given point in space from input constant plus dipolar fields.

SUBROUTINE BIAFIX
Modifies inhomogenous term of the potential equations to take into account biased conductors.

SUBROUTINE BINWGT
Calculates interpolation weights for boom mesh interface.

SUBROUTINE BJOINT
Find conductor or conducting surface cells which contact a boom node. Used when constructing surface conductivity information.

SUBROUTINE BKSCAT
Performs integrals over the incident spectrum to calculate total electron backscatter from a surface cell. Calls BSCAT for actual backscatter coefficients.

SUBROUTINE BLARGE
Calculates the capacitance between the outer dielectric coating and the underlying conductor for boom cells. NASCAP refers to these as large capacitances.

SUBROUTINE BLDCYC
Builds the cycle of surface cells surrounding a given surface node.

BLOCK DATA
Contains the weights for use in the three dimensional potential solving routines.

SUBROUTINE BMAREA
Calculates the fractional boom area which recieves solar illumination.

SUBROUTINE BMLINE
Determines if a boom and a line segment intersect.

SUBROUTINE BOOM
Defines boom during object definition. Reads and checks user specifications of size, material, and location.

FUNCTION BOOMAT
Looks up the material which covers a particular boom surface.

SUBROUTINE BOOMDQ
Calculates the change in surface charge for boom surfaces both with and without the emission of low energy electrons.

SUBROUTINE BOOMEJ
Finds edges separating boom surfaces and adds them to the edge list.

SUBROUTINE BOOMGT
Retrieves surface cell information for boom cells. Information returned includes material coating, area, underlying conductor, potential, and small and large capacitances.

SUBROUTINE BOOMLT
Constructs the list of boom surface cells during object definition. Also constructs the relevant matrix elements necessary for solving Poison's equation.

SUBROUTINE BOOMI
Forms the list of insulating boom points for addition to the list of all insulating points.

SUBROUTINE BOOPLT
Draws a boom or a stub which represents the boom depending upon whether or not the entire boom fits within the first mesh. This routine is called during from the material potting routine.

SUBROUTINE BOTCEL
Determines whether or not a surface is on the bottom of a thin plate or points into volume element that has even one node which is a bottom point.

SUBROUTINE BOTMBC
Sets initial potentials for bottom points.

SUBROUTINE BOTMDQ
Scales potentials of bottom points based upon net change in total charge.

SUBROUTINE BOTSUB
Substitutes bottom point values for ordinary nodal values in the potential array.

SUBROUTINE BRSSUB
Substitutes bottom point values for regular nodal values in the charge density array.

SUBROUTINE BSCAT
Calculates back scattering coefficients. Contains the physical models and uses the input or default parameters.

SUBROUTINE BSKET
Makes calls to the plot package to sketch booms on material plots. The end of the boom is closed if it fits within the first mesh. Otherwise, a jagged end is drawn.

FUNCTION BETWEEN
Logical function which is true if the first argument lies between the other two.

FUNCTION BULKB
Calculates the bulk conductivity between a boom surface cell and its underlying conductor.

SUBROUTINE BULKC Calculates the bulk conductivity current for a given surface cell.

SUBROUTINE BULKS
Finds bulk conductivity between surfaces and their underlying conductors during object definition.

SUBROUTINE CALFLX
Calculates charging fluxes to surface cells. Calls routines such as BKSCAT to perform actual physics. This routine loops over the surface cell list and stores the fluxes.

SUBROUTINE CAPACI
A major code module called by the main NASCAP routine. This routine uses the large three dimensional potential solver to form the capacitances used by the internal current integration algorithms. Capacitances to space are found by solving Laplace's equation with a single unit of charge on the satellite, finding the structure potential and then determing how the charge was distributed among the surface cells.

SUBROUTINE CAPERR

This subroutines zeroes out the capacitances for non used conductors - purely a bookkeeping task.

SUBROUTINE CAPPOT

Calls the matrix inverter (ICCG) during current integration calculation.

SUBROUTINE CAPPT2

Second routine to call matrix inverter during the current integeration calculation.

SUBROUTINE CCPRD

Matrix multiplication routine for ICCG.

SUBROUTINE CCSUM

Includes or excludes the small stray capacitances between conductors for use in the current integration calculations.

SUBROUTINE CELGET

Calculates and writes out capacitances to infinity, capacitances to underlying conductors , total cell areas, and the areas associated with each note. Called by CAPACI.

SUBROUTINE CELLGT

Retrieves information about the geometry and orientation of a given surface cell during the GENMTL surface connectivity calculation.

SUBROUTINE CELLIO

Fast and general file access utility which transfers block data between main memory and mass storage.

SUBROUTINE CELLST

Bookkeeping routine which expands or contracts information between the array of all surface cells and the array of insulating cells only.

SUBROUTINE CFLICT

Determines appropriate action for the case of a 1 0 0 surface which points into a partially filled volume element. Called during OBJDEF.

SUBROUTINE CHARGE

High level routine called by TRILIN which caluclates explicit particle fluxes and predictsthe charge accumulation and distribution.

SUBROUTINE CIRCLE

Draw a circle around the center of a plot.

SUBROUTINE CKEDGE
Checks that two points form an edge common to two adjacent surface cell. Called during the construction of the connectivity matrix.

SUBROUTINE CLARGE
Calculates and writes out the capacitances between the surfaces of insulating cells and their underlying conductors using a one dimensional approximation.

SUBROUTINE CLASFY
Used by the free format input routines to classify input as integer, real or literal.

SUBROUTINE CLINE
Plots the detector flux curves.

SUBROUTINE CMPRSS
Compresses the surface cell list by removing any surface cells which are internal to the object and thus play no role in the charging process.

SUBROUTINE CNDCUR
Calculates the incident conductor particle currents at the beginning of a time step.

SUBROUTINE CNDMAT
Assembles the conductivity matrix as a result of the connectivity calculation.

SUBROUTINE CNDSET
Sets surface cell potentials to the value of their underlying conductors. The insulating cells will be reset by a following call to CELLST.

LOGICAL FUNCTION CNDTST
Test whether a cell is an exposed conductor for initial potential specification.

SUBROUTINE CNDUCS
Calculates matrix product for conductor equations during the three dimensional conjugate gradient potential calculations.

SUBROUTINE CNTOUR
Finds appropriate levels and call contour routines during plotting.

SUBROUTINE CNVGRD
Converts coordinates of a point from one grid system to another.

SUBROUTINE CNVPLT
Plots convergence parameters during three dimensional potential caluculation.

FUNCTION COF
Utility which returns the value of a six bit word segment .

FUNCTION COINV
Determines if a vertex is unique during HIDECEL

SUBROUTINE CONDME
Adds conductors to the conductivity list during surface connectivity calculations.

SUBROUTINE CONDUC
Places conductor numbers with surface cells during OBJDEF.

SUBROUTINE CONECT
Connects line segments for contour plots.

SUBROUTINE CONPLT
Major contour plot routine including labeling.

SUBROUTINE CONPOT
Sets potentials on grid points interior to the satellite to the satellite structure potential. These points don't enter the calculation, but would make the plots misleading if they were left at zero potential.

SUBROUTINE CONTOR
Low level contour plot utility.

SUBROUTINE CONTUR
Utility to draw a single contour line on an Eulerian grid. Used during contour plotting.

SUBROUTINE COORD
Generates three dimensional coordinates for each surface cell according to NASCAP's storage conventions. The values are used for the SATPLT and HIDCEL calculations.

SUBROUTINE COPROD
Performs multiplication of the finite element matrix with the potential array during the three dimensional scaled conjugate gradient iterative potential solver.

SUBROUTINE COROUS
Converts code charge to physical units of charge density taking into account grid interfaces.

SUBROUTINE CROEFF
Called by CELGET to calculate spacecraft effective radius for use in potential and boundary condition scaling which is dependent upon Debye length.

SUBROUTINE CSSCAL
Rescales small capacitances to account for finite screening length. These capacitances are used in the charge integration algorithms.

SUBROUTINE CUBE56
Called during object definition to define a truncated cube; that is a cube with a tetrahedron removed.

SUBROUTINE CURCND
Prints conductor and so called "battery" currents during the current integration calculations.

SUBROUTINE CURINS
Calculates low energy emission from insulating surface cells.

SUBROUTINE CURVV
Low level plot routine to draw curves consisting of connected line segments.

SUBROUTINE CUTOFF
Increases effective flux derivatives in anticipation of low energy electron flux being cutoff.

SUBROUTINE CYLNDR
Places zeroes in the potential array exterior to a cylindrical boundary.

SUBROUTINE DATETM
Gets date and time from the system clock.

SUBROUTINE DCODE
Determines type and value of free format input.

SUBROUTINE DEADLN
Determines whether NASCAP should exit based upon time of day. Used to prevent computing center personnel from killing a run when shutting down for scheduled system maintenance.

SUBROUTINE DEDSET
Sets the deadline used in the above routine.

SUBROUTINE DEFOPT
Called by NASCAP to set all default input options.

SUBROUTINE DELETE
Declares a volume cell to be empty and deletes all surface cells within it or pointing out of it.

SUBROUTINE DETDUM
Dummy routine called by NASCAP to run the detector module. This routine was created to solve a mapping problem.

SUBROUTINE DETECT
Subroutine to calculate particle energy flux as a function of detector orientation for each detector located on a specific surface cell. Fluxes are determined using reverse trajectory particle pushing.

SUBROUTINE DETPLT
Plots the particle flux data generated by the detector routines.

SUBROUTINE DETRUN
High level detector routine which calls other routines which get detector requirements, set parameters, perform calculations, and plot results.

SUBROUTINE DETSET
Initializes detector parameters using keyword input data.

SUBROUTINE DFACST
Sets perspective distance factor for use in hidden line satellite plots.

SUBROUTINE DFDV
Calculates approximate derivative of the particle flux with respect to changes in the surface cell potential.

SUBROUTINE DFDVMX
Sets the maximum allowable value for the flux derivative to prevent the surface potential of any cell from changing more than DVLIM in a timestep.

SUBROUTINE DFIELD
Finds electric fields for pushing particles during the detector calculations.

SUBROUTINE DIAGNO
Print routine for the surface cell list called during object definition.

SUBROUTINE DIHEDA
Calculates the angle between two adjacent surface cells. Called when calculating the connectivity matrix.

SUBROUTINE DIM4
Low level boom matrix routine called during object definition.

SUBROUTINE DIM4Q
Low level boom matrix routine called during object definition.

SUBROUTINE DIRINT
Routine to perform direct integration of spectral data points using Gaussian weights.

SUBROUTINE DISCHG
Checks to see if discharge criteria are satisfied. If so, charge is redistributed according to type of discharge. This routine is called during the integration of particle currents.

SUBROUTINE DISPAC
Routine to handle the special case of a discharge to space based upon the magnitude of the surface potential.

SUBROUTINE DIVIDE
Low level routine to check denominator size prior to performing division to prevent divide checks .

SUBROUTINE DLINEV
Low level routine which draws lines connecting a series of points.

SUBROUTINE DOPLOT
Prints convergence plots during potential calculations.

SUBROUTINE DOSRAT
Provides the integrand for the dose rate integral for determining radiation induced conductivity.

SUBROUTINE DQSCND
Redistributes charge accumulation taking into account conduction currents.

SUBROUTINE DRAWV
Low level plot interface which produces vector drawn characters. For labels on plots.

SUBROUTINE DRISCM
Driver for construction of point list and surface conductivity matrix during OBJDEF. Calls GENMTL.

SUBROUTINE DTPUSH
Three dimensional leap-frog particle pusher used by the dectector routines.

SUBROUTINE DVLMIT
Called during the current integration to restrict the difference between trial potentials and orginal potentials to DVLIM.

SUBROUTINE ECUBE
Element stiffnes matrix residual evaluator for an empty cube.

SUBROUTINE EFIELD
Computes the local electric field at a point exterior to the object. Used to push particles by particle tracking routines.

SUBROUTINE EFPREP
Performs storage manipulations preparing common blocks prior to the use of EFIELD.

SUBROUTINE ELBEAM
Analytically calculates Rutherford scattering including magnetic field effects. Used for multiple gun tank simulations.

SUBROUTINE ELFLUX
Calculates the incident, secondary and backscattered electron fluxes to a specific surface cell. Calls lower level routines for models of the physical processes.

SUBROUTINE ELIMIT
Cuts back emission of low energy electrons to take into account surface electric fields.

SUBROUTINE ELSEC
Generates electron secondary emission coefficient for a given incident spectrum. Called by ELFLUX.

SUBROUTINE ELSEC
Identical routine as ELSEC but relabeled for efficient segmentation.

SUBROUTINE EMDIST
Sets up the energy and angle distribution of emitter particles.

SUBROUTINE EMFIXR
Subroutine to handle stubborn cases in which particle refuses to follow a reasonable trajectory which passes through a numbered volume cell just prior to passing through a cell surface.

SUBROUTINE EMISET
Initializes emitter parameters in common block EMIT using keyword input.

SUBROUTINE EMITER
Calculates current density array for a given emitter located on a specific surface cell.

SUBROUTINE EMTFLX
Calculates currents to surface cells resulting from emitter particles returning to the object.

SUBROUTINE EMTRUN
High level emitter routine which calls other routines to initialize parameters and perform emitter calculations.

SUBROUTINE ENPRT
Prints out potential , kinetic and total energies to check conservation in emitter particle pushing routines.

SUBROUTINE EPBOOM
Evaluates electric fields and potentials in boom cells.

LOGICAL FUNCTION EQUAL
Compares two packed integers prior to using XORR.

FUNCTION ERFC
Calls routine to evaluate error function.

SUBROUTINE ESPEC
Calculates electric fields for partially filled cells. The cell is assumed to be in the standard orientation and the resulting fields must be transformed back to the actual cell orientation.

SUBROUTINE ESURFS
Calculates effective surface electric fields for all surface cells.

FUNCTION BSCAT
Calculates the normal incidence backscatter coefficient as a function of atomic number.

SUBROUTINE ETNGUN
Forwards particle tracking routine for single monoenergetic gun tank simulation.

FUNCTION EXPINT
Performs interpolation between two points assuming exponential behavior of the function. If results are inconsistent then linear interpolation is performed.

SUBROUTINE FASTRW
ASCII Fortran version of FASTIO rapid disk access. routine to transfer block data to and from mass storage.

SUBROUTINE FBREAK
Breaks up characters into groups of contiguous characters which were separated by blanks. Used to perform free format reads.

SUBROUTINE FCOUNT
Count and decode the input types specified in free format routine call.

SUBROUTINE FILALL
Calls FILINP for all grids.

SUBROUTINE FILASG
Assigns all required disc files.

SUBROUTINE FILINP
Fills in internal boundary potentials of an outer grid using values from the grid nested inside .

SUBROUTINE FILPX
Fills in the entire two dimensional inner rectangle of potentials using values from nested grids to get a plane of constant X for contour plotting.

SUBROUTINE FILPY
Fills in the entire two dimensional inner rectangle of potentials using values from nested grids to get a plane of constant Y for contour plotting.

SUBROUTINE FILPZ
Fills in the entire two dimensional inner rectangle of potentials using values from nested grids to get a plane of constant Z for contour plotting.

SUBROUTINE FIL111
Creates a 111 filler surface during object definition.

SUBROUTINE FINDBP
Finds out location of a boom point in the point list.

SUBROUTINE FINDPT
Finds a given point in the point list.

SUBROUTINE FINDTM
Finds all the times associated with spectral data and stuffs them into a common block.

SUBROUTINE FINFUN
Determines what class of data is on a free format input card image. (Multigun test tank.)

SUBROUTINE FINISH
Called by high level routines to close plot file and exit.

SUBROUTINE FINSHV
Plot routine to close a graphics file.

SUBROUTINE FINTER
Interpolates between input spectral data energies and those required to perform gaussian quadratures for surface flux calculations.

SUBROUTINE FINVER
Adds necessary vertices to complete a partially shielded polygon. Part of the hidden line routines used for shadowing and satellite plots.

SUBROUTINE FIXPOT
Fixes insulating surface potentials and conductor potentials prior to calling POTENT.

SUBROUTINE FLASH
Locates pair of cells with largest overvoltage for flashover calculation.

SUBROUTINE FLDCON
Adds effects of field enhancement to bulk conductivity.

SUBROUTINE FLUXT1
Defines incident particle flux parameters from the flux file for single gun tank cases .

SUBROUTINE FLXDEF
Flux definition high level routine. Sets particle environment.

SUBROUTINE FLXSPA
Defines incident particle flux parameters from the flux file for space environments.

SUBROUTINE FNDSCE
Finds surface conducting edges.

SUBROUTINE FREAD
Reads in experimental particle flux data.

SUBROUTINE FREED
Free format read routine. Interprets card images where data fields are separated by blank spaces.

SUBROUTINE FSPACE
Finds phase space density from DeForest data.

SUBROUTINE FTITLE
Writes a plot frame with a user specified line of text, date and time the routine was called, and send a frame eject.

FUNCTION GCSTOT
Sums the small capacitances over the entire object surface.

SUBROUTINE GDQTRI
Gets estimated change in charge for use in implicit charge integration algorithims.

SUBROUTINE GENMFA
Sets markers for interface boom cells.

SUBROUTINE GENMTL
High level which generates the skeleton of the LONGTIMESTEP matrix and intializes it with surface conductivity contributions.

SUBROUTINE GENSCL
Generates records for the surface cell sub-list.

SUBROUTINE GETBAR
Calculates potential barrier height for emitted particles.

SUBROUTINE GETBCL
Sets up detector on a boom cell.

SUBROUTINE GETBFL
Calculates incident particle fluxes to boom cells.

SUBROUTINE GETCEL
Retrieves parameters of a specified surface cell.

SUBROUTINE GETCH
Generates incomplete Cholesky matrix for ICCG routines.

SUBROUTINE GETDIV
Gets diagonal elements from full three dimensional potential matrix for use in scaled conjugate gradient routine.

SUBROUTINE GETDQ
Gets change in electrical charge on surface cells. Also finds effective field above conductors.

SUBROUTINE GETFLX
Finds explicit particle fluxes for trial potentials during current integration calculations.

SUBROUTINE GETIGF
Opens a plot file if one has not already been opened.

SUBROUTINE GETNC
Determines the number of conductors specified in a given object.

SUBROUTINE GETROT
Gets rotation matrix to transform vectors for uniform cosine distribution.

SUBROUTINE GJR
Simple Gaussian elimination matrix inverter for use by hidden line routines.

SUBROUTINE GJRX
Same routine as GJR but given different name for mapping purposes. Used during object definition.

SUBROUTINE GJRY
Same routine as GJR but given different name for mapping purposes. Used during detector calculations.

SUBROUTINE GUNSHD
Estimates particle shadowing for multiple particle guns in a laboratory tank.

SUBROUTINE HBOOST
Increases particle timestep during emitter calculations to increase efficiency.

SUBROUTINE HIDCEL
High level routine which supervises the shadowing and hidden line satellite plot calculations.

SUBROUTINE HIGHQ
Called by LIMCEL to unfix nodes with impossibly high fluxes.

SUBROUTINE HREDUC
Reduces particle timestep during emitter calculations to increase accuracy.

SUBROUTINE HISTORY
Called by TRILIN to dump timeplot information.

SUBROUTINE ICCG
Main routine of the Incomplete Cholesky - Conjugate Gradient iterative symmetric linear equation solver. This routine is called during the implicit current integration algorithm.

SUBROUTINE ICCG1
Sets up matrix and calls ICCG driver.

SUBROUTINE ICCG1
Like ICCG1 , called by current integration routines to setup charging matrix and call ICCG driver.

SUBROUTINE ICORNS
Calculates contributions of corner cells which are at mesh interfaces to the residual vector. Low level routine in the three dimensional potential solver.

SUBROUTINE IEDGES
Calculates contributions of edge cells which are at mesh interfaces to the residual vector. Low level routine in the three dimensional potential solver.

SUBROUTINE IFACES
Calculates contributions of cells which form the mesh interfaces to the residual vector. Low level routine in the three dimensional potential solver.

SUBROUTINE IGFBUF
Begins updating the plot buffer and write it out as required.

SUBROUTINE IMPFI
Implict flux routine which calculates the charge required to change the surface voltage from V0 to VTRIal .

FUNCTION INBCEL
Checks whether a point is within a boom cell.

SUBROUTINE INCOND
Initializes potentials of fixed voltage conductors during three dimensional potential solution.

SUBROUTINE INDATA
Initializes potential and current data in accordance with user options.

SUBROUTINE INEIMP
Processes input material parameters to get them in the form necessary for secondary yield calculations.

SUBROUTINE INGUNS
Reads FLXDEF file to setup parameters for multiple guns in a laboratory test tank.

SUBROUTINE INIPOT
High level routine which supervises initialization of surface potentials.

SUBROUTINE INISET
Reads and processes initial potential specifications.

SUBROUTINE INPLOT
Initialization routine for printer plots.

SUBROUTINE INPUT
Main input routine for object definition module.

FUNCTION INSIDD
Double precision routine which determines whether a point is located inside a given polygon. Low level routine in the shadowing section of the code.

FUNCTION INSIDE
Single precision version of INSIDD.

FUNCTION INSID1
Determines whether a particle has penetrated the object. Called by the field routines during particle pushing.

SUBROUTINE INSLST
Forms the list of insulating surface cells after calculation of the connectivity matrix.

SUBROUTINE INTCHK
Calculates cell edge intersections with the polygons that make up the major object building blocks. Part of shadowing routines.

SUBROUTINE INTSEC
Called by INTCHK to calculate the intersection co-ordinates.

SUBROUTINE INVERS
Driver to call GJRX matrix invertor.

SUBROUTINE IOFLX
Prints fluxes to a given cell.

SUBROUTINE IOSCLP
Prints out potentials of all surface cells.

SUBROUTINE IOSTRS
Prints out electric field stresses for each surface cell.

SUBROUTINE IOXFLX
Prints out fluxes to a given boom cell.

SUBROUTINE IPSCHG
Computes estimated total charge for initially specified potentials.

SUBROUTINE IPSCND
Sets a given conductor and all cells overlying it to a specified potential. Part of the initialization of potentials.

SUBROUTINE IPSMAT
Like IPSCND, sets initial potentials , this time for all cells of a specified material with a given illumination.

SUBROUTINE IPSPOT
Called during intialization of potentials to read list of cells.

SUBROUTINE IRCALL
Part of three dimensional potential solver which calls mesh interface routines.

SUBROUTINE ISPACE
Finds matrix product with potentials for the innermost grid during the three dimensional potential solution.

FUNCTION IXV
Plot routine to convert a user x coordinate to a raster coordinate.

FUNCTION IYV
Plot routine to convert a user y coordinate to a raster coordinate.

SUBROUTINE JACIRC
Plots a circle of a specified radius.

FUNCTION KBITS
Machine dependent low level routine which specified bits from a word. UNIVAC version calls BITS ; CDC version uses a bit mask.

SUBROUTINE KINENG
Calculated kinetic energy and modified polar emission angle for particles used in the emitter routines.

SUBROUTINE LCODE
Decodes an entry in the element table and returns cell type and orientation. Used by the electric field routines when particle pushing.

SUBROUTINE LCTOUC
Converts lower case ASCII character to upper case.

SUBROUTINE LIMCEL
Performs cell by cell electric field limiting of low energy emission as part of the current integration step. This is a high level supervisory routine which enables NASCAP to treat barrier effects in spacecraft charging.

SUBROUTINE LIMITS
Called by mesh interface routines during three dimensional potential calculations to set limits on loop indices.

SUBROUTINE LINEUV
Plot routine which draws a straight line between two points which are specified in user coordinates.

SUBROUTINE LINPLN
Calculates the coordinates of the point of intersection of a line with a plane. Part of the hidden line routines.

SUBROUTINE LINPLT
Printer plotter routine called to plot convergence criteria from the potential solver.

SUBROUTINE LINSCH
Low level routine which performs a bit search.

SUBROUTINE LLTIV
Called during ICCG to calculate product with lower triangular Cholesky matrix.

SUBROUTINE LOWQ
Unfixes nodes having impossibly low fluxes during the current integration.

SUBROUTINE LQUADV
Plot routine to fill in a quadrangle with solid lines; used for material plots.

SUBROUTINE LSTMAT
Completes construction of the capacitor model matrix during the current integration.

SUBROUTINE LSTMT2
Same as LSTMAT with different name for mapping.

SUBROUTINE MAGCMP
Corrects initial particle velocities in the one gun laboratory environment by taking into account magnetic field curvature of orbits.

SUBROUTINE MATCAL
Retrieves surface cell data for satellite plots.

SUBROUTINE MATDEF
Contains default surface material properties.

SUBROUTINE MATPLT
Plots satellite as seen from plus and minus grid coordinae directions. Each surface cell is shaded according to its surface material.

SUBROUTINE MATPRO
Processes material properties to obtain derived quantities required by the charging algorithms.

SUBROUTINE MAXDEL
Limits timestep to prevent roundoff errors in the integration of particle fluxes.

SUBROUTINE MAXSWR
Integrates over a Maxwellian spectrum to obtain an emitted flux.

SUBROUTINE MIXG2D
Generates two dimensional interpolants for use in boom cell matrices.

SUBROUTINE MIXG3D
Linearly interpolates 2-D matrices to obtain full boom cell matrix.

SUBROUTINE MMPY
Low level matrix multiplication routine for rotational matrices.

SUBROUTINE MORCOR
Calls system routine to get more memory during execution.

SUBROUTINE MOVDAT
Performs block transfers between core and disc.

SUBROUTINE MOVEA1
Moves surface cell polygon to a new location on the polygon list during hidden line calculations.

SUBROUTINE MPTWGT
Multiplies boom weights during object definition.

SUBROUTINE MTWGT
Calculates empty cell weights for potential calculations.

SUBROUTINE MULGUN
Calculates incident particle flux intensity at a cell for a multiple particle gun laboratory environment.

SUBROUTINE NASCAP
The highest level, main procedure.

SUBROUTINE NEWFLX
Finds the next spectrum for use with direct integration algorithms.

SUBROUTINE NEWGRD
Determines which grid a point is in and returns its location in that grid's units.

SUBROUTINE NEWMAT
Changes material properties after object definition. Typically changed is the bulk resistivity to simulate degradation.

SUBROUTINE NIOOBJ
Object definition routine to construct large rectangular solids contained in shapes such as right octagonal cylinders.

SUBROUTINE NIIOCT
Object definition routine to construct right octagonal cylinders and quasispheres from simpler components.

SUBROUTINE NIOTET
Like NIOOBJ except constructs nescessary tetrahedral solids.

SUBROUTINE NIOWGE
Like NIOOBJ except constructs necessary wedge solids.

SUBROUTINE NORMSK
Generate corner code for right triangle surface. An object definition routine.

SUBROUTINE NORM3V
Low level routine to normalize a three component vector.

LOGICAL FUNCTION NOTEQL
Tests for inequality using exclusive or function.

SUBROUTINE NUMLTB
Numbers element table volume cells which border the satellite. This is done during object definition and the resulting list is used by particle pushing routines.

SUBROUTINE NUMPTS
Counts the number of points in the point list.

SUBROUTINE NWVTXL
Sets up array which identifies neighbors of an insulating surface cell.

SUBROUTINE OBJDEF
High level routine which supervises code conversion of user object specification into cell by cell lists for use by the charging sections.

SUBROUTINE OCORNS
Mesh interface routine from the potential section which handles corner cells in the outer mesh.

SUBROUTINE OCTGON
Decodes user OCTAGON input for use by object definition routines.

SUBROUTINE OCUBE
Empty volume element matrix weights called by OCORNS.

SUBROUTINE OEDGES
Mesh interface routine to handle potential calculations of edge cells in the outer mesh.

SUBROUTINE OFACES
Mesh interface routine to handle potential calculations of face cells in the outer mesh.

SUBROUTINE OLAP
Checks for overlapping of two polygons as part of the shadowing calculations.

SUBROUTINE OLDLIN
Printer plot routine which stores line information.

SUBROUTINE ORCALL
Calculates outer mesh interface element contributions to the potential matrix.

SUBROUTINE ORDPTS
Orders vertices so that the lowest index is first, then are counter clockwise.

SUBROUTINE OSPACE
Calculates outer grid empty volume element contributions to the potential matrix.

SUBROUTINE OUTLIN
Plot routine to draw an outline around the user plot area.

SUBROUTINE PCPDAT
Updates potentials as part of the current integration routines.

SUBROUTINE PDIL
Transforms projected surface cell coordinates for material plots.

SUBROUTINE PDIR
Same as PDIL but for viewer along a negative axis.

SUBROUTINE PERMU
Generate permutation vector from element code. Used to transform non cubic elements to the standard orientation.

SUBROUTINE PHCMAT
Adds photosheath conduction to the surface conductivity matrix.

SUBROUTINE PHCOND
Calculates effective photoconductivity.

SUBROUTINE PHOR
Area definition routine for shading for material plots.

SUBROUTINE PHOTOC
Pushes particles with Maxwellian energy distribution for photosheath calculation.

SUBROUTINE PLATE
Inputs thin plate parameters during object definition.

SUBROUTINE PLEMIT
Plots emitter particle trajectories.

SUBROUTINE PLOTCV
Plots a square array of four dots centered at the current point.

SUBROUTINE PLPART
Plots detector particle trajectories.

SUBROUTINE PMODQ
Scales potentials by relative change in total charge.

SUBROUTINE POINT
Printer plot routine which plots a single point. Part of the potential convergence plotting.

SUBROUTINE POLYN
Eliminates any redundant nodes from a polygon. Part of shadowing calculation.

SUBROUTINE POTENT
Supervisory routine for the three dimensional potential solver.

SUBROUTINE POTPLT
Produces potential contour plots from the three dimensional electric potentials.

SUBROUTINE PPJSET
Sets up the prospective projection matrix for shadowing calculations.

SUBROUTINE PRFLUX
Calculates proton (positive ion) flux and its associated secondary electrons for use in the charging calculation.

SUBROUTINE PROLIN
Projects the coordinates of a point on a line onto the viewer plane.

SUBROUTINE PROSEC
Low level routine which calculates the proton generated secondary electron yield.

SUBROUTINE PRSPPJ
Projects a point from three space onto the viewer plane.

SUBROUTINE PRSPPK
Converts from prospective view back to three space.

SUBROUTINE PRTLIM
Prints information from LIMCEL, the routine that limits the emission of low energy electrons when barriers are present.

FUNCTION PSURFB
Calculates surface resistance of a boom half-segment.

FUNCTION PSURFS
Calculates surface resistance of a half-cell.

SUBROUTINE PSWIT
Switches points in the potential array to take into account bottom points on thin plates.

SUBROUTINE PTCOMP
Part of shadowing calculation which checks to see if two points are close enough together to be treated as a single point.

SUBROUTINE PTLINE
Checks to see if a point is on a given line segment. Part of shadowing calculation.

SUBROUTINE PTROUS
Corrects charge density taking into account biased conductors.

SUBROUTINE PUPDAT
Updates the potential array with the conjugate gradient solution. Part of the three dimensional potential solver.

SUBROUTINE PUSH
Calculates the incident flux at a given surface cell using reverse trajectory particle pushing.

SUBROUTINE PUSHER
Forward trajectory particle pushing routine for tracking emitter particles.

SUBROUTINE PVER
Permutes surface cell vertices for material plots.

SUBROUTINE QCONCP
Calculates the charges on fixed and biased conductors. Used to determine battery currents for output.

SUBROUTINE QDISTR
Distributes blowoff charge to other cells and conductors. Part of the discharge model.

SUBROUTINE QDOT
Plots dotted material surface during object definition plotting.

FUNCTION QEQN
Low level routine to solve for secondary yield parameter during material properties input.

FUNCTION QEQNZ
Low level routine to solve for maximum yield energy durng materials properties input.

SUBROUTINE QSPHER
Object definition routine which takes quasi-sphere input and transforms it into a combination of right octagonal cylinders and tetrahedra.

SUBROUTINE QSUMER
Sums the change in computational space electric field in order to obtain the total charge on the object via Gauss's law. Used to perform potential scaling.

SUBROUTINE RADCON
Replaces intrinsic material conductivities with their radiation enhanced values.

SUBROUTINE RCPDAT
Updates the residual vector during ICCG. Part of the current integration step.

SUBROUTINE RDOBJ
Reads in object data for a restart.

SUBROUTINE RDOPT
Read user run time options from the options file.

SUBROUTINE READAN
Reads anisotropic flux data as part of the environment specification.

SUBROUTINE RECTAN
Defines volume and surface cells associated with a rectangular parallelepiped as part of the object definition calculation.

SUBROUTINE REDCRD
Low level routine to read a single card.

SUBROUTINE REDFIT
Read file of fits to observed spectra to determine range of times available.

SUBROUTINE REDO
Current integration routine which cuts back the timestep if changes in voltages are too great.

SUBROUTINE REFIX
Revises potential estimates for barrier limited cells by using information from neighboring cells. Part of the current integration.

SUBROUTINE REGRID
Reconstructs a potential location code for boom cells which are part of mesh interfaces.

SUBROUTINE REORDER
Reorders a boom matrix to account for a particular orientation.

SUBROUTINE REPLOT
Printer plot routine which sets up extrema and increments for plotting real numbers.

SUBROUTINE RESCRN
Rescales potentials to account for change in plasma screening.

SUBROUTINE RESETQ
Scales charges and potentials through out the mesh.

SUBROUTINE RETRNO
Low level emergency abort routine which forces a traceback in the case of a code failure.

SUBROUTINE REVERT
In the case of an internal restart, reverts the capacitances and magnetic fields back to physical input units from code units.

SUBROUTINE REWIND
Positions files pointer to the beginning of a mass storage file.

SUBROUTINE RHOSHE
Plots phosheath electron density contours.

FUNCTION RNORM
Computes a rational approximation to a normal distribution.

SUBROUTINE ROTATE
Rotates the sun direction and magnetic field vectors in time to simulate the shadowing of a spinning satellite.

SUBROUTINE ROUSP
Plots charge density contours.

SUBROUTINE RTSUP
Finds appropriate surface triangles for square surface cells which are superseded by right triangles. This is an object definition routine.

SUBROUTINE RUPDAT
Updates the residual vector during the three dimensional conjugate gradient potential calculation.

SUBROUTINE SATPLT
High level routine which performs satellite plots.

SUBROUTINE SBLIN
Low level routine to print scale values on plot base line.

SUBROUTINE SCACTR
Routine to find the effective scattering center for the multiple laboratory gun environment.

SUBROUTINE SCALEP
Guesses new potentials by scaling previous results by the change in total charge. Used to get good initial conditions for iterative potential solver.

SUBROUTINE SCAT
Rutherford scattering calculation with magnetic field to get current density and angle of incidence for multigun laboratory environment.

SUBROUTINE SCCYC
Reorders the surface cells around a point in cyclic order. Part of the surface conductivity matrix generation.

SUBROUTINE SCREAD
Reads in the surface conductivity list and matrix for initialization.

SUBROUTINE SEARCH
Searches a two dimensional mesh to find contour levels for plotting.

SUBROUTINE SETALL
Sets all potentials to monopole value.

SUBROUTINE SETAN
Sets up transformation matricies for particle pushing intial velocities.

SUBROUTINE SETAX
Sets up axis values for contour plots. The resolution is that of the coarsest mesh so that mesh interfaces don't cause wiggles on the plots.

SUBROUTINE SETBMI
Sets up matrices necessary to calculate electric fields in cells which contain booms. Used for particle pushing.

SUBROUTINE SETBTS
Low level routine to set bits in a computer word.

SUBROUTINE SETCOM
Sets values in common blocks.

SUBROUTINE SETEWX
Determines the energies and weights to be used for optimal resolution of emitted spectrum.

SUBROUTINE SETFAC
Sets bit information telling direction a surface cell is facing.

SUBROUTINE SEFFL
Routine to set surfaces of a FIL111 building block.

SUBROUTINE SETFOC
Fills in surface information for an octagon building block.

SUBROUTINE SETFTH
Sets surface information for a tetrahedron building block.

SUBROUTINE SETFWG
Sets surface information for a wedge building block.

SUBROUTINE SETIP
Sets inner grid potentials to zero for an initial guess.

SUBROUTINE SETLST
Sets the list of nodes whose potentials are fixed during the three dimensional potential solution.

SUBROUTINE SETMAX
Sets up environmental parameters for use with Maxwellian distributions for reverse trajectory particle tracking.

SUBROUTINE SETOP
Sets initial potentials in outer grids to zero with the possible exception of the outermost grid being filled with the monopole potential.

SUBROUTINE SETPOP
Sets the potentials on the outer surfaces of the outer grid to the monopole value.

SUBROUTINE SETROT
Sets up a rotation matrix for use by the particle pushers in the detector and emitter routines.

SUBROUTINE SEFFL
Routine to set surfaces of a FIL111 building block.

SUBROUTINE SETFOC
Fills in surface information for an octagon building block.

SUBROUTINE SETFTH
Sets surface information for a tetrahedron building block.

SUBROUTINE SETFWG
Sets surface information for a wedge building block.

SUBROUTINE SETIP
Sets inner grid potentials to zero for an initial guess.

SUBROUTINE SETLST
Sets the list of nodes whose potentials are fixed during the three dimensional potential solution.

SUBROUTINE SETMAX
Sets up environmental parameters for use with Maxwellian distributions for reverse trajectory particle tracking.

SUBROUTINE SETOP
Sets initial potentials in outer grids to zero with the possible exception of the outermost grid being filled with the monopole potential.

SUBROUTINE SETPOP
Sets the potentials on the outer surfaces of the outer grid to the monopole value.

SUBROUTINE SETROT
Sets up a rotation matrix for use by the particle pushers in the detector and emitter routines.

SUBROUTINE SETSHE
Sets up data for particle pushing photo sheath calculation.

SUBROUTINE SETUAV
Plot routine which defines relationship between user coordinates and plotting raster coordinates.

SUBROUTINE SETUPV
Plot routine to open a plot file and establish default parameters.

SUBROUTINE SETWE
Calculates macro particle energies and weights for particle pushing.

SUBROUTINE SHIELD
The workhorse routine in the shadowing / hidden line calculations. Does shadowing calculation for a single surface cell by a single large object surface. Shadowing is done by looking for edge intersections and redrawing only the exposed polygon.

SUBROUTINE SILHOU
Draws satellite including booms. For use in contour plots.

SUBROUTINE SKEL1
Initialize circuit matrix skeleton assuming no conductivity as an early step in the conductivity matrix construction.

SUBROUTINE SKEL2
Adds surface conductivity to the matrix skeleton.

SUBROUTINE SLLIN
Plot routine to print scale values along the left vertical axis.

SUBROUTINE SMAXMO
Fits input particle spectrum to a double Maxwellian by the method of moments.

SUBROUTINE SOLFLX
Calculates the photelectron current density for a given surface cell during charging.

SUBROUTINE SORTER
Simple bubble sort utility for ordering short lists.

SUBROUTINE SOURCE
Converts user input specification of a laboratory electron or ion source into code units for use during charging.

SUBROUTINE SPACEF
Machine dependent routine to space forwards in a mass storage file.

SUBROUTINE SPECEL
Sets up volume element information for partially filled cells for use in the element table.

SUBROUTINE SPIN
Simulates the shadowing of a rapidly spinning satellite by averaging the shadowing from several sun angles.

SUBROUTINE SQCWGT
Performs matrix multiplication with permuted cell vertices during potential calculation.

SUBROUTINE SQUARE
Defines a square surface cell during object definition.

SUBROUTINE SRFCLS
Loops through surface cells and gets their contributions to the matrix product during the three dimensional potential solution.

SUBROUTINE SRTWDS
Sorts a one dimensional array of words using a heapsort.

SUBROUTINE STOPAR
Stores particle trajectories for sheath plot.

SUBROUTINE STRESS
Calculates electric field stresses within dielectric surface cell coatings.

SUBROUTINE SUMOPT
Prints a summary of the run time options.

SUBROUTINE SUMQD
Sums up the charges on the dielectric surface, that is all surfaces except the exposed conductors.

SUBROUTINE SURFB
Calculates the surface resistance of half a boom cell during the conductivity matrix setup.

SUBROUTINE SURFS
Calculates the surface resistance of half a square surface cell.

SUBROUTINE SWPEN
Plot routine to request pen change in order to plot in a new color.

SUBROUTINE SWPPTS
Low level routine which swaps the location of data for two point entries. Used when ordering points for geometrical analysis.

SUBROUTINE S3MCHR
Fortran routine which transfers characters. Used in free format routines and is necessary since the language doesn't support string manipulations.

SUBROUTINE S3MOVE
Do-loop to move an array from source to destination.

SUBROUTINE S3SET
Do-loop to set all members of an array to a given value.

SUBROUTINE S3ZERO
Do-loop which zeroes an array.

SUBROUTINE TABSTF
Stuffs the TAB common block with data.

SUBROUTINE TERROR
Reports errors in the multiple gun input.

SUBROUTINE TETDEL
Deletes extraneous surface cells for tetrahedral objects during object definition.

SUBROUTINE TETRAH
Defines surface cells and volume elements for a tetrahedron object.

SUBROUTINE THNPLO
Performs material plot specifications for thin plates.

SUBROUTINE TIMER
Low level routine which prints remaining job time.

SUBROUTINE TIWARN
Checks to see whether enough time remains in a job so that a high-level routine can make a clean exit.

SUBROUTINE TLINEV
Plot routine which draws thick lines.

SUBROUTINE TMULT
Low level matrix multiply routine which transforms boom weights during objdef.

SUBROUTINE TOGETH
Low level routine which packs character data into computer words. (CDC only)

SUBROUTINE TQDOT
Plots dots in material plots.

SUBROUTINE TRAAN
Transforms a rotation matrix by interchanging axial directions.

SUBROUTINE TRANA
Transforms eight cubic element vertex potentials according to the cell orientation code.

SUBROUTINE TRAND
Transforms change in orbit length according to cell orientation. Used during particle pushing.

SUBROUTINE TRANE
Transforms electric field vector from standard orientation back to element orientation for use in the particle pushing routines.

SUBROUTINE TRILIN
High level routine which oversees the charging and potential calculations.

SUBROUTINE TRIPLT
Material plot routine which outlines a triangular cell and colors and fills it according to the surface material type.

SUBROUTINE TRIPOT
Performs trilinear interpolation in an empty cubic element.

SUBROUTINE TRIPRD
Calculates triple product of three vectors. Same as the determinant of the matrix composed of the vectors as columns.

SUBROUTINE TRISHR
Shares cell values to vertices according to trilinear interpolants.

SUBROUTINE TRNGLS
Stuffs appropriate orientation code into surface cell list for right triangle surfaces.

SUBROUTINE TRPLT2
Right triangle plotting routine from material plot section.

SUBROUTINE TURNON
Modifies flux derivative prior to removing potential barrier and turning on secondary emission.

SUBROUTINE TYPEV
Prints characters on a plot frame.

SUBROUTINE UAU
Calculates inner product for three dimensional potential routine.

SUBROUTINE UCPDAT
Updates vector at the end of an ICCG iteration.

SUBROUTINE UNEMIT
Determines whether a particle emitter current is so small that the satellite potential responds over several timesteps. If so, the underlying conductor is floated; if not the conductor potential is fixed by the current intergration routine.

SUBROUTINE UNEMT1
Calls UNEMIT routine for fixed conductors with emitters.

SUBROUTINE UNFIX
Unfixes cells when predicted emission exceeds maximum possible.

SUBROUTINE UNFIXC
Unfixes conductors when predicted emission exceeds explicit estimate.

SUBROUTINE UNFREE
Low level routine which marks the free format routine as being unloaded by stuffing its memory locations with blanks.

SUBROUTINE UNLOAD
Low level routine to mark the D-bank above the plot library as unloaded.

SUBROUTINE UNSTOR
Marks as unloaded D-bank locations that may have been overwritten by the STOR common block.

SUBROUTINE UNSURF
Decodes thin plate surface cell material information for plotting.

SUBROUTINE URCSET
Initializes residual and solution vectors for the ICCG potential solver.

SUBROUTINE URSETO
Initializes residual and solution vectors for three dimensional potential solver.

SUBROUTINE UUPDAU
Updates the solution vector in the three dimensional potential solver.

SUBROUTINE UXVEC
Converts the verticies of a surface cell from NASCAP coordinates to plotter raster coordinates.

SUBROUTINE UXYV
Performs the coordinate conversion for a single vertex.

SUBROUTINE VADD
Low level routine which adds two vectors.

SUBROUTINE VADDS
Low level routine which adds two vectors after multiplying one by a scalar.

SUBROUTINE VCEMT
Estimates the voltage change for a conductor which has a particle emitter.

SUBROUTINE VCENTR
Calculates the effective center of charge for calculating beam deflection for multiple guns in a tank. Presently restricted to the geometrical center.

SUBROUTINE VCFIX
Fixes potentials of conductors consistent with predicted fluxes.

SUBROUTINE VECROT
Low level routine which rotates a vector about a coordinate axis.

SUBROUTINE VFIX
Fixes surface cell potentials to make them consistent with their predicted fluxes.

SUBROUTINE VMAX
Predicts maximum voltage change for an object during a timestep. Used for cutting back timestep if it is greater than user specified limit.

SUBROUTINE VMULT
Multiplies a three vector by a matrix.

SUBROUTINE VPRED
Predicts surface cell potentials by solving implicitly the charging equations. Calls the ICCG potential solver.

SUBROUTINE VSURFS
Calculates the average surface potential above all surface cells in the element table during CAPACI.

SUBROUTINE WEDGE
Defines a wedge object's sufaces and volume elements.

SUBROUTINE WGEDEL
Deletes wedge surface cells which are internal or superceded.

SUBROUTINE WGTIN
Brings in element weights for the inner mesh to be used in the three dimensional potential routines.

SUBROUTINE WGTOUT
Brings in element weights for the outer mesh to used in the three dimensional potential solver.

SUBROUTINE WRDSRT
Object definition routine which sorts the surface cell list exclusive of the triangle bits.

FUNCTION XORR
Low level exclusive or routine which compares words after converting lower case to upper case (UNIVAC) or truncating to four characters (CDC).

SUBROUTINE XTRCLS
Forms matrix product for boom volume elements during three dimensional potential calculation.

SUBROUTINE XTRDIV
Calculated diagonal matrix elements for boom cells. Used for scaling the three dimensional matrix.

SUBROUTINE XTRFLX
Calculates the explicit flux to boom cells as the first step in the charging calculation.

SUBROUTINE XTRIR
Forms matrix product for inner mesh interface cells which have booms. Part of the three dimensional potential calculation.

SUBROUTINE XTROR
Forms matrix product for outer mesh interface cells which have booms.

SUBROUTINE XTRPTR
Calculates charges on fixed and biased boom cells after a potential calculation.

SUBROUTINE XTRQFX
Calculates contributions from fixed and biased boom cells to the total charge on each conductor.

SUBROUTINE XTRSOL

Calculates the photocurrent for boom cells.

SUBROUTINE ZDRAW

Low level plot routine which moves the cursor to a given location.

FUNCTION ZINT

Calculates the z coordinate of a line where the x and y values are that of an apparent intersection in two dimensions with another line. Used for hidden line drawings.

SUBROUTINE ZSYSTM

Preprocesses electron secondary emission parameters during object definition and new material specification.

APPENDIX B

IMPLEMENTATION OF NASCAP ON THE CRAY/IBM SYSTEM

NASCAP, along with several of its utility routines, is now functional on the CRAY/IBM system at Lewis Research Center. The main NASCAP program exists on the CRAY, together with a routine CRAYFILES to maintain NASCAP restart files and CRAYTOIBM to send to the IBM the data required by PLOTREAD, CONTOURS, and TERMTALK, which are resident on the IBM. MATCHG is resident only on the IBM. Libraries of low-level NASCAP utility routines (e.g., FREED) are resident on both machines. All files are currently stored under the username SEMANDEL. On the CRAY, all files have ID=NASCAP, except for restart files, which are currently without ID.

In making this conversion, every effort was made to maximize commonality of NASCAP coding to the various FORTRANS used: UNIVAC ASCII FORTRAN, CRAY FORTRAN (CFT), and CDC FORTRAN V. Only a small number of routines in the main NASCAP/GEO code need be changed among these three FORTRANS, including some low-level I/O routines (MOVDAT, CELLIO, REWIND, SPACEF), some executive request routines (ASGFIL, DATETM, S3MCOR, TIWARN), some machine-specific assembler routines (F2FRT, F2FCA, TIMLFT, SHIFT, XTIME), and a single routine, SETCHR, defining bits per word, characters per word, and bits per character. Many more changes must be made for the version of IBM FORTRAN implemented at NASA/LeRC, which does not properly handle continuation lines.

The documentation which follows is not intended as an operations manual for either system, but rather as a description of the present implementation of the NASCAP family of codes on the composite system.

B.1 FREED (IBM)

The IBM version of the NASCAP utility library may be created by compiling the file SOURCE.FREED. It is currently stored as FRDLIB. When using this library, FT47F001 must be DDEF'd as a scratch file.

B.2 FREED (CRAY)

The source code for the NASCAP utility library may be stored on the CRAY by SUBMITting the file CRAY.FREED. It is compiled by SUBMITting the file CFREED.COMPILE. The source code is stored in FREEDPROGLIB and the object code in FREEDOBJLIB.

B.3 MATCHG

The source code for MATCHG is stored in SOURCE.MATCHG, with the main routine in SOURCE.MATCHG$$. The object code is stored in MTGLIB, and the default material properties in MATCHG.DATA. It may be executed by the command (PROC) MATCHG.

B.4 CRAYFILES

The NASCAP restart file utility routine CRAYFILES may be created by SUBMITting the file CRAY.FILES. To run it,

```
ACCESS, DN=FILES, PDN=CRAYFILES, ID=NASCAP.
FILES.
```

Commands are read from $IN until an /EOF is reached. Available commands are:

ASSIGN prefix -	Save a new set of NASCAP files.
ACCESS prefix -	Make a set of files local and accessible through FORTRAN logical unit numbers.
ADJUST prefix -	Properly close set of NASCAP files.
DELETE prefix -	Delete set of NASCAP files.
COPY prefix1 TO prefix2 -	Copy from one existing set of files to another.

The files treated by CRAYFILES are:

Permanent Name	Local Name
prefix02	FT02
prefix10	FT10
prefix15	FT15
prefix16	FT16
prefix17	FT17
prefix21	FT21
prefix27	FT27
prefixOBJ	FT20
prefixOPT	FT26
prefixFLX	FT22
prefix19	FT19

At present, files are SAVEd, etc., with no ID.

B.5 CRAYTOIBM

The utility routine CRAYTOIBM may be created by SUBMITting the JOB CRAY.TOIBM. It is used to send restart files from the CRAY to the IBM, where they may be read by PLOTREAD, CONTOURS, or TERMTALK. CRAYTOIBM reads from $IN a card containing the list of units (LUN's) to be sent, or the literal 'ALL'. It writes to local file (LUN+50), which must have previously been TASSIGN'ed, and must subsequently be BINOUT'ed. The files required by the various routines are:

Routine	LUN(S)
PLOTREAD	2
CONTOURS	10, 17, 21.
TERMTALK	16, 17, 21.

To send all five files:

```
ACCESS, DN=FILES, PDN=CRAYFILES, ID=NASCAP.
ACCESS, DN=TOIBM, PDN=CRAYTOIBM, ID=NASCAP
TASSIGN, A=FT52, DN=FT52
TASSIGN, A=FT60, DN=FT60
TASSIGN, A=FT66, DN=FT66
TASSIGN, A=FT67, DN=FT67
TASSIGN, A=FT71, DN=FT71
FILES.
TOIBM.
BINOUT, DN=FT52, SDN='prefix.FILE02'.
BINOUT, DN=FT60, SDN='prefix.FILE10'.
BINOUT, DN=FT66, SDN='prefix.FILE16'.
BINOUT, DN=FT67, SDN='prefix.FILE17'.
BINOUT, DN=FT71, SDN='prefix.FILE21'.
/EOF
ACCESS prefix
/EOF
2  10  16  17  21
/EOF
```

Note that

1. TASSIGN takes an inordinate amount of memory. Using M=1700, only three files can be TASSIGN'ed.
2. The IBM prefix (in the SDN= parameter) need not be the same as the CRAY prefix.
3. Any previous IBM file with the name prefix.FILExx should be erased prior to sending a new one from the CRAY. Otherwise, the sent file will appear with a ridiculous system name.
4. The files sent from the CRAY will be stored as 'I/O PENDING' files, and should be properly disposed of in a timely fashion.

B.6 NASCAP

The NASCAP source (excluding FREED routines and a few modifications) resides on the IBM in the file CRAY.NASCAP (suitable for CRAY submission) and on the CRAY in NASCPROGLIB. The source may be compiled into NASCOBJLIB by submitting CRAY.COMPILE. Sources for routines found to require correction during testing are in CRAY.NASBLD, which will make the corrections to NASCOBJLIB. The absolute, NASCABS, will be created by CRAY.NASTRY.

An initial-run NASCAP runstream might be:

```
ACCESS, DN=FILES, PDN=CRAYFILES, ID=NASCAP
ACCESS, DN=NASCAP, PDN=NASCABS, ID=NASCAP
FILES.
REWIND, DN=FILES.
COPYF, O=FT20.
REWIND, DN=FT20.
COPYF, O=FT22.
REWIND, DN=FT22.
COPYF, O=FT26.
REWIND, DN=FT26.
NASCAP.
FILES.
/EOF
      ASSIGN prefix
      ACCESS prefix
/EOF
      Object definition input
/EOF
      Environment definition input
/EOF
      Option input
/EOF
      NASCAP input
/EOF
      ADJUST prefix
/EOF
```

1. For subsequent run, the ASSIGN command to CRAYFILES should be omitted, and the COPYF commands may be omitted if not needed.
2. As in other versions of NASCAP, commands such as OBJDEF 5 cause data to be read directly from NASCAP input rather than from a separate file.
3. In the above runstream, if NASCAP exits due to an 'END' command, the ADJUST will not be performed, as FILES will encounter the /EOF. Solutions are either (a) omit the 'END', in which case NASCAP will exit normally on encountering the /EOF; or (b) follow the 'NASCAP." command with

```
REWIND, DN=$IN.
SKIPF, NF=5.
```

which will position $IN following the sixth '/EOF'

B.7 TERMTALK, CONTOURS, AND PLOTREAD

These routines are accessed by the IBM commands (procedures)

```
TERMTALK prefix
CONTOURS prefix
PLOTREAD prefix.
```

Their sources are located in SOURCE.TTALK, SOURCE.CONTOURS, and SOURCE.IBMPLOT, and their objects in LIB.TERMTALK, LIB.CONTOURS, and LIB.IBMPLOT. The procedures contain statements to DDEF the appropriate files with DSNAME=prefix.FILExx (see CRAYTOIBM). Operation on the IBM is similar to the UNIVAC. See the TSS/370 Graphics Manual for plot destinations.

REFERENCES

1. Stannard, P. R., I. Katz and M. J. Mandell, "Additional Extensions to the NASCAP Computer Code, Volume II," NASA CR-167856, Chapter 3, 1982.

2. Katz, I., D. E. Parks, M. J. Mandell, J. M. Harvey, D. H. Brownell, Jr., S. S. Wang and M. Rotenberg, "A Three Dimensional Dynamic Study of Electrostatic Charging in Materials," NASA CR-135256, August 1977.

3. Katz, I., J. J. Cassidy, M. J. Mandell, G. W. Schnuelle, P. G. Steen, D. E. Parks, M. Rotenberg and J. H. Alexander, "Extension, Validation and Application of the NASCAP Code," NASA CR-159595, January 1979.

4. Feldman, C., Physical Review, 117, p. 455, 1960.

5. Hackenberg, O and W. Bauer, Advances in Electronics and Electron Physics, 16, p. 145, 1962.

6. Ashley, J. C., C. J. Tung, V. E. Anderson and R. H. Ritchie, (i) AFCRL-TR-75-0583; (ii) RADC-TR-76-220; (iii) RADC-TR-76-125; (iv) IEEE Transactions on Nuclear Science, NS-25/6, p. 1566, 1978.

7. Aarset, B., R. W. Cloud and J. G. Trump, "Electron Emission from Metals Under High-Energy Hydrogen Ion Bombardment," J. Appl. Phys., 25, p. 1365, 1954.

8. Foti, G., R. Potenza and A. Triglia, "Secondary-Electron Emission from Various Materials Bombarded with Protons at $E_p < 2.5$ MeV," Lett. al Nuovo Cim., 11, p. 659, 1974.

9. Hill, A. G., W. W. Buechner, J. S. Clark and J. B. Fisk, "The Emission of Secondary Electrons Under High-Energy Positive Ion Bombardment," Phys. Rev., 55, p. 463, 1939.

10. Cousinie, P., N. Colombie, C. Fert and R. Simon, "Variation du coefficient e'emission electronique secondaire de quelques metaux avec l'energie des ions incidents," Comptes Rendus 249, p. 387, 1959.

11. Darlington, E. H. and V. E. Cosslett, "Backscattering of 0.5-10 keV Electrons from Solid Targets," J. Phys. D5, p. 1969, 1972.

12. Shimizu, R., "Secondary Electron Yield with Primary Electron Beam of Kilo-electron-volts," J. Appl. Phys., 45, p. 2107, 1974.

13. Ademec, F. and J. H. Calderwood, "Electrical Conduction in Dielectrics at High Fields," J. Phys., D-8, p. 351, 1975.

14. Schnuelle, G. W., P. R. Stannard, I. Katz and M. J. Mandell, "Simulation of Charging Response of SCATHA (P78-2) Satellite," Spacecraft Charging Technology-1980, NASA CP-2182, AFGL-TR-81-0270, p. 580, 1981.

15. Frederickson, A. R., IEEE Transactions on Nuclear Science, NS-24, p. 2352, 1977.

16. Singley, G. W. and J. I. Vette, "The AE4 Model of the Outer Radiation Zone Electron Environment," NASA Report NSSDC-72-06, Ausut 1972.

17. Hilberg, R. H. et al., "Comparison of the Trapped-Electron Models AE4 and AE5 with AE2 and AE3," NASA Report NSSDC-74-13, September 1975.

18. Goldstein, H., Classical Mechanics, Addison-Wesley, Reading, MA, p. 83, 1957.

19. ibid, p. 135.

20. TERMTALK, POTPLT, and OBJCHECK are auxiliary codes to NASCAP proper. TERMTALK is a post-processor designed to generate reports showing time histories of charging simulations. POTPLT produces potential contour plots interactively, and OBJCHECK is an interactive version of the OBJDEF and SATPLT module.

21. Stannard, P. R., I. Katz and D. E. Parks, "Bootstrap Charging of Surfaces Composed of Multiple Materials," IEEE Transactions on Nuclear Science, NS-28, p. 4563, 1981.

22. Purvis, C. K., "Evolution of Spacecraft Charging Technology," AIAA Paper 82-0273, 1982.

23. Mandell, M. J., I. Katz, G. W. Schnuelle and P. G. Steen, "The Decrease in Effective Photocurrents Due to Saddle Points in Electrostatic Potentials Near Differentially Charged Spacecraft," IEEE Transactions on Nuclear Science, NS-25, p. 1313, 1978.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	May 1993	Final Contractor Report

4. TITLE AND SUBTITLE

NASCAP Programmer's Reference Manual

5. FUNDING NUMBERS

WU-506-41-52
C-NAS3-22826

6. AUTHOR(S)

M.J. Mandell, P.R. Stannard, and I. Katz

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

S-Cubed
Division of Maxwell Laboratories, Inc.
P.O. Box 1620
La Jolla, California 92038-1620

8. PERFORMING ORGANIZATION REPORT NUMBER

E-7850

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135-3191

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA CR-191044

11. SUPPLEMENTARY NOTES

Project Manager, James C. Roche, Power Technology Division, (216) 433-2295.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category 46

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

The NASA Charging Analyzer Program (NASCAP) is a computer program designed to model the electrostatic charging of complicated three-dimensional objects, both in a test tank and at geosynchronous altitudes. This document is a programmer's reference manual and user's guide. It is designed as a reference to experienced users of the code, as well as an introduction to its use for beginners. All of the many capabilities of NASCAP are covered in detail, together with examples of their use. These include the definition of objects, plasma environments, potential calculations, particle emission and detection simulations and charging analysis.

14. SUBJECT TERMS

Spacecraft charging code; Geosynchronous satellites

15. NUMBER OF PAGES

530

16. PRICE CODE

A23

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	