NASCAP Programmer's Reference Manual

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S-Cubed
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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:

$$i_{net} = i_{electrons} + i_{ions} + i_{electrons} + i_{ions}$$

$$+ i_{backscatter} + i_{conductivity} + i_{photoemission}$$

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.](image)

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
OBJDEF
HIDCEL
CAPACI
TRILIN
END
```

```
RDOPT
OBJDEF
CAPACI
HIDCEL
TRILIN
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:
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>
<thead>
<tr>
<th>Module and Keyword</th>
<th>Task</th>
<th>Additional Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPACI</td>
<td>Calculates object capacitances</td>
<td>No</td>
</tr>
<tr>
<td>DETECT</td>
<td>Enables DETECTOR run option</td>
<td>Yes. Default - assumes input follows keyword (Unit 5)</td>
</tr>
<tr>
<td>HIDCEL</td>
<td>Calculates the shadowing of an object illuminated by the sun</td>
<td>No</td>
</tr>
<tr>
<td>IPS</td>
<td>Sets up initial potentials other than zero on surface cells</td>
<td>Yes. Default - assumes input follows keyword (Unit 5)</td>
</tr>
<tr>
<td>NEWMAT</td>
<td>Defines new material properties</td>
<td>Yes. (No default - input file must be specified)</td>
</tr>
<tr>
<td>OBJDEF</td>
<td>Reads and processes object definition information</td>
<td>Yes. Default - read object definition from file 20</td>
</tr>
<tr>
<td>RDOPT</td>
<td>Reads run option and initializes program parameters</td>
<td>Yes. Default - read option from file 26</td>
</tr>
<tr>
<td>ROTATE</td>
<td>Causes NASCAP to model a rotating object</td>
<td>Yes. (No default - input file must be specified)</td>
</tr>
<tr>
<td>SATPLT</td>
<td>Produces plots and pictures of the object</td>
<td>No</td>
</tr>
<tr>
<td>SPIN</td>
<td>Causes NASCAP to model a rotating object by averaging the effect of the sun and magnetic field over one rotation</td>
<td>Yes. (No default - input file must be specified)</td>
</tr>
<tr>
<td>STRESS</td>
<td>Searches for insulating cells having the highest internal stress</td>
<td>Yes. (No default - input file must be specified)</td>
</tr>
<tr>
<td>TANK</td>
<td>Defines a test tank environment with multiple particle guns</td>
<td>Yes. Default - read gun definitions from file 22</td>
</tr>
<tr>
<td>TRILIN</td>
<td>Reads parameters describing the plasma environment and calculates potentials and currents</td>
<td>Yes. Default - read environment from file 22</td>
</tr>
</tbody>
</table>
TABLE 2.2. PRECEDENCE OF PRIMARY KEYWORDS

<table>
<thead>
<tr>
<th>Keyword</th>
<th>Must Be Preceded By</th>
<th>Logically Precedes</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPACI</td>
<td>OBJDEF</td>
<td>TRILIN or IPS</td>
</tr>
<tr>
<td>DETECT</td>
<td>TRILIN (or IPS)</td>
<td>(None)</td>
</tr>
<tr>
<td>HIDCEL</td>
<td>OBJDEF</td>
<td>TRILIN</td>
</tr>
<tr>
<td>IPS</td>
<td>CAPACI</td>
<td>TRILIN or DETECT</td>
</tr>
<tr>
<td>NEWMAT</td>
<td>OBJDEF</td>
<td>TRILIN</td>
</tr>
<tr>
<td>OBJDEF</td>
<td>RDOPT</td>
<td>CAPACI</td>
</tr>
<tr>
<td>RDOPT</td>
<td>(None)</td>
<td>(ALL)</td>
</tr>
<tr>
<td>ROTATE</td>
<td>TRILIN</td>
<td>TRILIN</td>
</tr>
<tr>
<td>SATPLT</td>
<td>OBJDEF</td>
<td>(None)</td>
</tr>
<tr>
<td>SPIN</td>
<td>OBJDEF</td>
<td>TRILIN</td>
</tr>
<tr>
<td>STRESS</td>
<td>TRILIN</td>
<td>(None)</td>
</tr>
<tr>
<td>TANK</td>
<td>RDOPT</td>
<td>TRILIN*</td>
</tr>
<tr>
<td>TRILIN</td>
<td>CAPACI</td>
<td>DETECT</td>
</tr>
<tr>
<td>COMMENT</td>
<td>(None)</td>
<td>(None)</td>
</tr>
</tbody>
</table>

* If shadowing options HIDCEL, SPIN or ROTATE are chosen, they must follow TANK before TRILIN.
<table>
<thead>
<tr>
<th>Default File No.</th>
<th>File Name</th>
<th>Written By</th>
<th>Read By</th>
<th>Information Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>None</td>
<td>OBJDEF, SATPLT, HIDCEL, *ROTATE, SPIN, DETECT, TRILIN</td>
<td>NASCAP*PLOTREAD. (Chapter 9)</td>
<td>NASCAP graphics calls.</td>
</tr>
<tr>
<td>10 (RESTART)</td>
<td>IP</td>
<td>TRILIN, CAPACI, IPS</td>
<td>TRILIN, CAPACI, IPS</td>
<td>Conjugate gradient scratch file (Section 3.15). Contains potential array on completion of TRILIN, CAPACI or IPS.</td>
</tr>
<tr>
<td>11</td>
<td>IAUN</td>
<td>TRILIN, CAPACI, IPS, SPIN</td>
<td>TRILIN, CAPACI, IPS</td>
<td>Conjugate gradient scratch file (Section 3.15). SPIN scratch file - used to store shadowing information.</td>
</tr>
<tr>
<td>12</td>
<td>IR</td>
<td>TRILIN, CAPACI, IPS</td>
<td>TRILIN, CAPACI, IPS</td>
<td>Conjugate gradient scratch file (Section 3.15).</td>
</tr>
<tr>
<td>13</td>
<td>IU</td>
<td>TRILIN, CAPACI, IPS</td>
<td>TRILIN, CAPACI, IPS</td>
<td>Conjugate gradient scratch file (Section 3.15).</td>
</tr>
</tbody>
</table>
TABLE 2.3. NASCAP OUTPUT FILES (CONTINUED)

<table>
<thead>
<tr>
<th>Default File No.</th>
<th>File Name</th>
<th>Written By</th>
<th>Read By</th>
<th>Information Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>ISPARSE</td>
<td>(TRILIN CAPACI IPS)</td>
<td>(TRILIN CAPACI IPS)</td>
<td>Conjugate gradient scratch file (Section 3.15).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(HIDCEL SPIN TANK SATPLT ROTATE)</td>
<td>(HIDCEL SPIN TANK SATPLT ROTATE)</td>
<td>Scratch file for shadowing information.</td>
</tr>
<tr>
<td>15 (RESTART)</td>
<td>IROUS</td>
<td>(TRILIN CAPACI IPS)</td>
<td>(TRILIN CAPACI IPS)</td>
<td>Charge density array.</td>
</tr>
<tr>
<td>16 (RESTART)</td>
<td>IPQCND</td>
<td>TRILIN</td>
<td>OBJDEF</td>
<td>Associated independent program 'TERMTALK'</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(OBJDEF CAPACI TRILIN IPS DETECT)</td>
<td>TERMTALK information (Section 3.15).</td>
</tr>
<tr>
<td>17 (RESTART)</td>
<td>ILTBL</td>
<td>OBJDEF</td>
<td>TRILIN</td>
<td>Object volume element table (LTBL).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(OBJDEF CAPACI TRILIN IPS DETECT)</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>IOBJ</td>
<td>None</td>
<td>None</td>
<td>Reserved for future use.</td>
</tr>
<tr>
<td>19 (RESTART when 'TANK' is specified)</td>
<td>IOBPLT</td>
<td>TANK</td>
<td>TRILIN</td>
<td>Beam shadowing information.</td>
</tr>
<tr>
<td>Default File No.</td>
<td>File Name</td>
<td>Written By</td>
<td>Read By</td>
<td>Information Content</td>
</tr>
<tr>
<td>-----------------</td>
<td>-----------</td>
<td>------------</td>
<td>---------</td>
<td>---------------------</td>
</tr>
<tr>
<td>21 (RESTART)</td>
<td>ICNOW</td>
<td>All</td>
<td>All</td>
<td>Individual cell information (Section &quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>IDIV</td>
<td>{TRILIN, CAPACI, IPS}</td>
<td>{TRILIN, CAPACI, IPS}</td>
<td>$D^2$ (Scaled conjugate gradient array).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27 (RESTART)</td>
<td>IAREA OBJDEF</td>
<td>{TRILIN, CAPACI, IPS}</td>
<td>Boom conjugate gradient matrices.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>IPART TRILIN</td>
<td>DETECT</td>
<td>Particle plotting information.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>None DETECT</td>
<td>(User program)</td>
<td>Particle trajectory information (Chapter 7).</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>None END</td>
<td>EXEC file to automatically execute PLOTREAD.</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Table 2.4: User Input Files</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NASCAP Name</strong></td>
<td><strong>Default File Number</strong></td>
<td><strong>Read By</strong></td>
<td><strong>Information Content</strong></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>5</td>
<td>Main Program</td>
<td>NASCAP KEYWORDS and runstream (cannot be changed).</td>
<td></td>
</tr>
<tr>
<td>ISPECTR</td>
<td>9</td>
<td>TRILIN in 'UPDATE' or 'DIRECT' modes (Chapter 5)</td>
<td>Environment information (Chapter 5).</td>
<td></td>
</tr>
<tr>
<td>ISAT</td>
<td>20</td>
<td>OBJDEF</td>
<td>Object definition statements (Chapter 3).</td>
<td></td>
</tr>
<tr>
<td>IFLUX</td>
<td>22</td>
<td>TRILIN or TANK</td>
<td>Environment information (Chapter 5).</td>
<td></td>
</tr>
<tr>
<td>IKEYWD</td>
<td>26</td>
<td>RDOPT</td>
<td>User specified options (Chapter 6).</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>None</td>
<td>TRILIN - when EMITTER option is enabled</td>
<td>Emitter information (Chapter 7).</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>None</td>
<td>DETECT</td>
<td>Detector information (Chapter 7).</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>None</td>
<td>NEWMAT</td>
<td>Material properties (Chapter 4).</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>None</td>
<td>IPS</td>
<td>Initial potential specifications (Chapter 8).</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>None</td>
<td>ROTATE</td>
<td>ROTATE parameters (Chapter 8).</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>None</td>
<td>SPIN</td>
<td>SPIN parameters (Chapter 8).</td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 2.5. SPARE FILES AVAILABLE TO THE USER

<table>
<thead>
<tr>
<th></th>
<th>30</th>
<th>37</th>
<th>47</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>31</td>
<td>39</td>
<td>48</td>
</tr>
<tr>
<td>4*</td>
<td>32</td>
<td>40**</td>
<td>49</td>
</tr>
<tr>
<td>8</td>
<td>33</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>34</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>35</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>36</td>
<td>45</td>
<td></td>
</tr>
</tbody>
</table>

* 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>
<thead>
<tr>
<th>Record No.</th>
<th>Record ID</th>
<th>Length</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>VINS</td>
<td>1024</td>
<td>Potentials of insulating surface cells (V)</td>
</tr>
<tr>
<td>2</td>
<td>VPTS</td>
<td>1024</td>
<td>Not used</td>
</tr>
<tr>
<td>3</td>
<td>EINS</td>
<td>1024</td>
<td>Electric field external to insulating surface cells (V mesh⁻¹)</td>
</tr>
<tr>
<td>4</td>
<td>ATOT</td>
<td>1250</td>
<td>Areas of surface cells (mesh)²</td>
</tr>
<tr>
<td>5</td>
<td>AREA</td>
<td>1250</td>
<td>Fraction of the area of surface cells sunlit</td>
</tr>
<tr>
<td>6</td>
<td>C-INF</td>
<td>1024</td>
<td>Capacitance of insulating cells to plasma ground or tank wall (code units)</td>
</tr>
<tr>
<td>7</td>
<td>DPTLST</td>
<td>500</td>
<td>List of double points (see 3.13)</td>
</tr>
<tr>
<td>8</td>
<td>C-COND</td>
<td>1024</td>
<td>Capacitance from the surface of an insulating cell to its underlying conductor (code units)</td>
</tr>
<tr>
<td>9</td>
<td>FLUX</td>
<td>1250</td>
<td>Explicit net particle flux to each surface cell (code units)</td>
</tr>
<tr>
<td>10</td>
<td>DQEMIT</td>
<td>1024</td>
<td>Change in charge due to low energy emitted electron for each insulating cell (code units)</td>
</tr>
<tr>
<td>11</td>
<td>DQ</td>
<td>1024</td>
<td>Change in charge for each insulating cell (code units)</td>
</tr>
<tr>
<td>12</td>
<td>PTLIST</td>
<td>1024</td>
<td>List of all points that are corners of insulating surface cells</td>
</tr>
<tr>
<td>13</td>
<td>APT</td>
<td>1024</td>
<td>Areas associated with above points (PTLIST) (mesh)²</td>
</tr>
<tr>
<td>Record No.</td>
<td>Record ID</td>
<td>Length</td>
<td>Content</td>
</tr>
<tr>
<td>-----------</td>
<td>-----------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>14</td>
<td>LINS</td>
<td>1024</td>
<td>List of insulating surface cell numbers</td>
</tr>
<tr>
<td>15</td>
<td>VBOOM</td>
<td>100</td>
<td>Potentials of the boom cells (V)</td>
</tr>
<tr>
<td>16</td>
<td>SIGMA</td>
<td>1024</td>
<td>(Not used)</td>
</tr>
<tr>
<td>17</td>
<td>EBOOM</td>
<td>100</td>
<td>Electric fields external to boom surface cells (V mesh⁻¹)</td>
</tr>
<tr>
<td>18</td>
<td>DFDV</td>
<td>1024</td>
<td>Flux derivatives for insulating surface cells</td>
</tr>
<tr>
<td>19</td>
<td>CSCOND</td>
<td>15</td>
<td>Capacitance of each conductor to plasma ground or test tank wall (code units)</td>
</tr>
<tr>
<td>20</td>
<td>CIJSMA</td>
<td>15</td>
<td>Stray capacitances of conductor to spacecraft ground (code units)</td>
</tr>
<tr>
<td>21</td>
<td>SCMAT</td>
<td>9537</td>
<td>Conductivity matrix (code units)</td>
</tr>
<tr>
<td>22</td>
<td>SCLIST</td>
<td>9537</td>
<td>Sparseness pattern of conductivity matrix (who connects to whom)</td>
</tr>
<tr>
<td>23</td>
<td>CPTLST</td>
<td>1024</td>
<td>List of surface points which are not corners of insulating cells</td>
</tr>
<tr>
<td>24</td>
<td>BINF</td>
<td>141</td>
<td>BINF common block - boom parameters</td>
</tr>
<tr>
<td>25</td>
<td>BSHAD</td>
<td>100</td>
<td>Shadowing factors for boom cells</td>
</tr>
<tr>
<td>Record No.</td>
<td>Record ID</td>
<td>Length</td>
<td>Content</td>
</tr>
<tr>
<td>------------</td>
<td>-----------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>26</td>
<td>XFLUX</td>
<td>200</td>
<td>Explicit net flux for boom cells (code units)</td>
</tr>
<tr>
<td>27</td>
<td>PPEE</td>
<td>500</td>
<td>Potentials for bottom point of a double point (conjugate gradient)</td>
</tr>
<tr>
<td>28</td>
<td>PYOU</td>
<td>500</td>
<td>Vector U (conjugate gradient) for bottom points</td>
</tr>
<tr>
<td>29</td>
<td>PARR</td>
<td>500</td>
<td>Vector R (conjugate gradient) for bottom points</td>
</tr>
<tr>
<td>30</td>
<td>PAUN</td>
<td>500</td>
<td>Vector AU (conjugate gradient) for bottom points</td>
</tr>
<tr>
<td>31</td>
<td>PDIV</td>
<td>500</td>
<td>Vector $D^2$ (scaled conjugate gradient) for bottom points</td>
</tr>
<tr>
<td>32</td>
<td>PROUS</td>
<td>500</td>
<td>Charge densities for bottom points (code units)</td>
</tr>
<tr>
<td>33</td>
<td>VCELLS</td>
<td>1250</td>
<td>Potentials of surface cells (V)</td>
</tr>
<tr>
<td>34</td>
<td>ECELLS</td>
<td>1250</td>
<td>External electric fields of surface cells $V$ (mesh$^{-1}$)</td>
</tr>
<tr>
<td>35</td>
<td>PZLIST</td>
<td>500</td>
<td>List of bottom points held at fixed potentials</td>
</tr>
<tr>
<td>36</td>
<td>ZLIST</td>
<td>1024</td>
<td>List of top points held at fixed potentials</td>
</tr>
<tr>
<td>37</td>
<td>RFLAGS</td>
<td>1</td>
<td>Type of shadowing performed</td>
</tr>
<tr>
<td>38</td>
<td>SURF3</td>
<td>1251</td>
<td>Common block – number of surface cells (1) and surface cell list (1250)</td>
</tr>
<tr>
<td>39</td>
<td>MATLS</td>
<td>316</td>
<td>Material properties (MATLS common block) (see Chapter 4)</td>
</tr>
<tr>
<td>40</td>
<td>VTXL</td>
<td>6200</td>
<td>Vertex surface cell list</td>
</tr>
<tr>
<td>41</td>
<td>BOOMS</td>
<td>111</td>
<td>Common block – boom information</td>
</tr>
</tbody>
</table>
TABLE 2.6. FILE 21 RECORDS (CONTINUED)

<table>
<thead>
<tr>
<th>Record No.</th>
<th>Record ID</th>
<th>Length</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>42</td>
<td>SILHOU</td>
<td>6289</td>
<td>Non-hidden line object plotting information</td>
</tr>
<tr>
<td>43</td>
<td>BLOCKS</td>
<td>597</td>
<td>Common block - volume cell information</td>
</tr>
<tr>
<td>44</td>
<td>TIMHIS</td>
<td>150</td>
<td>Elapsed time for each cycle performed so far (seconds)</td>
</tr>
<tr>
<td>45</td>
<td>QSUHIS</td>
<td>150</td>
<td>Total charge on the object at each cycle (code units)</td>
</tr>
<tr>
<td>46</td>
<td>RELSAV</td>
<td>35</td>
<td>Time and conductor potentials and charges for current cycle (volts and code units)</td>
</tr>
<tr>
<td>47</td>
<td>INTSAV</td>
<td>35</td>
<td>Cycle number, number of conductors, etc.</td>
</tr>
<tr>
<td>48</td>
<td>RDOTSV</td>
<td>100</td>
<td>Residuals for each conjugate gradient iteration</td>
</tr>
<tr>
<td>49</td>
<td>CAPRDO</td>
<td>100</td>
<td>Residuals from each conjugate gradient iteration called from CAPACI</td>
</tr>
<tr>
<td>50</td>
<td>PCONSV</td>
<td>2250</td>
<td>Conductor potential for each cycle completed (V)</td>
</tr>
<tr>
<td>51</td>
<td>PHCMAT</td>
<td>9537</td>
<td>Conductivity matrix including photoconductivity (code units)</td>
</tr>
<tr>
<td>52</td>
<td>CNDCUR</td>
<td>60</td>
<td>Currents to each conductor (A)</td>
</tr>
<tr>
<td>53</td>
<td>FIFLUX</td>
<td>1350</td>
<td>Average flux to each surface cell during the previous timestep (A m⁻²)</td>
</tr>
<tr>
<td>54</td>
<td>SCOPT</td>
<td>5</td>
<td>Common block - screening options</td>
</tr>
<tr>
<td>55</td>
<td>GUNS</td>
<td>181</td>
<td>Common block - multigun definition information</td>
</tr>
<tr>
<td>56</td>
<td>FIN</td>
<td>1250</td>
<td>Incident electron current to surface cells (A m⁻²)</td>
</tr>
<tr>
<td>Record No.</td>
<td>Record ID</td>
<td>Length</td>
<td>Content</td>
</tr>
<tr>
<td>-----------</td>
<td>-----------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>57</td>
<td>FOU</td>
<td>1250</td>
<td>( \text{Secondary electron current from surface cells (A m}^{-2} )</td>
</tr>
<tr>
<td>58</td>
<td>FINP</td>
<td>1250</td>
<td>( \text{Incident ion current to surface cells (A m}^{-2} )</td>
</tr>
<tr>
<td>59</td>
<td>FOUP</td>
<td>1250</td>
<td>( \text{Secondary electron current due to ion impact from surface cells (A m}^{-2} )</td>
</tr>
<tr>
<td>60</td>
<td>FELB</td>
<td>1250</td>
<td>( \text{Backscatter from surface cells (A m}^{-2} )</td>
</tr>
<tr>
<td>61</td>
<td>PCURR</td>
<td>1250</td>
<td>( \text{Photocurrent from surface cells (A m}^{-2} )</td>
</tr>
<tr>
<td>62</td>
<td>BFIN</td>
<td>250</td>
<td>( \text{Incident electron current to boom cells (A m}^{-2} )</td>
</tr>
<tr>
<td>63</td>
<td>BFOU</td>
<td>250</td>
<td>( \text{Secondary electron current from boom cells (A m}^{-2} )</td>
</tr>
<tr>
<td>64</td>
<td>BFIP</td>
<td>250</td>
<td>( \text{Incident ion current to boom cells (A m}^{-2} )</td>
</tr>
<tr>
<td>65</td>
<td>BFOP</td>
<td>250</td>
<td>( \text{Secondary electron current due to ion impact on boom cells (A m}^{-2} )</td>
</tr>
<tr>
<td>66</td>
<td>BFEL</td>
<td>250</td>
<td>( \text{Backscatter from boom cells (A m}^{-2} )</td>
</tr>
<tr>
<td>67</td>
<td>BPCU</td>
<td>250</td>
<td>( \text{Photocurrent from boom cells (A m}^{-2} )</td>
</tr>
<tr>
<td>68</td>
<td>ANIP</td>
<td>4</td>
<td>( \text{Anisotropic flux parameters} )</td>
</tr>
<tr>
<td>69</td>
<td>TNKSZ</td>
<td>5</td>
<td>( \text{Grid truncation information} )</td>
</tr>
<tr>
<td>70</td>
<td>CLST</td>
<td>1024</td>
<td>( \text{Field-induced bulk conductivity of insulating cells (code units)} )</td>
</tr>
<tr>
<td>71</td>
<td>FINER</td>
<td>61</td>
<td>( \text{(Not used by NASCAP)} )</td>
</tr>
<tr>
<td>72</td>
<td>MCOND</td>
<td>286</td>
<td>( \text{Common block - capacitance between conductors and fixing information} )</td>
</tr>
</tbody>
</table>
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
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
- FIL11

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

<table>
<thead>
<tr>
<th>Keyword</th>
<th>Building Block Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOOM</td>
<td>Long thin BOOM</td>
</tr>
<tr>
<td>FILL11</td>
<td>Smooth inside of a diagonal corner</td>
</tr>
<tr>
<td>OCTAGON</td>
<td>Right octagonal cylinder</td>
</tr>
<tr>
<td>PATCHR</td>
<td>Surface of a rectangle</td>
</tr>
<tr>
<td>PATCHW</td>
<td>Diagonal face of a wedge</td>
</tr>
<tr>
<td>PLATE</td>
<td>Arbitrarily thin plate or cuboid</td>
</tr>
<tr>
<td>QSPHERE</td>
<td>Quasisphere</td>
</tr>
<tr>
<td>RECTAN</td>
<td>Cuboid or rectangular parallelepiped</td>
</tr>
<tr>
<td>TETRAH</td>
<td>Tetrahedron</td>
</tr>
<tr>
<td>WEDGE</td>
<td>Wedge derived from half a cube</td>
</tr>
</tbody>
</table>
the building block, its orientation and the materials that cover its surface. (Surface materials are discussed in Chapter 4.) Finally, OBJJDEF 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

- **RECTAN**
  - CORNER x y z
  - DELTAS Δx Δy Δz
  - (UP TO 6 SURFACE CARDS)
  - ENDOBJ

- **WEDGE**
  - CORNER x y z
  - FACE materialname normal
  - (type 110)
  - LENGTH Δx Δy Δz
  - (UP TO 4 SURFACE CARDS)
  - ENDOBJ

- **TETRAH**
  - CORNER x y z
  - FACE materialname normal
  - (type 111)
  - LENGTH Δx
  - (UP TO 3 SURFACE CARDS)
  - ENDOBJ

- **OCTAGON**
  - AXIS x y z x’ y’ z’
  - WIDTH w
  - SIDE s
  - (UP TO 3 SPECIAL SURFACE CARDS or "C")
  - ENDOBJ

- **BOOM**
  - AXIS x y z x’ y’ z’
  - RADIUS radius (floating point)
  - SURFACE materialname
  - ENDOBJ

- **CSPHERE**
  - CENTER x y z
  - DIAMETER d
  - SIDE s
  - MATERIAL materialname
  - ENDOBJ

- **QSPHERE**
  - CENTER x y z
  - DIAMETER d
  - SIDE s
  - MATERIAL materialname
  - ENDOBJ

#### OBJECT DEFINITION EXAMPLES

<table>
<thead>
<tr>
<th>NAME</th>
<th>EXAMPLE 1</th>
<th>EXAMPLE 2</th>
<th>EXAMPLE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIL111</td>
<td>CORNERLINE x z' y' z'</td>
<td>FACE materialname normal (type 111)</td>
<td>SURFACE SOLAR -1 -1 -1</td>
</tr>
<tr>
<td>CORNER</td>
<td>CORNER 3 2 8</td>
<td>CORNER 3 2 6</td>
<td>CORNER 3 2 6</td>
</tr>
<tr>
<td>SURFACE</td>
<td>+X ALUMINUM</td>
<td>-Y ALUMINUM</td>
<td>+Z ALUMINUM</td>
</tr>
<tr>
<td>TOP</td>
<td>TOP ± (2)</td>
<td>TOP ± (2)</td>
<td>TOP ± (2)</td>
</tr>
<tr>
<td>BOTTOM</td>
<td>BOTTOM ± (2)</td>
<td>BOTTOM ± (2)</td>
<td>BOTTOM ± (2)</td>
</tr>
<tr>
<td>PATCHR</td>
<td>PATCHR</td>
<td>PATCHR</td>
<td>PATCHR</td>
</tr>
<tr>
<td>CORNER</td>
<td>CORNER 3 2 8</td>
<td>CORNER 3 2 8</td>
<td>CORNER 3 2 8</td>
</tr>
<tr>
<td>DELTAS</td>
<td>Δx Δy Δz</td>
<td>Δx Δy Δz</td>
<td>Δx Δy Δz</td>
</tr>
<tr>
<td>TOP</td>
<td>TOP ± (2)</td>
<td>TOP ± (2)</td>
<td>TOP ± (2)</td>
</tr>
<tr>
<td>BOTTOM</td>
<td>BOTTOM ± (2)</td>
<td>BOTTOM ± (2)</td>
<td>BOTTOM ± (2)</td>
</tr>
</tbody>
</table>

#### NOTES

- "normal" is three values, each either +1.0, 0, or -1.
- SURFACE CARD has the following format:
  - SURFACE ± (2) materialname
- SPECIAL SURFACE CARD is:
  - SURFACE (3) 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 ≤ n ≤ 15).
- **DELETE i j k**
  - Deletes surfaces, leaving empty cell.
  - 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 within 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 TEFLO
{ <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:
      +1, +1, 0
      +1, 0, +1
      0, +1, +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

<table>
<thead>
<tr>
<th>Normal of WEDGE Face</th>
<th>Normals of Four Remaining Surfaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1 0</td>
<td>-X, -Y, Z, -Z</td>
</tr>
<tr>
<td>-1 1 0</td>
<td>X, -Y, Z, -Z</td>
</tr>
<tr>
<td>1 -1 0</td>
<td>-X, Y, Z, -Z</td>
</tr>
<tr>
<td>-1 -1 0</td>
<td>X, Y, Z, -Z</td>
</tr>
<tr>
<td>1 0 1</td>
<td>-X, Y, -Y, -Z</td>
</tr>
<tr>
<td>-1 0 1</td>
<td>X, Y, -Y, -Z</td>
</tr>
<tr>
<td>1 0 -1</td>
<td>-X, Y, -Y, Z</td>
</tr>
<tr>
<td>-1 0 -1</td>
<td>X, Y, -Y, Z</td>
</tr>
<tr>
<td>0 1 1</td>
<td>X, -X, -Y, -Z</td>
</tr>
<tr>
<td>0 -1 1</td>
<td>X, -X, Y, -Z</td>
</tr>
<tr>
<td>0 1 -1</td>
<td>X, -X, -Y, Z</td>
</tr>
<tr>
<td>0 -1 -1</td>
<td>X, -X, -Y, -Z</td>
</tr>
</tbody>
</table>
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 TEFLOF
SURFACE -Y TEFLOF
SURFACE +Z TEFLOF
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:

   +1, +1, +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 TEFLOF: 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>
<thead>
<tr>
<th>Normal of TETRAHedron Face</th>
<th>Normals of Three Remaining Surfaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1 1</td>
<td>-X, -Y, -Z</td>
</tr>
<tr>
<td>-1 1 1</td>
<td>X, -Y, -Z</td>
</tr>
<tr>
<td>1 -1 1</td>
<td>-X, Y, -Z</td>
</tr>
<tr>
<td>1 1 -1</td>
<td>-X, -Y, Z</td>
</tr>
<tr>
<td>-1 -1 1</td>
<td>X, Y, -Z</td>
</tr>
<tr>
<td>-1 1 -1</td>
<td>X, -Y, Z</td>
</tr>
<tr>
<td>1 -1 -1</td>
<td>-X, Y, Z</td>
</tr>
<tr>
<td>-1 -1 -1</td>
<td>X, Y, Z</td>
</tr>
</tbody>
</table>
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 + TEFLO
SURFACE - TEFLO
SURFACE C TEFLO
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 FIL11

The following cards define a FIL11:

FIL11
  CORNERLINE x y z x' y' z'
  FACE KAPTON 1 -1 -1
ENDOBJ

Notes:
1. FIL11: is the building block keyword.
2. CORNERLINE x y z x' y' z': defines both the length and the
direction of the "step" FIL11 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 Δx = -2, and
Δy = +2. Hence the line is 2√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 FIL11 and defines its orientation via
the surface normal of its exposed face: 1 -1 -1. The surface
normal can only be combinations of

+1 +1 +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 \( \Delta x \), \( \Delta y \), \( \Delta z \), 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

\[
\begin{pmatrix}
X \\
Y \\
Z \\
\end{pmatrix}
\]

TOP + \[
\begin{pmatrix}
Y \\
Z \\
\end{pmatrix}
\] ALUMIN

BOTTOM + \[
\begin{pmatrix}
X \\
Y \\
Z \\
\end{pmatrix}
\] 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 + \[
\begin{pmatrix}
X \\
Y \\
Z \\
\end{pmatrix}
\] 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 + \[
\begin{pmatrix}
X \\
Y \\
Z \\
\end{pmatrix}
\] 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 SI02
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
CORNER $x_1 \ x_2 \ x_3$      PLATE
DELTAS $d_1 \ d_2 \ d_3$       CORNER -4 -5 -6
ANTENNA matl                 DELTAS 0 3 5
ENDOBJ
ANTENNA GOLD

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

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

<table>
<thead>
<tr>
<th>Command</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATET</td>
<td>ATET</td>
</tr>
<tr>
<td>CORNER</td>
<td>CORNER 5 -3 5</td>
</tr>
<tr>
<td>FACE</td>
<td>FACE AQUADG -1 1</td>
</tr>
<tr>
<td>LENGTH</td>
<td>LENGTH 3</td>
</tr>
<tr>
<td>ENDOBJ</td>
<td>ENDOBJ</td>
</tr>
</tbody>
</table>

ATET will not accept any additional 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.
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.
Figure 3.16. (Continued)
Figure 3.16. (Continued)
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.

<table>
<thead>
<tr>
<th>Default coordinate system</th>
<th>Absolute coordinate system</th>
</tr>
</thead>
<tbody>
<tr>
<td>QSPHERE</td>
<td>OFFSET 0 0 0</td>
</tr>
<tr>
<td>CENTER 0 0 0</td>
<td>QSPHERE</td>
</tr>
<tr>
<td>DIAMETER 7</td>
<td>CENTER 9 9 17</td>
</tr>
<tr>
<td>SIDE 3</td>
<td>DIAMETER 7</td>
</tr>
<tr>
<td>MATERIAL KAPTON</td>
<td>SIDE 3</td>
</tr>
<tr>
<td>ENDOBJ</td>
<td>MATERIAL KAPTON</td>
</tr>
<tr>
<td></td>
<td>ENDOBJ</td>
</tr>
</tbody>
</table>

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 ≤ n ≤ 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.
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'.

77
Row of Double Points Extending in the Z Direction

Disjoint Volume Elements

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 \( \phi \) everywhere is given by the solution to Poisson's equation

\[
\nabla^2 \phi = -\rho / \varepsilon 
\]

(3.1)

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

\[
\frac{\delta}{\delta \phi} \left[ \left( \int_{V} \frac{1}{2} (\nabla \phi)^2 + \frac{\rho \phi}{\varepsilon} \right) + \int_{c_S} \frac{\rho \phi}{\varepsilon} \, ds + \int_{c_B} \phi \cdot dS' \right] = 0
\]
Figure 3.24. Examples of plates intersecting objects.
where we integrate over both the object and boundary surfaces (cS, cB).

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

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

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 $\phi$ 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

$$\int dV \frac{1}{2} (\nabla \phi)^2 = \sum_{e} \int_{V_e} \sum_{i} |\nabla N_{i}^{e}(x,y,z)\phi_i|^2$$
The quantity
\[ W_{ij}^e = \int dV_e \nabla N_{i}^{xyz} \cdot \nabla N_{j}^{xyz} \quad (3.3) \]
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:
\[ \frac{\delta}{\delta \phi} \left[ \sum_j \sum_i \sum_e W_{ij}^e \phi_i \phi_j = 0 \right] \quad (3.4) \]

Let \( \sum_e W_{ij}^e = M_{ij} \). Equation (3.4) becomes
\[ \frac{\delta}{\delta \phi} \left[ \sum_{ij} \phi_i M_{ij} \phi_j \right] = 0 = \tilde{M} \phi \]

Thus the set of \( \phi \) values at each node (\( \phi \)) that satisfy \( \tilde{M} \phi \) 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 \( \phi \) will yield a residual \( \tilde{r} \)
\[ \tilde{M} \phi = \tilde{r} \]
The iterative scheme used is the Scaled Conjugate Gradient technique. It is based on the following equations:

\[ r_0 = -M p_0 \]

\[ D_{ij} = |M_{ij}|^{-1/2} s_{ij} \]

\[ r^0_s = D r_0 \]

\[ u^0_s = r^0_s \]

\[ M^s_s = D M D \]

Then solve iteratively:

\[ a^i_s = (r^i_s, r^i_s)/(u^i_s, M_s u^i_s) \]

\[ (D^{-1} p)^i+1 = (D^{-1} p)^i + a^i_s p_s^i \]

\[ r^i+1_s = r^i_s - a^i_s M_s u^i_s \]

\[ b^i_s = (r^i+1_s, r^i+1_s)/(r^i_s, r^i_s) \]

\[ u^i+1_s = r^i+1_s + b^i_s u^i_s \]

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

\[
\tilde{r} = \sum_{e} r_{e} = \sum_{e} w_{e} u_{e}
\]

The residual \( \tilde{r} \) is constructed element by element (where the \( w_{e} \) matrix is only 8 x 8) and then summed. The 8 x 8 "weight" matrices \( w_{e} \) 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, $W_{ij}$: $\int d\Omega |\nabla \phi|^2 = \sum_{ij} W_{ij} \phi_i \phi_j$

<table>
<thead>
<tr>
<th>Point Index</th>
<th>Cube Corner</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 0 0</td>
</tr>
<tr>
<td>2</td>
<td>1 0 0</td>
</tr>
<tr>
<td>3</td>
<td>0 1 0</td>
</tr>
<tr>
<td>4</td>
<td>1 1 0</td>
</tr>
<tr>
<td>5</td>
<td>0 0 1</td>
</tr>
<tr>
<td>6</td>
<td>1 0 1</td>
</tr>
<tr>
<td>7</td>
<td>0 1 1</td>
</tr>
<tr>
<td>8</td>
<td>1 1 1</td>
</tr>
</tbody>
</table>
Standard Cell 0
Empty trilinear cube
Orientation: Arbitrary

Potential Function:

\[
\begin{array}{cccc}
1 & 2 & 3 & 4 \\
(1-x)(1-y)(1-z) & (1-z)(1-y)x & (1-x)y(1-z) & (1-z)yx \\
5 & 6 & 7 & 8 \\
z(1-y)(1-x) & x(1-y)(z) & zy(1-x) & xyz \\
\end{array}
\]

\[
W_{ij}
\]

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:

\[ i \]
\[ 1 \]
\[ 2 \]
\[ 3 \]
\[ 4 \]
\[ 5 \]
\[ 6 \]
\[ 7 \]
\[ 8 \]

\[ N_i \]
\[ 0 \]
\[ (1-y)(1-z) \]
\[ (1-x)(1-z) \]
\[ (x+y-1)(1-z) \]
\[ 0 \]
\[ (1-y)z \]
\[ (1-x)z \]
\[ (x+y-1)z \]

\[ W_{ij} \]
\[ 0 \]
\[ 0 \]
\[ 1/4 \]
\[ 1/24 \]
\[ 1/4 \]
\[ 0 \]
\[ 0 \]
\[ -1/8 \]
\[ -1/8 \]
\[ 5/12 \]
\[ 0 \]
\[ 0 \]
\[ 0 \]
\[ 0 \]
\[ 0 \]
\[ 0 \]
\[ -1/24 \]
\[ -1/8 \]
\[ 0 \]
\[ 1/4 \]
\[ 0 \]
\[ -1/24 \]
\[ 0 \]
\[ -1/8 \]
\[ 0 \]
\[ 1/24 \]
\[ 1/4 \]
\[ 0 \]
\[ -1/8 \]
\[ -1/8 \]
\[ -1/12 \]
\[ 0 \]
\[ -1/8 \]
\[ 5/12 \]
Standard Cell 2  
Cube with diagonal line on one face  
Orientation: Line from 2 to 3  
Potential Function:

\[
\begin{align*}
1 & \quad (1-x-y)(1-z)e(1-x-y) \\
2 & \quad [x (1-x-y)+(1-y)e(x+y-1)](1-z) \\
3 & \quad [y (1-x-y)+(1-x)e(x+y-1)](1-z) \\
4 & \quad (x+y-1)(1-z)e(x+y-1) \\
5 & \quad (1-x)(1-y)z \\
6 & \quad x(1-y)z \\
7 & \quad (1-x)yz \\
8 & \quad xyz \\
\end{align*}
\]

\[
\begin{array}{cccccc}
W_{ij}:
\hline
& 5/12 & -1/8 & 1/2 & -1/8 & 1/12 & 1/2 & 5/12 \\
\hline
\end{array}
\]
Standard Cell 3
Tetrahedron
\[ 2 < x + y + z < 3 \]
Orientation: Empty corner at point 8
Potential Function:

<table>
<thead>
<tr>
<th>( i )</th>
<th>( N^i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>1-z</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>1-y</td>
</tr>
<tr>
<td>7</td>
<td>1-x</td>
</tr>
<tr>
<td>8</td>
<td>( x+y+z-2 )</td>
</tr>
</tbody>
</table>

\( W_{ij} \):

\[
\begin{array}{cccc}
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1/6 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1/6 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1/6 \\
0 & 0 & 0 & -1/6 & 0 & -1/6 & -1/6 & 1/2 \\
\end{array}
\]
Standard Cell 4
Truncated Cube
Orientation: 000 corner (point 1) missing
Potential Function:
\[
\begin{array}{c|cccc}
\text{N} & 1 & 2 & 3 & 4 \\
0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 \\
2 & 0 & 0 & 0 & 0 \\
3 & 0 & 0 & 0 & 0 \\
4 & 0 & 0 & 0 & 0 \\
\end{array}
\]

\text{exercise for reader}

\[
W_{ij}:
\]
\[
\begin{array}{cccccccc}
0 & 5/12 & 5/12 & 5/12 & 5/12 & 5/12 & 5/12 & 5/12 \\
0 & 1/72 & 1/72 & 1/72 & 1/72 & 1/72 & 1/72 & 1/72 \\
0 & 1/45 & 1/45 & 1/45 & 1/45 & 1/45 & 1/45 & 1/45 \\
0 & 7/20 & 7/20 & 7/20 & 7/20 & 7/20 & 7/20 & 7/20 \\
\end{array}
\]
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.
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)]**

```
5 432 [10987654321] 0 9 8 7 6 5 432109876 5 [43210]
```

Field | Bits | Description
--- | --- | ---
A | 4-0 | Elt-type code
B | 14-6 | Orientation code
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 \( \mathbf{r} \) into vector \( \mathbf{s} \), where

\[
\mathbf{r} = (x, y, z)
\]

\[
\mathbf{s} = (q(i_1), q(i_2), q(i_3))
\]
$i_1$ 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

$q(1) = x$  \hspace{1cm} q(5) = 1-x
$q(2) = y$  \hspace{1cm} q(6) = 1-y
$q(3) = z$  \hspace{1cm} q(7) = 1-z

For example, the octal code 365 implies the transformation

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

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.

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

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).
Two bits are taken for each crystallographic index. The rightmost of the pair for 1, 0, the leftmost for + (set for minus).

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.

Conductor number - from 1 to 15.

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:

<table>
<thead>
<tr>
<th>Normal</th>
<th>i</th>
<th>j</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z</td>
<td>X</td>
<td>Y</td>
</tr>
<tr>
<td>X</td>
<td>Y</td>
<td>Z</td>
</tr>
<tr>
<td>Y</td>
<td>Z</td>
<td>X</td>
</tr>
</tbody>
</table>
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

        218*[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, $i^S_e$.
2. Secondary emission due to ion impact, $i^S_i$.
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:

$$i_{net} = i_e + i_p + i^S_e + i^S_i + i_b + i_P + i_c$$
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 $i_{\text{net}}$ 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 $i_{\text{net}} = 0$ 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 $i_{\text{net}}$ 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 $\varepsilon_r$

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

where $\varepsilon$ is the absolute dielectric constant and $\varepsilon_0$ is the dielectric constant of free space. $\varepsilon_r$ is dimensionless.
### TABLE 4.1. MATERIAL PROPERTIES
(see Section 4.3 for notes)

<table>
<thead>
<tr>
<th>Property No.</th>
<th>User Input Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>None</td>
<td>Relative dielectric constant</td>
</tr>
<tr>
<td>2</td>
<td>m</td>
<td>Dielectric material thickness</td>
</tr>
<tr>
<td>3</td>
<td>ohms(^{-1}) m(^{-1})</td>
<td>Bulk conductivity (= -1 for a metallic conductor)</td>
</tr>
<tr>
<td>4</td>
<td>None</td>
<td>Atomic number</td>
</tr>
<tr>
<td>5</td>
<td>None</td>
<td>Maximum secondary electron yield for electron impact</td>
</tr>
<tr>
<td>6</td>
<td>keV</td>
<td>Primary electron energy that produces maximum secondary yield</td>
</tr>
<tr>
<td>7</td>
<td>angstroms</td>
<td>Range parameters (4.3)</td>
</tr>
<tr>
<td>8</td>
<td>None</td>
<td>R = P7E(^P8) + P9E(^P10)</td>
</tr>
<tr>
<td>9</td>
<td>angstroms</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>None</td>
<td>Secondary electron yield due to impact of 1 keV protons</td>
</tr>
<tr>
<td>12</td>
<td>keV</td>
<td>Incident proton energy that produces maximum secondary electron yield</td>
</tr>
<tr>
<td>13</td>
<td>A m(^{-2})</td>
<td>Photoelectron yield for normally incident sunlight</td>
</tr>
<tr>
<td>14</td>
<td>ohms square(^{-1})</td>
<td>Surface resistivity (= -1 for non-conducting surface)</td>
</tr>
<tr>
<td>15</td>
<td>Volts</td>
<td>Maximum (absolute) potential attainable before a discharge must occur</td>
</tr>
<tr>
<td>16</td>
<td>Volts</td>
<td>Maximum potential difference between surface and underlying conductor before a discharge must occur</td>
</tr>
<tr>
<td>17</td>
<td>ohms(^{-1}) m(^{-1}) ((m^2 \text{s}^{-3}))(^{-1})</td>
<td>Radiation-induced conductivity coefficient (k)</td>
</tr>
<tr>
<td>18</td>
<td>None</td>
<td>Radiation-induced conductivity power ((\Delta))</td>
</tr>
<tr>
<td>19</td>
<td>kg m(^{-3})</td>
<td>Material density</td>
</tr>
</tbody>
</table>
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 $\sigma_0$ of the surface material in ohms$^{-1}$m$^{-1}$. $\sigma_0$ 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 $\sigma_0$ 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 ($\text{CH}_2)_n$ 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 $\delta$

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

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

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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

\[
R = P_7 E^8 + P_9 E^{10}
\]

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

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

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

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

i.e. $$\text{ohms} = \text{(ohms per square)} \times \text{dimensionless geometrical factor}$$
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 \( \sigma_r \) is given by

\[
\sigma_r = k D^\Delta
\]
where \( D \) 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\(^{-1}\) \((\text{m}^2 \text{s}^{-3})^{-1}\) (1 rad \( s^{-1} = 10^{-2} \text{ m}^2 \text{s}^3\)) and the power \( \Delta \), 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 \( \sigma_0 \) 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 not 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 must 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
NPAcNT
SIO2
SOLAR
TEFLON
SILVER
COMMENT DEFINITION OF SATELLITE "BIG EARS"

Material Name 1
{ material property cards

Material Name 2
{ 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.
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
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
DELTAS
1 1 1
SURFACE
-z GOLD
ENDOBJ
ENDSAT
```
Figure 4.3. 3D-VIEW of object produced by SATPLT (hidden lines).
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 $\delta$ 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, $\delta$, 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 $\theta$ 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:

$$E^n(x) = E^n_0 - \frac{x}{b}$$

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

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 $E^0$.

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, $R \ll 1/\alpha$, 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 $R \gg 1/\alpha$, $S(E_0,x)$ 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 $x = 0$.

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

NASCAP allows for a bi-exponential range law:

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

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 $\rho$ 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 $\Delta$ is given by

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

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.

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

$E_{\text{max}}$ 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

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

where the value of \( \eta \) is, within the uncertainty in the data, what would be obtained by assuming total backscattering at glancing incidence, viz. \( \eta = \log n_0 \). The net albedo for an isotropic flux is then

\[ A_0 = 2[1 - n_0(1 - \log n_0)]/\log(n_0)^2 \]

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

\[ \delta n_0 = 0.1 \exp[-E/5 \text{ keV}] \]

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
\[ n_0 = \left[ \log\left(E/0.05\right) \cdot \left( E - 0.05 \right) \cdot \left( 1.0 - E \right) / \log(20) \right] + \Theta(E - 1.0) \cdot 0.1 \exp(-E/5) + 1 - (2/e)^{0.372} \]

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 \( \theta \), according to the formula

\[ i_{\text{phot}} = (\text{Area exposed}) \cdot Y \cdot \cos \theta \]

This assumes that the yield per photon is, on average, independent of \( \theta \).

4.8.5 CONDUCTIVITY

The bulk conductivity \( \sigma_0 \) 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 \( \sigma \) 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.

\[ I_c = -\sigma \Delta V = -\sigma (V_s - V_c) \]
\( \sigma \) is the bulk conductivity of the sample in mhos. If \( \bar{\sigma} \) is the specific conductivity in mhos \( \text{m}^{-1} \) and \( A \) is the area of the sample in \( \text{m}^2 \)

\[
\sigma = \frac{\bar{\sigma} A}{d}
\]

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

\( I_c \) depends on \( \Delta V \) in a nonlinear way due to the electric field enhancement of \( \sigma \). Assuming a thin film, the field \( E \) is given by

\[
E = \frac{\Delta V}{d}
\]

Adamec and Calderwood\[13]\] have shown that \( \sigma \) depends on \( E \) in the following way:

\[
\sigma(E) = \frac{\sigma_0}{3} \left[ 2 + \cosh \left( \frac{\beta_F |E|^{1/2}}{2 kT} \right) \right]
\]

where

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

and \( q \) is the charge on the electron and \( \varepsilon \) 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 (≤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 $\sigma_r$.

Frederickson[15] has expressed $\sigma_r$ in terms of the dose rate $D$ and two parameters $k$ and $\Delta$.

$$\sigma_r = kD^\Delta$$

$k$ and $\Delta$ are characteristic of each material and $\Delta$ 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.

$$S(E) = \frac{dE}{dx}$$

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 $\rho$ 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:

\[
<n_f> = \frac{2}{m^2} \int E f(E) \, dE
\]

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

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 \( 3 \times 10^2 \) m\(^{-3}\) for the density \( N \) and \( 2.5 \times 10^2 \) 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.

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

(\text{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 A\(^{-1}\) and \( I \) is the value of the integral:
\[ D = \frac{2c^2}{\rho m} N \left( \frac{m}{2\pi T} \right)^{3/2} \cdot I \text{ keV}^{-1} \text{A}^{-1} \]

Substituting:

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

where \( N \) is in units of \text{m}^{-3}, \( \rho \), (\text{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 \( \Delta \) values are usually close to 1. We assume values of \( k = 1 \times 10^{-17} \text{ mhos cm}^{-1} \text{ (rad s}^{-1})^{-1} \)
\[ = 1 \times 10^{-13} \text{ mhos m}^{-1} \text{ (m}^2 \text{ s}^{-3})^{-1} \text{ and } \Delta = 1 \text{ as default} \]
material properties 17 and 18, respectively. The density \( \rho \), in \text{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 \times 10^3 \text{ 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 \( V \):
\[ J(E) = J_0 \left( E + qV \right) \left( 1 - \frac{qV}{E+qV} \right) \]

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

<table>
<thead>
<tr>
<th>MATERIAL</th>
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<th>INPUT VALUE</th>
<th>CODE VALUE</th>
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<td>-1.00E-02 MCG/M</td>
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<td>1.00E+01 (NONE)</td>
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<td>2.44E+01 (NONE)</td>
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<td>2.50E+003 VOLTS</td>
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<td>1.00E+000 (NONE)</td>
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<td>1.90E+003 KG/M^3</td>
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| AGUA     | DIELECTRIC CONSTANT | 1.00E+00 (NONE) | 1.00E+00 (NONE) |
|          | THICKNESS | 1.00E-03 METERS | 1.00E-02 MESH |
|          | CONDUCTIVITY | -1.00E+00 MCG/M | -1.00E-02 MCG/M |
|          | ATOMIC NUMBER | 1.00E+01 (NONE) | 1.00E+01 (NONE) |
|          | DELTA MAX >COEFF | 9.70E-03 (NONE) | 9.18E-00 (NONE) |
|          | E-MAX > DEPTH=1 | 3.00E-001 KEV | 3.00E-002 ANG-C1 |
|          | RANGE | 1.54E+02 ANG. | 1.23E+02 ANG. |
|          | EXPONENT > RANGE | 8.00E-001 (NONE) | 8.37E-002 ANG. |
|          | EXPONENT | 2.20E+02 ANG. | 1.76E+00 (NONE) |
|          | YIELD FOR 1KEV PROTONS | 2.44E+01 (NONE) | 2.44E+01 (NONE) |
|          | MAX DE/DX FOR PROTONS | 2.37E+02 KEV | 2.39E+02 KEV |
|          | PHOTOCURRENT | 4.00E-05 A/M=2 | 4.00E-05 A/M=2 |
|          | SURFACE RESISTIVITY | -1.00E+00 OHMS | -8.85E+01 V/S/C |
|          | SPACE DISCHARGE POT'L | 1.20E+004 VOLTS | 1.20E+004 VOLTS |
|          | INTERNAL DISCHARGE POT'L | 2.50E+003 VOLTS | 2.50E+003 VOLTS |
|          | RADN INDUCEDCOND*YCOEFF | 1.00E-013 MCG/M | 1.00E-013 MCG/M |
|          | RADN INDUCEDCOND*YPOWER | 1.00E+000 (NONE) | 1.00E+000 (NONE) |
|          | DENSITY | 1.90E+003 KG/M^3 | 1.90E+003 KG/M^3 |
### TABLE 4.2. MATERIAL PROPERTIES (Continued)

#### MATERIAL 3: CPEAI

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<td>-1.00E-000 MHO/M</td>
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<td>10 EXPONENT</td>
<td>1.77+000 (NONE)</td>
<td>1.77+000 (NONE)</td>
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<td>11 YIELD FOR 1KEV PROTONS</td>
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</tr>
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<td>12 MAX DE/OX FOR PROTONS</td>
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<td>14 SURFACE RESISTIVITY</td>
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#### MATERIAL 4: GOLD

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<td>1.00E+000 (NONE)</td>
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<td>1.00E+002 MESH</td>
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<td>-1.00E+000 MHO/M</td>
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<td>7.90E+001 (NONE)</td>
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<td>4.13E-001 (NONE)</td>
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<td>2.00E+002 ANG-01</td>
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<td>9.25E-01 ANG.</td>
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<td>4.13E-001 (NONE)</td>
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<td>1.35E+002 KEV</td>
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### TABLE 4.2. MATERIAL PROPERTIES (Continued).

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<td>ATOMIC NUMBER</td>
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### TABLE 4.2. MATERIAL PROPERTIES (Continued).

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<td>1.20×10⁻⁰¹</td>
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**MATERIAL 10: S1O2**

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<td>4 Atomic number</td>
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<tr>
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### TABLE 4.2. MATERIAL PROPERTIES (Continued).

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<td>3. CONDUCTIVITY</td>
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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:

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

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 protons!

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

- SINGLE MAXWELLIAN
- TYPE 2

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:

<table>
<thead>
<tr>
<th>Density</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;CGS&quot; (cm(^{-3}))</td>
<td>&quot;KEV&quot;</td>
</tr>
<tr>
<td>&quot;MKS&quot; (m(^{-3}))</td>
<td>&quot;EV&quot;</td>
</tr>
<tr>
<td></td>
<td>&quot;JOULES&quot;</td>
</tr>
<tr>
<td></td>
<td>&quot;ERGS&quot;</td>
</tr>
<tr>
<td></td>
<td>&quot;KELVIN&quot;</td>
</tr>
</tbody>
</table>

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 $1 \text{ cm}^{-3}$ 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 $N_e = 0.1 \text{ cm}^{-3}$
- Electron temperature $T_e = 2.0 \text{ keV}$
- Ion density $N_i = 0.3 \text{ cm}^{-3}$
- Ion temperature $T_i = 3.5 \text{ keV}$

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:
\[
N_e = 0.1 \text{ cm}^{-3}
\]
\[
T_e = 3.5 \text{ keV}
\]
\[
N_i = 0.3 \text{ cm}^{-3}
\]
\[
T_i = 2.0 \text{ keV}
\]
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.

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

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 }
```

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 \(N_1^e = 0.1 \text{ cm}^{-3}\), and a temperature \(T_1^e\) 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

\[
\begin{align*}
\text{DOUBLE} \\
\text{ELECTRONS} & \quad 0.2E6 \text{ MKS} \quad 8 \text{ KEV} \\
\text{IONS} & \quad 6 \quad \text{CGS} \quad 0.3 \text{ KEV} \\
\text{ELECTRONS} & \quad 0.5 \quad \text{CGS} \quad 6000 \text{ EV} \\
\text{PROTONS} & \quad 1.\text{E6} \quad \text{MKS} \quad 10 \text{ KEV}
\end{align*}
\]

defines a double Maxwellian with the following parameters:

\[
\begin{align*}
N_1^e &= 0.2 \text{ cm}^{-3} & N_1^i &= 0.6 \text{ cm}^{-3} \\
T_1^e &= 8 \text{ keV} & T_1^i &= 0.3 \text{ keV} \\
N_2^e &= 0.5 \text{ cm}^{-3} & N_2^i &= 1.0 \text{ cm}^{-3} \\
T_2^e &= 6 \text{ keV} & T_2^i &= 10 \text{ keV}
\end{align*}
\]

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 \(F_1(E), F_e(E)\) 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. YEAR0, DAY0, SEC0, YEAR1, DAY1, SEC1 FORMAT (10F8.0)**
   - YEAR0, DAY0, SEC0 = time of earliest spectrum on tape
   - YEAR1, DAY1, SEC1 = 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

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, $\log_{10}(F_i)$, $\log_{10}(F_e)$, $\Omega$, $\alpha$, BX, BY, BZ

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 distribution function ($sec^3/m^6$)
$\Omega$ = detector view angle (degrees)
$\alpha$ = pitch angle (degrees)
BX, BY, BZ = magnetic field vector components ($nT = 10^{-9} W/m^2$)
(The $\alpha$ value is redundant since it can be calculated from $\Omega$ and the magnetic field vector.)

DATA RECORD NBINS+2. (END OF DATA MARKER)

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 ($\theta$) 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 $\phi$ 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.

$$R = 3 \frac{b}{a}.$$ 

$R$ 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

\[ N_e = 0.1 \text{ cm}^{-3} \]
\[ T_e = 0.1 \text{ keV} \]
\[ N_i = 0.2 \text{ cm}^{-3} \]
\[ T_i = 0.3 \text{ keV} \]

The angular distribution is the standard anisotropic form with a ratio

\[ R = 0.5 \text{ (electrons)} \]

and

\[ R = -0.2 \text{ (ions)}. \]

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 \(\infty\). 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

<table>
<thead>
<tr>
<th>Energy (keV)</th>
<th>R Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>1.0</td>
<td>1</td>
</tr>
<tr>
<td>2.0</td>
<td>0.75*</td>
</tr>
<tr>
<td>3.0</td>
<td>0.5</td>
</tr>
<tr>
<td>3.5</td>
<td>0.6*</td>
</tr>
<tr>
<td>4.0</td>
<td>0.7*</td>
</tr>
<tr>
<td>5.0</td>
<td>0.9</td>
</tr>
<tr>
<td>100.0</td>
<td>0.9</td>
</tr>
</tbody>
</table>

*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
Figure 5.2b. File 22 (IFLUX).

KEV   ERATIO
---   ----
0.1   0.90
0.5   0.50
0.2   -0.20
10.0  -0.01
50.0  0.00
1000  -0.02
3000  -0.05
40000 0.06

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''
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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>
<thead>
<tr>
<th>Keyword</th>
<th>Default</th>
<th>Recommended Range</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>VCODE</td>
<td>0.2</td>
<td>0.1 &lt; VCODE &lt; 0.3</td>
<td>Initial code velocity (mesh units per $\delta t$)</td>
</tr>
<tr>
<td>NSTEPS</td>
<td>500</td>
<td>200 &lt; NSTEPS &lt; 1000</td>
<td>Maximum number of pushing steps per particle</td>
</tr>
<tr>
<td>NTHETA</td>
<td>8</td>
<td>5 &lt; NTHETA &lt; 15</td>
<td>Number of particles per beam is approximately $(\pi/4)NTHETA^2$</td>
</tr>
</tbody>
</table>
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

\[(E_f/E_i)^{1/2} \text{ VCODE} < 0.5\]

for attracted particles, and

\[(E_f/E_i) \text{ VCODE} > 0.1\]

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

\[D \tan (2W/NTHETA) < 1\]

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.
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:

```plaintext
@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.,

```plaintext
@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 e_1 e_2 ... e_n unit.
BEAMWIDTH b_1 b_2 ... b_n unit.
CURRENT c_1 c_2 ... c_n 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 \{ e_1 \ldots e_n \} \text{unit}
ENERGIES
    Defines beam energies of gun. Unit is 'EV' or 'KEV'. The default unit is 'KEV'.

BEAMWIDTH(S) b_1 \ldots b_n \text{unit}
    Defines half-angle of beam. Unit is assumed to be radians, unless 'DEGREES' is specified.

ALL BEAMWIDTHS b \text{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 \text{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. \(<\text{species}>\) GUN AT \(x\ y\ z\)
   \(<\text{species}>\) is optional and may be 'ELECTRON' or 'ION' to define an electron or ion gun, respectively. Omission of any \(<\text{species}>\) 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 \(e_1\ e_2\ e_3\ \ldots\ e_n\ \text{unit}\)
   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 \(<\text{units}>\) at the end of the energies is optional. The default units are 'KEV'. The only other acceptable unit is EV.

3. BEAMWIDTH \(b_1\ b_1\ \ldots\ b_n\ \text{<units>}\)
   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 \(<\text{units}>\).

4. CURRENT \(c_1\ c_2\ \ldots\ c_n\)
   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 b₂**
- **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.
Gun definition input for example 1.

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 -1 -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 2.

1. ION GUN AT -44., 0.5, 6.2
2. NOSHADE
3. ION MASS 14 AMU
4. BEAMWIDTH 20 DEGREES
5. CURRENT 5.E-6
6. ENERGY 5000 EV
7. DIRECTION 3.0.4.
8. END

Gun definition input for example 3.

1. ELECTRON GUN AT -20 0.0.
2. DIRECTION 1 0 0
3. ENERGIES 0.1 10 KEV
4. BEAMWIDTHS 40 40 DEGREES
5. CURRENTS 1.E-6 0.5E-6
6. END

Gun definition input for example 4.

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
A SHADOWING TABLE WAS PREVIOUSLY GENERATED FOR THIS OBJECT USING THE GUNS OPTION

GUN AT 0 16 16
ENERGY 6.0 KEV
CURRENT 5.0E-6
BEAMWIDTH 30 DEGREES
DIRECTION 0 -1 -1
GUN AT 0 -16 16
ENERGY 6.0 KEV
CURRENT 5.0E-6
BEAMWIDTH 30 DEGREES
DIRECTION 0 1 -1

GUN AT 0 -16 -16
ENERGY 6.0 KEV
CURRENT 5.0E-6
BEAMWIDTH 30 DEGREES
DIRECTION 0 1 1
GUN AT 0 16 -16
ENERGY 6.0 KEV
CURRENT 5.0E-6
BEAMWIDTH 30 DEGREES
DIRECTION 0 -1 1

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 -0.00 -1.00 1.00
BEAM 1: ENERGY = 6.00-003 EV CURRENT = 5.00-006 AMPS
CUT-OFF ANGLE = 30.000000 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 -0.00 1.00 -1.00
BEAM 1: ENERGY = 6.00-003 EV CURRENT = 5.00-006 AMPS
CUT-OFF ANGLE = 30.000000 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 -0.00 1.00 1.00
BEAM 1: ENERGY = 6.00-003 EV CURRENT = 5.00-006 AMPS
CUT-OFF ANGLE = 30.000000 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 -0.00 -1.00 1.00
BEAM 1: ENERGY = 6.00-003 EV CURRENT = 5.00-006 AMPS
SHADOWING BEING CALCULATED FOR GUN 1
DISTANCE EQUALS 22.627417

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

FINAL NA1 = 2D
SHADOWING BEING CALCULATED FOR GUN 3
DISTANCE EQUALS 22.627417

FINAL NA1 = 2C
SHADOWING BEING CALCULATED FOR GUN 4
DISTANCE EQUALS 22.627417

FINAL NA1 = 2C
Gun definition (INGUNS and GUNSHD) output for example 1.
****TANK 5
ION GUN AT -44.5, 3.5, 6.2
QNSHAP
ION MASS 14 AMU
BEAM WIDTH 20 DEGREES
CURRENT 5.5E-6
ENERGY 5000 EV
DIRECTION 0, 0, 1.
END

GUN DEFINITION ------
GUN 1 HAS BEEN DEFINED AS AN ION GUN WITH AN ION MASS = 2.34E-C26 KILOGRAMS.
GUN IS LOCATED AT GRID COORDINATES -35.0C 9.5C 15.20
GUN DIRECTION IS 1.00 0.00 1.00
BEAM 1: ENERGY= 5.00+003 EV CURRENT= 5.00E-06 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 0 0 0
ENERGIES 0.1 10 KEV
BEAMWIDTHS 4.1 10 DEGREES
CURRENTS 1.5E-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 0.00 0.00
BEAM 1: ENERGY= 1.00E+002 EV CURRENT= 1.00E-06 AMPs CUT-OFF ANGLE= 45.0000 DEGREES
BEAM 2: ENERGY= 1.00E+004 EV CURRENT= 5.00E-08 AMPs CUT-OFF ANGLE= 15.0000 DEGREES
SHADOWING BEING CALCULATED FOR GUN 1
DISTANCE EQUALS 20.000000

FINAL MA1 = 16

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

****TANK 5
ELECTRON GUN AT 50 35
DIRECTION -2 -1 0
ENERGIES 5 10 20 KEV
ALL BEAMWIDTHS 25 DEGREES
ALL CURRENTS 1.5E-6
END

GUN DEFINITION ------
GUN 1 HAS BEEN DEFINED AS AN ELECTRON GUN
GUN IS LOCATED AT GRID COORDINATES 59.0C 44.0C 13.0C
GUN DIRECTION IS -6.00 -1.00 0.00
BEAM 1: ENERGY= 5.00E+003 EV CURRENT= 1.00E-06 AMPs CUT-OFF ANGLE= 25.0000 DEGREES
BEAM 2: ENERGY= 1.00E+004 EV CURRENT= 1.00E-06 AMPs CUT-OFF ANGLE= 25.0000 DEGREES
BEAM 3: ENERGY= 2.00E+004 EV CURRENT= 1.00E-06 AMPs CUT-OFF ANGLE= 25.0000 DEGREES
SHADOWING BEING CALCULATED FOR GUN 1
DISTANCE EQUALS 61.163713

FINAL MA1 = 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 $v_\parallel$ along the field direction is unchanged and the radius of the spiral trajectory $r_L$ depends on the perpendicular component $v$

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

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 $\beta$ of an incoming vector $\vec{r}$ is related to the two angles of rotation shown, $\theta$ and $\phi$, 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 $\theta$. The choice of $\theta$ becomes unique when the second rotation ($\phi$) 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 $\theta, \phi$ 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 \( \psi \) 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 \( 2\pi \).

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

In the "fan" coordinate system:

\[
d\omega = \cos \phi \, d\phi \, d\theta
\]

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

\[
\therefore 2\pi a + \frac{2\pi b}{3} = 2\pi
\]

i.e.,

\[
a + \frac{b}{3} = 1
\]
We define the ratio of integrated fluxes $R$ as

$$ R = \frac{b}{3a} $$

$$ a = \frac{1}{1 + R} $$

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

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

1. The angle $\theta_0$ between the field direction $\mathbf{n}_B$ and the surface normal $\mathbf{n}$.
   $$ \cos \theta_0 = \mathbf{n}_B \cdot \mathbf{n} $$

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 $F_{IN}(E)$ is given by:

$$ F_{IN}(E) = \frac{F(E) \int_{-\pi/2}^{\pi/2} \int_{-\pi/2}^{\pi/2} (a(E) + b(E) \cos^2(\theta - \theta_0) \cos^2 \phi \cos \theta \cos^2 \phi \cos \theta) d\phi d\theta}{183} $$
where for a Maxwellian

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

Integrating gives

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

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.

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

\[ = 2 F(E) A(E) \delta_{\text{ISO}}(E) + \kappa(E) \]

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

\[ \kappa(E) = \kappa_1(E) + \kappa_2(E) \]

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

\[ \cdot \left[ \frac{C_1}{Q} \left( \frac{2}{Q^3} - e^{-Q} \left( \frac{1}{Q} + \frac{2}{Q^2} + \frac{2}{Q^3} \right) - \frac{1}{3} \right) + \frac{C_2}{Q^2} \left( \frac{3}{Q^2} - e^{-Q} \left( 1 + \frac{3}{Q} + \frac{3}{Q^2} \right) - \frac{1}{2} \right) \right] \]
where

\[ \delta(\beta) = C \cdot \left[ C_1 \left( \frac{1-e^{-Q\cos\beta}}{Q\cos\beta} \right) - C_2 \left( \frac{1-(\cos\beta+1)e^{-Q\cos\beta}}{Q^2\cos^2\beta} \right) \right] \]

\[ Q = aR \text{ (R is the range of electrons of energy E).} \]

\[ \kappa_2(E) = \sin^2\theta_0 \frac{F(E)}{\pi} b(E) C \left[ C_1 \cdot I_1 + C_2 \cdot I_2 \right] \]

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 \( Q \).

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

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

By dividing the values of \( F_{OUT}(E) \) so calculated by the incident current normalization \( ANGF(E) \)

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

we obtain the anisotropic yield for secondary emission

\[ \delta_{ANISO} = \frac{F_{OUT}(E)}{ANGF(E)} \]
The proton secondary emission is much simpler to calculate since 
\( F_{\text{OUT}}(E) \) is independent of angle:

\[
\varepsilon_{\text{ANISO}}(E) = \frac{F_{\text{OUT}}(E)}{\text{ANGF}(E)} = \frac{F_{\text{OUTISO}}(E)}{\text{ANGF}(E)}
\]

The backscatter requires an additional tabulated integral:

\[
\eta(\theta) = n_0 e^{-\log n_0 \log n_0 \cos \theta}
\]

\[
\therefore F_{\text{OUT}}(E) = \frac{F(E)}{\pi} n_0(E) e^{-\log n_0(E)}
\]

where

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

where

\[
\gamma = \log n_0
\]

Separating as before:

\[
\kappa_\eta = J_1 + J_2
\]

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

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

\( J_2 \) is tabulated for values of \( n_0 \).
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 $R = 0.50$. 

Angular distribution ($\phi$) and fit for electrons.
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.
Particles leaving the source in the range \( dE_o \, d\Omega_o \) about \((E_o, \vec{\Omega}_o)\) cross a surface element of area \( dS \) about the point \( \vec{r} = r(E_o, \vec{\Omega}_o) \) on a sphere of radius \( a \) with energies in the range \( dE \). In a steady state particle conservation requires that

\[
\int \frac{d^2I}{dE_o \, d\Omega_o} \, dE_o \, d\Omega_o = \int \vec{J} \cdot d\vec{S} \, dE
\]

\[
= a^2 \int \vec{J} \cdot \hat{n} \, dE \, d\Omega
\]

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 \( \Delta S \) at the center of force, and \( \hat{n} = \hat{n} = \vec{r}/r \) is the unit vector normal to the surface of the sphere of radius \( r \) with center at the center of force. Since \( \Delta E_o \) and \( \Delta \Omega_o \) are arbitrary

\[
|\vec{J} \cdot \hat{n}| = \frac{1}{a^2} \frac{d^2I}{dE_o \, d\Omega_o} \frac{1}{|\vec{J}|}
\]

where

\[
J = \frac{\partial}{\partial \vec{r}} \left( \frac{E_o, \vec{\Omega}_o}{E_o, \vec{\Omega}_o} \right)
\]
Once $|\mathbf{j} \cdot \mathbf{n}|$ is determined, the current density $\mathbf{j}$ per unit energy follows from

$$\mathbf{j} = |\mathbf{j} \cdot \mathbf{n}| \frac{\mathbf{V}}{\mathbf{V} \cdot \mathbf{\Omega}}$$

where $\mathbf{V} = \mathbf{V}(E_o, \Omega_0)$ is the velocity at $r = r(E_o, \Omega_0)$.

The primary problem in the determination of $\mathbf{j}$ 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 $\epsilon$ in terms of which the orbit is given by [18].

$$\frac{1}{r} = -\frac{mk}{\ell^2} (1 + \epsilon \cos \phi).$$

Here $\phi$ is measured from the symmetry axis of the orbit, $m$ is the particle mass, $\ell = mv_0 r_0 \sin \alpha = (2mE_o)^{1/2} r_0 \sin \alpha$ is the angular momentum, and

$$\epsilon = \left[ 1 + 4 \left( 1 + \frac{E_o}{V_o} \right) \frac{E_o}{V_o} \sin^2 \alpha \right]^{1/2}$$

where $V_0 = k/r_0$. In the following we shall use the orbit equation in the form

$$\cos \phi = -\frac{1}{\epsilon} \left( \frac{2E_o \sin^2 \alpha}{V_o^2 x} + 1 \right)$$

with $x = r/r_0$. 195
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

\[ \cos \chi = -\cos(e - e_o) \]

\[ = -(\cos e \cos e_o + \sin e \sin e_o) \]

\[ \mu = \cos \alpha \]

and \( e_o \) is obtained from the equation given earlier with \( x = 1 \). We find

\[ J = -\frac{1}{\epsilon} \left[ \left( -\frac{\epsilon}{\mu} \cos e + \frac{4E_o}{V_o} \frac{\mu}{\chi} \right) (\cos e_o - \sin e_o \cot e) \right. \]

\[ + \left. \left( -\frac{\epsilon}{\mu} \cos e_o + \frac{4E_o}{V_o} \frac{\mu}{\chi} \right) (\cos e - \sin e \cot e_o) \right] \]

with

\[ \frac{\epsilon}{\mu} = -\frac{4}{\epsilon} \left( 1 + \frac{E_o}{V_o} \right) \frac{E_o}{V_o} \mu \]

In the presence of a constant magnetic field, \( \mathcal{B} \), 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 \( \omega \). In the rotating
system the effective force is \([19]\)

\[
F_{\text{eff}} = q \left[ \ddot{E} + \frac{\dot{V}_s x B}{c} \right] - 2m(\omega x \dot{V}_r) - m\omega x (\omega x r)
\]

where \(\dot{V}_r = \dot{V}_s - \omega x r\)

and \(\dot{V}_s\) and \(\dot{V}_r\) are the velocities of the particle relative to the space and rotating axes respectively. If we choose

\[
\dot{\omega} = -\frac{qB}{2mc}
\]

then

\[
F_{\text{eff}} = q\ddot{E} + m\omega x (\omega x r)
\]

Neglecting terms of second and higher order in the \(\dot{B}\) field, the equation of motion in the rotating system becomes

\[
m \frac{d\dot{V}_r}{dt} = q\ddot{E}.
\]

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 \(-\dot{\omega}\). The magnitude of the rotation requires a knowledge of the flight time, which to the required order of accuracy
is given by

\[ t = \int_{r}^{r_0} \frac{dr}{\sqrt{1 - \frac{r^2}{r_0^2}}} \]

where

\[ |r^2| = \left[ \frac{2}{m} E_0 - V_0 \left( 1 - \frac{r_0}{r} \right) - E_0 \frac{r_0^2}{r^2} \sin^2 \alpha \right]^{1/2} \]

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 \( \mathbf{B} \) 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

<table>
<thead>
<tr>
<th>Command</th>
<th>Meaning</th>
<th>Default</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D-VIEW x y z</td>
<td>3D-VIEW NONE</td>
<td>3D-VIEW 4.2 4.9 -8</td>
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</tr>
<tr>
<td>3D-VIEW NONE</td>
<td>APRT grids#</td>
<td>APRT 2</td>
<td></td>
</tr>
<tr>
<td>BFIELD bx by bz</td>
<td>BFIELD .01 1.E-5 1.E-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BIAS cond# volts</td>
<td>BIAS 2 : 500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C/J conda# conde farads</td>
<td>C/J 3 4 1.E-4</td>
<td></td>
<td></td>
</tr>
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<td>COMMENT &lt;anything&gt;</td>
<td>COMMENT SEPT 25 CHANGES</td>
<td></td>
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<td>CONTOURS NONE</td>
<td>CONTOURS NONE</td>
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<tr>
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<td>CONTOURS STANDARD</td>
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<td>CONVEX</td>
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<td>CONVERGENCE PLOTS ON</td>
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<td>DEADLINE hhmmss#</td>
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<td>DESTINATION CALCOMP</td>
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<td>DIPOLE MOMENT 1.E-2 1.E-2 0 AT 0, 0, 5</td>
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<tr>
<td>IOUTER</td>
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MEANING

- new SATPLT view
- clear view table
- number grids potential print
- constant mag field—Webers/m²
- conductor bias relative to conductor 1
- mutual conductor capacitance
- comment—no effect
- clear contour table
- 3 center cuts
- additional contour cut
- clear specific cut
- convex object, self-shadowing only
- potential solver printer plots
- finish before time of day
- activates Debye screening
- timestep = timestep * factor
- initial timestep (seconds)
- plot destination
- magnetic dipole moment (A — M²)
- and location
- perform discharge analysis
- effective surface conductivity
- activate particle emitter
- end of input file
- fix conductor potential
- remove all previous FIXP and BIAS
- float previously fixed or biased conductor
- 0—grounded outer boundary
- 2—monopole outer boundary
- new SATPLT view
- clear view table
- number grids potential print
- constant mag field—Webers/m²
- conductor bias relative to conductor 1
- mutual conductor capacitance
- comment—no effect
- clear contour table
- 3 center cuts
- additional contour cut
- clear specific cut
- convex object, self-shadowing only
- potential solver printer plots
- finish before time of day
- activates Debye screening
- timestep = timestep * factor
- initial timestep (seconds)
- plot destination
- magnetic dipole moment (A — M²)
- and location
- perform discharge analysis
- effective surface conductivity
- activate particle emitter
- end of input file
- fix conductor potential
- remove all previous FIXP and BIAS
- float previously fixed or biased conductor
- 0—grounded outer boundary
- 2—monopole outer boundary
TABLE 6.1. NASCAP USER OPTIONS (Concluded)

SYNTAX
LONGTIMESTEP <dvlm>
MATVIEW ± (x) cuta cutb
MATVIEW NONE
NCYC steps
NG grids
NOEMIT
NOLONG
NOPRINT module
NOSCALE
NOSHEATH
NOTIME
NZ zadv
OFFSET x y z
POTCON decades
PRINT module
REPEAT times
RESTART
RIJ
SCALE
SECONDARY <EMISSION> ANGLE
SECONDARY <EMISSION> NORMAL
SHEATH
SUNDIR x y z
SUNINT intensity
SURFACE CORNER x y z ...
...<norx nory norz>
SURFACE CELL cell
TANKCUR OFF
TANKCUR ON
TANKTRAJ OFF
TANKTRAJ ON
TIMER
TITLE
TYPE type
XMESH unit
ZTRUNCATE zlo zhi

MEANING
implicit charging,
<voltage limit per timestep>
additional material plot
clears MATVIEW table
number timesteps to run
number computational grids
turn off previously defined emitter
see LONGTIMESTEP
see PRINT
see SCALE
see SHEATH
see TIMER
z grid size
moves coordinate origin
convergence of potential solver
diagnostic prints module
is LIMCEL, POTENT, HIDCEL, or OBJDEF
plot repetition factor (IGS only)
next timestep—old problem
interconductor resistance
potential solver scales potential
and boundary conditions
secondary formulation
secondary formulation
plot space charge density
sun direction vector
sun intensity
surface cell of interest
(especially object definition required)
surface cell of interest
tank current contour plots
tank particle trajectory plots
execution time each module
plot title
environment type
physical grid spacing (meters)
truncation of outer grid
DEFAULT
NOLONG
6 default plots
6 default plots
1
2
previous status
explicit charging
no extra printout
SCALE
no sheath plot
no timer
33
center of mesh (9, 9, 17)
8—CAPAC, 4—TRILIN
NOPRINT
NOSC
SCALE
NOSHEATH
NOTIME
NZ 29
OFFSET 0 0 0
POTCON 3
PRINT POTENT
EXAMPLE
LONGTIMESTEP 2000
MATVIEW -Z -5 +5
MATVIEW NONE
NCYC 5
NG 3
NOEMIT
NOLONG
NOPRINT POTENT
NOSCALE
NOSHEATH
NOTIME
NZ 29
OFFSET 0 0 0
POTCON 3
PRINT POTENT
REPEAT 3
RESTART
RIJ 1 2 3.08
SCALE
SECONDARY ANGLE
SECONDARY EMISSION NORMAL
SHEATH
SUNDIR 1, 0, 2.5
SUNINT 0.8
SURFACE CORNER 3, 3, 2 –1.0, 0
SURFACE CELL 541
TANKCUR OFF
TANKCUR ON
TANKTRAJ OFF
TANKTRAJ ON
TITLE P78-2
TYPE 6
XMESH .03
ZTRUNCATE -12 +12

202
### TABLE 6.2. RUN OPTIONS THAT CONTROL PROGRAM PROCEDURE

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<thead>
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<th>Option</th>
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<td>DELTA</td>
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<tr>
<td>EMITTER</td>
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<td>END</td>
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### TABLE 6.3. RUN OPTIONS THAT DEFINE ELECTRICAL CONNECTIONS

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<th>Option</th>
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<td>RADCON</td>
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<td>RIJ</td>
</tr>
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</table>
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

<table>
<thead>
<tr>
<th>Options</th>
</tr>
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<tbody>
<tr>
<td>3D-VIEW</td>
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<td>CONTOURS</td>
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<tr>
<td>DESTINATION</td>
</tr>
<tr>
<td>MATVIEW</td>
</tr>
<tr>
<td>REPEAT</td>
</tr>
<tr>
<td>SHEATH/NOSHEATH</td>
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<tr>
<td>TANKCUR</td>
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<tr>
<td>TANKTRAJ</td>
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<tr>
<td>TITLE</td>
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</table>

### TABLE 6.7. RUN OPTIONS THAT DEFINE LOGICAL UNIT NUMBERS

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<td>IDIV</td>
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<tr>
<td>IFLUX</td>
</tr>
<tr>
<td>IKEYWD</td>
</tr>
<tr>
<td>ILTBL</td>
</tr>
<tr>
<td>IOBJ</td>
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<td>IOBPLT</td>
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<td>IP</td>
</tr>
<tr>
<td>IPART</td>
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<td>IPQCND</td>
</tr>
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<td>IR</td>
</tr>
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<td>IROUS</td>
</tr>
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<td>ISAT</td>
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<tr>
<td>ISPARE</td>
</tr>
<tr>
<td>ISPCTR</td>
</tr>
<tr>
<td>IU</td>
</tr>
</tbody>
</table>
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 end of each cycle. For example the cards
DELTA 10
DELFA 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:

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 x 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

\[
\begin{align*}
CIJ & \ 1 \ 2 \ \ 1.E-3 \\
CIJ & \ 1 \ 3 \ \ 2.E-3 \\
CIJ & \ 2 \ 3 \ \ 3.E-4 \\
\end{align*}
\]

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:

![Circuit Diagram](image)

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

\[
\text{DISCHARGE } d
\]

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.

\[
\text{Severity of discharge for cell } i = \frac{\text{potential of cell } i}{\text{property 15 of cell } i}
\]
(a) RDOPT input for example 1 (default options).

(b) RDOPT output for example 1 (default options).

(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

\[
\text{DISCHARGE } d \text{ lun}
\]

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.)
(a) RDOPT input for example 3.

```
KEYWORD INPUT
DISCHARGE .7 5
IGNORE PUNCHTHROUGH
IGNORE SPACE
RESTRICT CONDUCTOR 2
KAPTON .8
TEFLON 2500
SOLAR 2800 .9
NPAINT .9 4000
END
END
```

(b) RDOPT output for example 3.

```
DISCHARGE OPTION SUMMARY
REGION RESTRICTION:

<table>
<thead>
<tr>
<th>COND-1</th>
<th>NO</th>
<th>COND-2</th>
<th>YES</th>
<th>COND-3</th>
<th>NO</th>
<th>COND-4</th>
<th>NO</th>
<th>COND-5</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>COND-6</td>
<td>NO</td>
<td>COND-7</td>
<td>NO</td>
<td>COND-8</td>
<td>NO</td>
<td>COND-9</td>
<td>NO</td>
<td>COND-10</td>
<td>NO</td>
</tr>
<tr>
<td>COND-11</td>
<td>NO</td>
<td>COND-12</td>
<td>NO</td>
<td>COND-13</td>
<td>NO</td>
<td>COND-14</td>
<td>NO</td>
<td>COND-15</td>
<td>NO</td>
</tr>
</tbody>
</table>

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
```

(c) LIMCEL output for example 3.

```
***WARNING*** DISFIL - MATERIAL NPAI NOT FOUND.

DISCHARGE PARAMETERS:
DISCHARGE REGION:

<table>
<thead>
<tr>
<th>COND-1</th>
<th>NO</th>
<th>COND-2</th>
<th>YES</th>
<th>COND-3</th>
<th>NO</th>
<th>COND-4</th>
<th>NO</th>
<th>COND-5</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>COND-6</td>
<td>NO</td>
<td>COND-7</td>
<td>NO</td>
<td>COND-8</td>
<td>NO</td>
<td>COND-9</td>
<td>NO</td>
<td>COND-10</td>
<td>NO</td>
</tr>
<tr>
<td>COND-11</td>
<td>NO</td>
<td>COND-12</td>
<td>NO</td>
<td>COND-13</td>
<td>NO</td>
<td>COND-14</td>
<td>NO</td>
<td>COND-15</td>
<td>NO</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COND-1</th>
<th>1-NO</th>
<th>2-YES</th>
<th>3-NO</th>
<th>4-NO</th>
<th>5-NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-NO</td>
<td>7-NO</td>
<td>8-NO</td>
<td>9-NO</td>
<td>10-NO</td>
<td></td>
</tr>
<tr>
<td>11-NO</td>
<td>12-NO</td>
<td>13-NO</td>
<td>14-NO</td>
<td>15-NO</td>
<td></td>
</tr>
</tbody>
</table>

MATERIAL RELAX
<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>RELAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALUM</td>
<td>.700</td>
</tr>
<tr>
<td>KAPT</td>
<td>.800</td>
</tr>
<tr>
<td>TEFL</td>
<td>.500</td>
</tr>
<tr>
<td>GOLD</td>
<td>.700</td>
</tr>
<tr>
<td>SOLA</td>
<td>.400</td>
</tr>
</tbody>
</table>
```

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:
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. Interconductor 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:

\texttt{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.,

\texttt{BFIELD 0 0 0}

For example, the card:

\texttt{BFIELD 1.\times10^{-5} 1.\times10^{-5} 0.}

describes a field pointing between the positive X and Y axes in the XY plane with magnitude \( \sqrt{2} \times 10^{-5} \text{ W m}^{-2} \) (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:

\texttt{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 \( \mathbf{e} \).

\[ \text{degree of illumination} = \cos \theta. \]

The default behavior is to demand a call to HIDCEL to determine cell shadowing.

6.4.3 DEBYE

The card:

\texttt{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 \( \lambda \) much
greater than a mesh unit XMESH (6.4.15). The Debye length is defined
for Maxwellian environments as

\[
\lambda = \left( \frac{\varepsilon_0 kT}{ne^2} \right)^{1/2} = 7.43 \times 10^3 \left( \frac{e}{n} \right)^{1/2}
\]

where \( e \) 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 \( \rho \) linear in the
potential \( \phi \):

\[
\frac{\rho}{\varepsilon_0} = -\frac{\phi}{\lambda^2}
\]

This is a good approximation when the Debye length \( \lambda \) 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 \( \lambda \) 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 $\delta$ as a function of angle and integrates $\delta(\theta)$ over an appropriate incident flux distribution $f(\theta)$ to obtain the overall yield $\Delta$.

$$\Delta = \int f(\theta) \delta(\theta) \, d\theta$$

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 25×2×XMESH 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 ($\mathbf{r}^2 + \mathbf{r}$) for each iteration to be produced after each cycle. The residual vector $\mathbf{r}$ 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 LONGLIMESTEP 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 LONGLIMESTEP 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. 2A

CODE = 004612210403
LOCATION = 61011
NORMAL = 0010
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/MeV
INCIDENT ELECTRONS
RESULTING SECONDARIES
RESULTING BACKSCATTER
INCIDENT PROTONS
RESULTING SECONDARIES
BULK CONDUCTIVITY
PHOTOCURRENT

NET FLUX

1.23-006
5.07-008
5.25-007
5.55-008
1.11-010
1.36-006
5.67-007

[5.28-007]
[5.21-007]
[1.41-005]

Figure 6.4. Flux breakdown for SURFACE CELL 2A.
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:

\[
\text{CONTOURS Y 6}
\]

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

\[
\text{CONTOURS Y 6 GRIDS 1 MOD 5}
\]

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

\[
\text{CONTOURS Y 6 OFF}
\]

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.
Module SATPLT (8.7) also produces plots showing the pattern of the different surface materials covering the satellite. The card:

```
MATVIEW + (X Y Z) 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
```

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
```
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

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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). $\theta$ gives the azimuthal angle of the incident direction about the surface normal. The angle $\theta$ 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, $\theta$ and $\phi$, 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
INPUT
FILE
END

DETECT
INPUT
CARDS
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.
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 $\theta$ and $\phi$. $\theta$ is the angle between the normal (the Z axis) and the direction vector. $\phi$ 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.

```
ΔE = E x (DEK/100)
```

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
```
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 $\Delta \phi$. This is set with the card

```
DTH  $\Delta \phi$
```

$\Delta \phi$ may range from 0 to 90°. The default value is 0. For example:

```
DTH  8
```

sets $\Delta \phi$ to 8°.

7.2.3.7 PHI

The angle $\phi$ does not uniquely define the chosen direction. One more angle is required. The angle $\phi$ 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  $\phi$
```

where $\phi$ 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 $\zeta$ (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 $\zeta$
```

The default value of zeta is 0. For example:

```
ZETA 25
```

sets $\zeta$ 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 $E$, $\theta$ and $\phi$. The number of samples taken over the energy range and the range of $\theta$
Figure 7.2. Boom cell coordinate system.
and $\phi$ 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 $10 \times 10 \times 10 = 1000$. 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:

\[
\text{NSTP n}
\]

$n$ 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.

\[
\text{NSTP 1300}
\]

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

\[
\text{VCODE v}
\]

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 $2^{(IG-1)}$. 

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7.2.5.3 NE

The number of points sampled over the energy range $E + \Delta E$ (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
```

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 $\phi'$ in the detector coordinate system from 360° to 360°/n. The default value of $n$ is 1, in which case $\phi'$ is chosen to be 0. (See Figure 7.1 for definition of $\phi'$.)
Two types of DETECT plots are produced: plots of energy flux density against one of the variables $E$, $e$, or $\phi$, and particle trajectories.

The variable $E$, $e$, or $\phi$, 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 $\psi$ 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.,

$$\psi = \frac{q}{4\pi\varepsilon_0 r}$$

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:

\[ \text{INDVAR} = \text{var} \]

\( \text{var} \) may be the words ENERGY, THETA and PHI, corresponding to the choice of \( E, \theta \) or \( \phi \) 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:

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Axis Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENERGY (E)</td>
<td>LOG</td>
</tr>
<tr>
<td>THETA (( \theta ))</td>
<td>LINEAR</td>
</tr>
<tr>
<td>PHI (( \phi ))</td>
<td>LINEAR</td>
</tr>
</tbody>
</table>

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

\[ \text{FINALV} = f \]

For example, the cards:

\begin{align*}
\text{THETA} & \quad 45 \\
\text{PHI} & \quad 10 \\
\text{ENERGY} & \quad 10,000 \\
\text{DEK} & \quad 10 \\
\text{INDVAR} & \quad \text{ENERGY} \\
\text{FINALV} & \quad 20,000
\end{align*}
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 (10 keV, 11 keV) to (20 keV, 22 keV).

The default value of $f$ is 49999 eV, since the default independent variable is ENERGY. If $\theta$ and $\phi$ are chosen as independent variables FINALV must be changed explicitly from this default value to an acceptable limit for the variables. For $\theta$ acceptable limits are within $\pm (90-\Delta \theta)^\circ$. For $\phi$ FINALV may range from 0 to 720$^\circ$.

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 minimum value to $10^6 \text{eV/(cm}^2\text{s sr eV)}$ and the maximum to $10^{14} \text{eV/(cm}^2\text{s sr eV)}$. 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 $6 \times 10^8 \text{eV/(cm}^2\text{s sr eV)}$ to $6 \times 10^{10}$ 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

\[ IG = NGBND + (I-1) \times NGINC \]

(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.
<table>
<thead>
<tr>
<th></th>
<th>DETECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.</td>
<td>COMMENT</td>
</tr>
<tr>
<td>3.</td>
<td>COMMENT</td>
</tr>
<tr>
<td>4.</td>
<td>ICCELL</td>
</tr>
<tr>
<td>5.</td>
<td>N</td>
</tr>
<tr>
<td>6.</td>
<td>NSIP</td>
</tr>
<tr>
<td>7.</td>
<td>ENVR=ENERGY</td>
</tr>
<tr>
<td>8.</td>
<td>ENERGY</td>
</tr>
<tr>
<td>9.</td>
<td>ENVR=ENERGY</td>
</tr>
<tr>
<td>10.</td>
<td>PHI</td>
</tr>
<tr>
<td>11.</td>
<td>THEA</td>
</tr>
<tr>
<td>12.</td>
<td>AUTOS</td>
</tr>
<tr>
<td>13.</td>
<td>PEPARI</td>
</tr>
<tr>
<td>14.</td>
<td>END</td>
</tr>
</tbody>
</table>

**225 INDEX OF DETECTOR SURFACE CELL**

| 25 NUMBER OF INDEPENDENT VARIABLE POINTS |
| 350 MAXIMUM NUMBER OF TRAJECTORY STEPS |

- **10.0 eV** (Low end of detector energy range)
- **49000.0 eV** (High end of detector energy range)
- **0.0 deg** (Fixed azimuthal angle)
- **50.0 deg** (Fixed polar angle)
- **Activate plot auto-scaling option**
- **Request particle trajectory plots**

**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
NSIP = 350   NP = 1
DTH = .00 DEG   NH02 = 1

INDEPENDENT VARIABLE FOR PLOT = ENERGY
INDEPENDENT VARIABLE RANGE = 1.00x10^1 EV TO 4.90x10^4 EV
IS DIVIDED INTO 25 POINTS

FIXED VARIABLES

PHI = .00 DEG
THETA = 50.00 DEG

PROTON ENERGY FLUX PLOT SEPARATION SCALE FACTOR = 1.00x10^5
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 not a separate module. An emitter is defined and included in a TRILIN calculation by including the card

EMITTER <n>

in the run options 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 \( \theta' \) 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 \( \theta \) and \( \phi \) 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.

<table>
<thead>
<tr>
<th>JTYPE</th>
<th>Distribution Chosen</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Uniform Angular, Gaussian energy</td>
</tr>
<tr>
<td>2</td>
<td>Cosine $\theta$ Angular, Gaussian energy</td>
</tr>
<tr>
<td>3</td>
<td>Uniform Angular, Lorentzian energy</td>
</tr>
<tr>
<td>4</td>
<td>Cosine $\theta$ Angular, Lorentzian energy</td>
</tr>
</tbody>
</table>

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 $\cos \theta$ (7.4).
7.3.3.6 PHI

The card

PHI  \( \phi \)

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  \( \theta \)

sets the polar angle \( \theta \) (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 \( 2 \times 10^{-5} \) 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 $\zeta$, 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

\[ NPHIS \times NTHETS \times NENGS \]
where NPHIS, NTHETS AND NENGS are the number of samples in $\phi$, $\theta$ 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 $2^2 = 4$. 

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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 global command and affects all 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 \( \theta \) 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 \( \phi' \), (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 \( n \times T_{\text{NG}} \), where \( T_{\text{NG}} \) 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 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.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPHI</td>
<td>index number of discrete azimuthal angle at which the particle was emitted.</td>
</tr>
<tr>
<td>ITH</td>
<td>index number of discrete polar angle at which the particle was emitted.</td>
</tr>
<tr>
<td>IEK</td>
<td>index number of discrete energy at which the particle was emitted.</td>
</tr>
<tr>
<td>VINIT</td>
<td>initial code velocity with which particle was emitted (in inner grid units/timestep).</td>
</tr>
<tr>
<td>VIN</td>
<td>initial velocity with which particle was emitted (in meters/second).</td>
</tr>
<tr>
<td>JCLAST</td>
<td>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.)</td>
</tr>
<tr>
<td>PXYZ</td>
<td>potential (in volts) at the particle position at the last timestep completed prior to hitting the satellite or abandoning tracking.</td>
</tr>
</tbody>
</table>
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:

\[
\vec{E}_0 = -k \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \left( \frac{m|\vec{V}_0|^2}{2e} \right) \frac{1}{e} \left\{ (e\vec{V}_0 \cdot \hat{k}) f_0(\vec{V}_0) \right\} d^3V_0
\]

where \( \vec{E}_0 \) = energy flux vector (eV/(M^2-sec)) at cell surface.
Figure 7.7. Sample Emitter input file.
**TRILIN**

**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)

*** RESTART AT NEW CYCLE = 1

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 FROM LAST CYCLE = -1.2969*005

*** THE SYSTEM IS NOW AT TIME 0.000 SECONDS. 1 CYCLES HAVE BEEN REQUESTED.
DELTA = 5.00*000 SECONDS, DELTAC = 1.00*000.

Figure 7.8. TRILIN output with EMITTER option selected.
### ALGIN CYCLE NO. 1

**TIME = 0.000 SECONDS.**

- **QSUM** = -1.300005 CODE UNITS
- **QSUM** = -1.300005
- **SCALE** = -1.300005
- **QCUM** = -1.2969005
- **PCOND** = -1.0000000
- **QCOND** = 1.0000000

---

**EXPLICITLY CALCULATED FLUXES FOR CYCLE**

**TIME = 0.000 SECONDS.**

**DURING THIS TIMESTEP, NASCAP WILL TAKE INTO ACCOUNT SUCH ADDITIONAL EFFECTS AS SURFACE CONDUCTIVITY, DISCHARGES, EMISSOR OPERATION, AND VARIATION OF LIMITING FACTORS FOR LOW-ENERGY EMMITT ELECTRONS.**

---

**SURFACE CELL NO. 167**

- **CODE** = 011111120302
- **LOCATION** = 9 9 10
- **NORMAL** = 0 0 -1
- **MATERIAL** = SOLA

- **POTENTIAL** = -2.00000003 VOLTS
- **STRESS** = 0.000 VOLTS/METER
- **EXTERNAL FIELD** = -2.6090003 VOLTS/METER
- **LIMITING FACTOR** = 1.0000000

**FLUXES IN A/M**

<table>
<thead>
<tr>
<th>INCIDENT ELECTRONS</th>
<th>RESULTING SECONDARIES</th>
<th>RESULTING BACKSCATTER</th>
<th>INCIDENT PROTONS</th>
<th>RESULTING SECONDARIES</th>
<th>BULK CONDUCTIVITY</th>
<th>PHOTOCURRENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.27-006</td>
<td>1.02-006</td>
<td>4.34-007</td>
<td>6.20-008</td>
<td>8.45-008</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

**NET FLUX**

- **3.30-007**

**INITIAL NET CHARGING CURRENT (WITHOUT LIMITING) = 3.98-007 AMPERES.**

**INITIAL NET CHARGING CURRENT (WITH LIMITING) = -6.50-007 AMPERES.**

**ICELL 3**

- **ICFLL SET TO 3**
- **ENERGY SET TO 1.000000003**
- **SIGMA SET TO 1.000000001**
- **DTHETA SET TO 5.000000000**
- **BEAMI 2.000000-0.005**
- **NENG 10**
- **NENG SET TO 10**
- **JCYCFM 1**
- **JCYCEM SET TO 1**
- **PRFLUX**
- **NON-ZERO EMMITT 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
PEAK CURRENT = 2.00-000 AMS

BEAM CURRENT INTEGRAL

ENERGY = 1.00·003 EV
SIGMA = 1.00·001

PHI = 00·00 DEG
THETA = 00·00 DEG
NPHI = 1
NTHETA = 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

-----------------------------------------------------------------
NEPIMA = 0
**FFRPL -- 2 GRIDS OUT OF 2 READ IN.
***** EMITTER ROUTINE EXECUTION INITIATED BY EMRUN *** ***

PARTICLE EMITTER ENERGIES (EV):
1.0035·003 9.8355·002 9.8964·002 9.9326·002 9.9615·002 9.9875·002 1.0013·003

PARTICLE EMITTER ENERGY WEIGHTS:
2.6993·003 3.1462·003 4.2889·003 9.7011·003

CURRENT TO CELL 167 ORIGINATING FROM EMITTER 1 = 0.0000 AMS. VOLUME CELL INDEX = 167 SHARED WITH 0 OTHER CELLS
NON-ZERO SURFACE CELL CURRENT CONTRIBUTIONS FROM EMITTER NUMBER 1

SUM OF CELL CURRENTS = 0.000000 AMS

****** 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 AMS
NUMERICAL CURRENT WHICH ESCAPED TO ENVIRONMENT = 2.00000·005 AMS
NUMERICAL CURRENT WHICH RETURNED TO SATELLITE = 0.00000 AMS
TOTAL NUMBER OF PARTICLES TRACKED = 10

Figure 7.8. (Continued).
EMITTER CONDUCTOR POTENTIAL = -1.0000*003 VOLTS

CALLED EMITTER NECELS = 1 ICYC = 1 XMESH = 2.0000-001 HMAT = 4 HSURF = 180 QTOT = -1.2969+005 NX = 17 NY = 17 NZ = 33 IER = 0

IN PLEMIT IEMIT = 1 IG = 3 IGS = 4 GSSCALE = 2.5000000-001 IVIEW = 1

CALLED PLEMIT IXYZ = 1 IG = 3 IGS = 4 GSSCALE = 2.5000000-001 IVIEW = 1

CALLED PLEMIT IXYZ = 2 IG = 3 IGS = 4 GSSCALE = 2.5000000-001 IVIEW = 1

CALLED PLEMIT IXYZ = 3 IG = 3 IGS = 4 GSSCALE = 2.5000000-001 IVIEW = 1

***IN ADEMIT*** IFMIT = 1 CURRENT = 2.000-005 FRAC = 5.000-001 EMBCAM = 2.000-005 VC = 1.000+003

IN ADEMIT CURRENT TO CELL 167 CHANGED BY FLUX FROM EMITTER 1 FROM 7.4672+003 TO 7.4672+003 CODE UNITS

Figure 7.8. (Continued).
1 EMITTERS FOUND BY ADEMIT ON FILE 11

<table>
<thead>
<tr>
<th>NO.</th>
<th>CONDUCTOR</th>
<th>FMT-INF (AMPS)</th>
<th>BARRIER (VOLTS)</th>
<th>SPECIES</th>
<th>WIDTH (EV)</th>
<th>ENERGY (EV)</th>
<th>NOIST</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2.0000-005</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TOTAL CAPACITANCE TO INFINITY = 49.9 CODE UNITS; 8.83-011 FARADS.

BARDEM 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 -- VCTR1 = +2.016+003 -2.048+003

BARDEM 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 -- VCTR1 = +2.010+003 -2.074+003
ICCG --- RDOTR/RDOTR1 = 1.97-020/ 1.57+011
LEAVING ICCG1 -- VCTR1 = +2.000+003 -2.058+003

UNEMIT: IRET1 = 1  DQC= -5.91+005  DQCD= -1.05+006  DQDC= -5.65+003
CONDUCTOR 1 UNFIXED

ICCG --- RDOTR/RDOTR1 = 1.80-017/ 5.46+007
LEAVING ICCG1 -- VCTR1 = -1.070+003 -2.057+003

HIGHN --- NUMH= 2
ICCG --- RDOTR/RDOTR1 = 2.56-017/ 6.02+007
LEAVING ICCG1 -- VCTR1 = -1.070+003 -2.074+003
LOWW --- NUMW= 3
ICCG --- RDOTR/RDOTR1 = 3.23-019/ 3.56+007
LEAVING ICCG1 -- VCTR1 = -1.070+003 -2.037+003
LOWW --- NUMW= 2
ICCG --- RDOTR/RDOTR1 = 3.65-016/ 6.20+007
LEAVING ICCG1 -- VCTR1 = -1.070+003 -1.413+003
VFIX --- 0 OUT OF 164 NODES FIXED.
ICCG --- RDOTR/RDOTR1 = 3.65-016/ 6.20+007
LEAVING ICCG1 -- VCTR1 = -1.070+003 -1.413+003

NO DISCHARGE ANALYSIS
NO DISCHARGE ANALYSIS
ICCG --- RDOTR/RDOTR1 = 7.04-023/ 3.66+007
LEAVING ICCG2 -- VCTR1 = -1.070+003 -1.413+003

AVGERAGE FLUXLS (ONLY AVAILABLE FOR INSULATING CELLS)
AVERAGE FLUX TO CELL 167 IS 2.651-007 A/M**2

NEW CONDUCTOR POTENTIALS

<table>
<thead>
<tr>
<th>VNEW</th>
<th>VQ</th>
<th>VOLD</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1.046+003</td>
<td>9.1690+005</td>
<td>-1.0000+003</td>
</tr>
<tr>
<td>-1.4126+003</td>
<td>-1.4554+000</td>
<td>-2.0000+003</td>
</tr>
</tbody>
</table>

Figure 7.8. (Continued).
TOTAL CHANGE IN CHARGE = 3.517-003 CODE UNITS
                      6.264-009 COULOMBS

AVERAGE NET CHARGING CURRENT = 1.253-009 AMPERES
                                7.078-002 CODE UNITS/SEC.

CONDUCTOR CURRENTS (AMPS; POSITIVE INTO CONDUCTORS):

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>NET CURRENT (AVG dQ/dt):</td>
<td>3.25-007</td>
<td>-5.15-013</td>
</tr>
<tr>
<td>CONDUCTIVITY CURRENT (NEW)</td>
<td>-8.95-009</td>
<td>9.60-015</td>
</tr>
<tr>
<td>CONDUCTIVITY CURRENT (NEW)</td>
<td>-3.63-007</td>
<td>.00</td>
</tr>
<tr>
<td>PLASMA CURRENT (INITIAL) (TO BARE CELLS):</td>
<td>6.97-007</td>
<td>-5.25-013</td>
</tr>
<tr>
<td>REMAINDER CURRENT:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 7.8. (Continued).
CONTINUE CYCLE NO. 1 AT UPDATED TIME = 5.000000 SECONDS.
QSUM = -1.2616+005

SURFACE POTENTIALS - ALL 180 CELLS

<table>
<thead>
<tr>
<th>CELL NO.</th>
<th>POTENTIAL (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>-3.071+003</td>
</tr>
<tr>
<td>12</td>
<td>-3.071+003</td>
</tr>
<tr>
<td>31</td>
<td>-3.071+003</td>
</tr>
<tr>
<td>41</td>
<td>-3.071+003</td>
</tr>
<tr>
<td>51</td>
<td>-3.071+003</td>
</tr>
<tr>
<td>61</td>
<td>-3.071+003</td>
</tr>
<tr>
<td>71</td>
<td>-3.071+003</td>
</tr>
<tr>
<td>81</td>
<td>-3.071+003</td>
</tr>
<tr>
<td>91</td>
<td>-3.071+003</td>
</tr>
<tr>
<td>101</td>
<td>-3.071+003</td>
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<tr>
<td>111</td>
<td>-3.071+003</td>
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<tr>
<td>121</td>
<td>-3.071+003</td>
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<tr>
<td>131</td>
<td>-3.071+003</td>
</tr>
<tr>
<td>141</td>
<td>-3.071+003</td>
</tr>
<tr>
<td>151</td>
<td>-3.071+003</td>
</tr>
<tr>
<td>161</td>
<td>-3.071+003</td>
</tr>
<tr>
<td>171</td>
<td>-3.071+003</td>
</tr>
</tbody>
</table>

26 POTENTIAL ITERATIONS COMPLETED.
ROOTR/ROOTMAX = 2.42+001/ 2.46+007
PCOND = -1.0696+003 -1.4126+003
QCOND = 1.521+009 -2.3461+005
NEXTRA = 0
EFPREP -- 1 GRIDS OUT OF 1 READ IN.
IP = 13 IR = 12 IU = 10 1SPARE = 14 1PSAVE = 10
LAST CYCLE COMPLETED IS 1.
IP = 10 IR = 12 IU = 13 1SPARE = 14 1PSAVE = 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)

\[ d^3V_o = dv_x \, dv_y \, dv_z \]

\[ f_o(\vec{V}_o) = \text{phase space density function evaluated at the surface for particles with velocity } \vec{V}_o. \]

\[ m = \text{mass of incident particles.} \]

\[ e = \text{charge of incident particles (electrons or protons).} \]

To evaluate the integral it is expedient to change from rectangular to spherical coordinates. The necessary substitutions are:

\[ V_o = |\vec{V}_o| \]

\[ d^3V_o = V_o^2 \sin \theta \, d\theta \, d\phi \, dv_o \]

\[ (eV_o \cdot \hat{k}) = ev_o \cos \theta \]

With these the energy flux integral transforms into

\[ \vec{E}_o = -k \int_0^\infty \int_0^{2\pi} \int_0^{\pi/2} \left( \frac{mv_o^2}{2e} \right) \left\{ ev_o \cos \theta f_o(\theta, \phi, V_o) \right\} V_o^2 \sin \theta \, d\theta \, d\phi \, dv_o \]

\[ = -k \int_0^\infty \int_0^{2\pi} \int_0^{\pi/2} \left( \frac{m}{2e} \right) V_o^5 f_o(\mu, \phi, V_o) \frac{d\mu^2}{2} \, d\phi \, dv_o \]

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

\( \frac{1}{2} m v_0^2 = e E_0 \) (factor e because \( E_0 \) is in eV)

\[ dv_0 = \frac{edE_0}{mv_0} \]

Then the energy flux integral becomes

\[
\dot{E}_0 = -k \int_0^\infty \int_0^{2\pi} \int_0^1 2\left(\frac{e}{m}\right)^2 E_0^2 f_0(\mu, \phi, E_0) \frac{d\mu}{2} d\phi dE_0
\]

\[
= -k \int_0^\infty \int_0^{2\pi} \int_0^1 2\left(\frac{e}{m}\right)^2 E_0^2 f_0(E_0, \Omega) \mu d\Omega dE_0
\]

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

\[
\dot{E}_0 = -k \int_0^\infty \int_0^{2\pi} G_0(E_0, \Omega) \mu d\Omega dE_0
\]

Comparison of the integrands yields the identity

\[ 2\left(\frac{e}{m}\right)^2 f_0(E_0, \Omega_0) G_0(E_0, \Omega_0) = \frac{G_0(E_0, \Omega_0)}{E_0^2} \]
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 $\hat{\mathbf{v}}_0$:

$$f_0(E_0, \hat{\mathbf{v}}_0) = f_\infty (E_\infty, \hat{\mathbf{v}}_\infty)$$

$$\frac{G_0(E_0, \hat{\mathbf{v}}_0)}{E_0^2} = \frac{G_\infty (E_\infty, \hat{\mathbf{v}}_\infty)}{E_\infty^2}$$

where

- $f_0$ = phase space density function evaluated at cell surface.
- $f_\infty$ = phase space density function evaluated at infinity.
- $G_0$ = energy flux density function evaluated at cell surface.
- $G_\infty$ = energy flux density function evaluated at infinity.
- $E_0$ = initial kinetic energy of particle to be tracked.
- $E_\infty$ = kinetic energy of particle after reverse trajectory tracking to infinity.
- $\hat{\mathbf{v}}_0$ = initial velocity direction vector of particle at cell surface.
- $\hat{\mathbf{v}}_\infty$ = 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
\[ \hat{E}_0 = -\hat{k} \int_0^\infty \int_0^{2\pi} E_0^2 \left\{ \frac{G_\infty(E_\infty, \hat{\Omega}_\infty)}{E^2} \right\} \mu \ d\Omega \ dE_0 \]

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 \( \hat{n} \) is the unit normal pointing in the direction in which the particle detector is pointing. If the detector responds to particles having energy \( E_0 \) then the measured value for the energy flux will be

\[ \frac{\alpha^{2 E_0^+}}{E_0} = -\hat{n} E_0^2 \left\{ 2 \left( \frac{e}{m} \right)^2 f_0(E_0, \hat{n}) \right\} \mu \]

\[ = -\hat{n} E_0^2 \left\{ \frac{G_\infty(E_\infty, \hat{\Omega}_\infty)}{E_\infty^2} \right\} \mu \]

where

\( \hat{E}_0 \) = energy flux vector at cell surface.

\( f_0 \) = phase space density function evaluated at cell surface.

\( E_0 \) = kinetic energy (in eV) of particles at cell surface.
\( \phi = \) azimuthal angle in detector coordinate system.

\( \theta = \) polar angle in detector coordinate system.

\( E_\infty = \) kinetic energy (in eV) of particles after reverse trajectory tracking to infinity.

\( \vec{v}_\infty = \) velocity direction vector for particles after reverse trajectory tracking to infinity.

\( m = \) mass of particles.

\( G_{E_\infty}(E, \Omega) = \) energy flux density function (i.e., tabulated Deforest data, for example. Units are eV/(sec-cm\(^2\)-sr-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 \( \frac{\partial^2}{\partial E_0 \partial \Omega} \) averaged over the energy and angular apertures of the detector. Thus, in general, the value which the detector yields is of the form

\[
\frac{\partial^2}{\partial E_0 \partial \Omega} \int_0^{2\pi} \int_0^{2\pi} W(E_0, \Omega) \frac{G_{E_\infty}(E, \Omega)}{E^2} \cos \Omega \, d\Omega \, dE_0
\]

\[
= \frac{\int_0^{2\pi} \int_0^{2\pi} W(E_0, \Omega) \, d\Omega \, dE_0}{\int_0^{2\pi} \int_0^{2\pi} W(E_0, \Omega) \, d\Omega \, dE_0}
\]

where \( W(E_0, \Omega) \) 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 $E + \Delta E$ and 0 elsewhere. The angular aperture is assumed to be a hemispherical cap of "width" $\Delta \varnothing$ in the polar angle. (The vector $\hat{n}$ 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

\[
\frac{\partial}{\partial E_0} \frac{\partial^2 \Phi}{\partial \varnothing \partial \Omega} = \frac{2}{\Delta \theta \Delta \varnothing} \int_{E}^{E+\Delta E} \int_{0}^{2\pi} \int_{\cos^2 \Delta \varnothing}^{1} \frac{E_0^2 \left( \frac{G_\infty(E_\infty, \hat{n})}{E_\infty^2} \right)}{E^2 \left( \frac{E_\infty^2}{E^2} \right)} d\mu \frac{2}{d \varnothing \, dE_0}
\]

\[
\int_{E}^{E+\Delta E} \int_{0}^{2\pi} \int_{0}^{1} \sin \varnothing \, d\varnothing \, d\varnothing \, dE_0
\]

\[
= \frac{1}{(1 - \cos \Delta \varnothing) 2\pi \Delta E}
\]

where $\mu = \cos \varnothing$.

This integral is evaluated by a three-dimensional approximation formula which uses the mid-point rule with $n_\varnothing$ points to compute the integral over $\varnothing$, the mid-point rule with $n_\mu$ points to compute the integral over $\mu^2$, and the even-order Gauss-Legendre formula with $n_\varnothing$ points to compute the integral over $E_0$. The composite formula used is:

\[
\frac{\partial^2 \Phi}{\partial E_0 \partial \varnothing} \approx -\hat{n} \left( \frac{2\pi}{n_\varnothing} \right) \sum_{i=1}^{n_\varnothing} \left( \frac{1 - \cos^2 \Delta \varnothing}{2m} \right) \sum_{j=1}^{n_\mu} \left( \frac{\Delta E}{2} \right) \sum_{k=1}^{n_\varnothing / 2} W_k \varepsilon_k \left( \varnothing_i, \mu_j, \varepsilon_k \right)
\]
\[ + W_{-k} \epsilon_{-k} F(\phi_i^2, \mu_j^2, \epsilon_{-k}) \left\{ \frac{1}{(1 - \cos \theta)} \right\} \frac{1}{2 \pi \Delta E} \]

\[ = \sum_{i=1}^{n_{\phi}} \sum_{j=1}^{n_{\psi}} \sum_{k=1}^{n_{\epsilon}/2} \left\{ W_{k} \epsilon_{k}^2 F(\phi_i^2, \mu_j^2, \epsilon_{k}) + W_{-k} \epsilon_{-k}^2 F(\phi_i^2, \mu_j^2, \epsilon_{-k}) \right\} \]

where

\[ \epsilon_k = \frac{\Delta E}{2} (\chi_k + 1) + \epsilon \]

\[ \phi_i = \frac{2 \pi}{n_{\phi}} (i - 1/2) \]

\[ \mu_j^2 = \Delta \mu^2 (j - 1/2) + (1 - n_{\psi} \Delta \mu^2) \]

\[ \gamma = \frac{1 + \cos \theta}{4 \pi n_{\psi} n_{\phi}} \] (multiply by \(10^{-4}\) to put units in \(\text{cm}^{-2}\))

\[ F(\phi_i, \mu_j^2, \epsilon_k) = \frac{G_{12}(E_{\infty}, \chi_{\infty})}{E_{\infty}^2} \]

\[ E_{\infty} \] and \( \chi_{\infty} \) 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 \( \phi_i, \mu_j^2, \) and \( \epsilon_k \)) to infinity.

The \( \chi_k \) and \( W_k \) are the Gauss-Legendre integration coefficients for \( n_\epsilon \) an even integer. (Note the \( \chi_k = - \chi_{-k} \) and \( W_k = W_{-k} \).) A slightly modified formula is used to permit \( n_\epsilon = 1 \). (Also note that \(-1 < \chi_k < 1\) 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 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 $n_e$ discrete energies, $n_\phi n_\theta$ particles are emitted. The initial emission velocity direction vector of each particle (measured in the emitter coordinate system ) is

$$\hat{V}_{ij} = (\sin \theta_j \cos \phi_i)^i + (\sin \theta_j \sin \phi_i)^j + (\cos \phi_i)^k$$

where
\[
\phi_i = \frac{2\pi}{n_\phi} (i - 1/2) \quad i = 1, 2, \ldots, n_\phi \\
\Theta_j = \frac{\Delta\Theta}{n_\Theta} (j - 1/2) \quad j = 1, 2, \ldots, n_\Theta
\]

For the special choice of \( n_\phi = n_\Theta \) each particle represents the same solid angle fraction of the emitted current.

(b) Cosine \( \Theta \) Angular Current Density Dependence

For each of \( n_\epsilon \) discrete energies, \( n_\phi n_\Theta \) particles are emitted. The initial velocity direction vector of each particle (measured in the emitter coordinate system) is

\[
\mathbf{v}_{ij} = (\sin_j \cos_i \hat{i} + (\sin_j \sin_i \hat{j}) + (\cos_j \hat{k})
\]

where

\[
\phi_i = \frac{2\pi}{n_\phi} (i - 1/2) \quad i = 1, 2, \ldots, n_\phi \\
\Theta_j = \sin^{-1} \left( \frac{(j - 1/2) \sin \Delta \Theta}{n_\Theta} \right) \quad k = 1, 2, \ldots, n_\Theta
\]

(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

\[
J(\epsilon) = \frac{I_B}{\sqrt{2\pi} \sigma} \exp \left( -\frac{1}{2} \left( \frac{\epsilon - \epsilon_0}{\sigma} \right)^2 \right)
\]

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

\[ \int_{0}^{\infty} J(\varepsilon) \, d\varepsilon \to I_B \quad \text{for} \quad \varepsilon_0 > 0 \quad \text{and} \quad \frac{\sigma}{\varepsilon_0} \ll 1. \]

Thus the mono-energetic energy peak can be represented to any degree of accuracy desired simply by choosing \( \sigma/\varepsilon_0 \) small enough. It is worth noting that \( \sim 68 \) percent of the current falls in the range \( \varepsilon = \varepsilon_0 + \sigma \) and \( \sim 92 \) percent of the current falls in the range \( \varepsilon = \varepsilon_0 + 2\sigma. \)

NASCAP chooses the discrete energy representation of the Gaussian energy distribution as follows:

\[ \varepsilon_i = F^{-1}\left(1 + \frac{(1/2 - i)}{\eta_{\varepsilon}}\right) \quad i = 1, 2, \ldots, n_{\gamma} \]

where

\[ F(X) = \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi} \sigma} \exp\left\{-\frac{1}{2} \left(\frac{\varepsilon - \varepsilon_0}{\sigma}\right)^2\right\} \, d\varepsilon \quad (7.1) \]

This choice results in the following equality being satisfied:

\[ \int_{\varepsilon_i}^{\varepsilon_{i+1}} J(\varepsilon) \, d\varepsilon = \frac{I_B}{n_{\varepsilon}} \quad (7.2) \]

where we define \( \varepsilon_0 = 0 \) and \( \varepsilon_{n_{\varepsilon} + 1} = \infty. \)
Thus each discrete energy $\epsilon_i$ represents the same fraction $(1/n_c)$ of the total emitted current. Furthermore, half of this fraction is a result of energy in the range $\epsilon_{i-1} < \epsilon \leq \epsilon_i$ and half is a result of energy in the range $\epsilon_i \leq \epsilon < \epsilon_{i+1}$.

(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

$$J(\epsilon) = \frac{\mu I_B}{(\pi/2 + \tan^{-1} \mu)} \left\{ \frac{\alpha^2 \epsilon_0 \epsilon}{(\epsilon^2 - \epsilon_0^2)^2 + (\epsilon_0 \alpha)^2} \right\}$$

where $I_B = \text{total emitter beam current}$.

$$\mu = \sqrt{2 - \alpha^2 / \alpha} \text{ and } \alpha = \sigma / \epsilon_0$$

This density function has the property that

$$\lim_{\sigma \to 0} J(\epsilon) \quad I_B \quad \delta(\epsilon - \epsilon_0)$$

and

$$\int_0^{\infty} J(\epsilon) \, d\epsilon = I_B \text{ for all } \sigma / \epsilon_0 < \sqrt{2}.$$ 

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 \( \theta \) 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**

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

\[
\text{ROTATE} \ <n> \n\]

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 preceded by OBJDEF and logically precedes 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.
The first card that \texttt{ROTATE} expects to find contains the angular velocity vector (in rad s\textsuperscript{-1}) \( \omega_x \omega_y \omega_z \). The second contains the initial sun direction for cycle 1! Obviously this remains the same for all further \texttt{TRILIN} cycles. For example, the sequence:

\begin{verbatim}
TRILIN
ROTATE 5
\omega_x \omega_y \omega_z
x y z
TRILIN
ROTATE 5
\omega_x \omega_y \omega_z
x y z
TRILIN
\end{verbatim}

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 \texttt{TRILIN} (before any call to \texttt{ROTATE}) is required to establish the elapsed time (usually equal to \texttt{DELTA} (6.2.2) – but see (6.2.6)). The subsequent call to \texttt{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 $5 \times
0.2 = 1.0$ 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 $\omega_x \omega_y \omega_z$ and $x y z$ to be set at the default values, i.e.,

\[
\text{angular velocity} = \omega_x \omega_y \omega_z \quad 0 \quad 0 \quad \frac{2\pi}{60}
\]

(1 rpm about the Z axis)

\[
\begin{array}{c}
x y z \\
1 \quad 0 \quad 0
\end{array}
\]

(The initial sun direction along the X axis)

For example

\[
\begin{array}{c}
\text{TRILIN} \quad \text{TRILIN} \\
\text{ROTATE} \quad \text{ROTATE} 5 \\
\text{TRILIN} \quad 0 \quad 0 \quad \frac{2\pi}{60} \\
\end{array}
\]

\[
\begin{array}{c}
1 \quad 0 \quad 0 \\
\text{TRILIN}
\end{array}
\]

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 average illumination of each surface cell over one rotation period. The card:

\[
\text{SPIN <n>}
\]

included in the NASCAP runstream will execute module SPIN. SPIN should proceed 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 preceded by TRILIN and logically precedes a second call to TRILIN.

4. ROTATE reads two cards from file n, e.g. for n = 5
   ROTATE 5
   \omega_x \omega_y \omega_z \text{ angular velocity vector (rad/5)}
   \begin{align*}
x & y & z 
& \text{ initial sun direction at the beginning of cycle 1.}
\end{align*}

5. NCYC should usually be 1.

6. Calls to ROTATE should follow calls to TANK.

Figure 8.2. ROTATE summary.
The first card read by SPIN:

'SPIN 5
num
x y z
TRILIN
'

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 \(\theta\) 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 \( \cos \theta \) 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 preceded by OBJDEF and logically precedes 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.)

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 TEFLOM -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 not 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 must 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 surface cells to potential v.

SURFACE CELL i v

Set insulating surface cell i to potential v.

BOOM CELL i v

Set the ith 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

S1 S2 ... END

Set a list of surface cells to potential v. The list appears on subsequent cards, with up to fifteen numbers per card. Processing continues 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.
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.
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:
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, \( E_{\text{stress}} \) is defined as

\[
E_{\text{stress}} = \frac{V_c - V_s}{d}
\]

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 be 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.
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.
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
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 9.7. 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/cm².
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 $\pi$ (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.
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<thead>
<tr>
<th>SUBROUTINE</th>
<th>ARGUMENTS</th>
<th>FUNCTION</th>
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<tbody>
<tr>
<td>ADF</td>
<td>None</td>
<td>Eject current plot frame</td>
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<tr>
<td>APRNTV</td>
<td>(IDX, IDY, N, TEXT, IX, IY)</td>
<td>Print horizontal or vertical plot labels</td>
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<td>AXISXV</td>
<td>(X, Y, XEND)</td>
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<td>AXISYV</td>
<td>(X, Y, YEND)</td>
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<td>CONECT</td>
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<td>Connect line segments for contours</td>
</tr>
<tr>
<td>CURVV</td>
<td>(N, X, JDX, JDY, IDUM)</td>
<td>Draw connected line segments</td>
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<td>DLINEV</td>
<td>(N, IX, IY)</td>
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<td>DRAWV</td>
<td>(LINE, N, IX, IY, KEYPOS, KCSIZE)</td>
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<tr>
<td>IGFBUF</td>
<td>(NWDS, NAME)</td>
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<tr>
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</tr>
<tr>
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<td>None</td>
<td>Draw box around plot</td>
</tr>
<tr>
<td>PLOTCV</td>
<td>(N, X, Y, IC)</td>
<td>Plot a character (or dot) at listed points</td>
</tr>
<tr>
<td>SBLIN</td>
<td>(NN, KK)</td>
<td>Print scale values for linear baseline</td>
</tr>
</tbody>
</table>

NN subdivisions
- 0 I6
- 1-5 F6.0 - F6.4
- 6-12 E12.1 - E12.7
<table>
<thead>
<tr>
<th>SUBROUTINE</th>
<th>ARGUMENTS</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
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<td>SETUAV</td>
<td>(XL, XR, YB, YT, IXL, IXR, IYB, IYT)</td>
<td>Define user area and establish raster coordinates</td>
</tr>
<tr>
<td>SETUPV</td>
<td>None</td>
<td>Open plot file</td>
</tr>
<tr>
<td>SLLIN</td>
<td>(NN, KK)</td>
<td>Print scale values for linear grid left line (See SBLIN)</td>
</tr>
<tr>
<td>SWPEN</td>
<td>(COLOR)</td>
<td>Switch pen color</td>
</tr>
</tbody>
</table>
| 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 (R0) = 4.00*000 CODE UNITS
#7 POTENTIAL ITERATIONS COMPLETED.
RDOIT/RODMAX= 1.85-009/ 2.78-001
1 PCOND = 2.0106E-002  2.0106E-002
QCOND = 2.0105E-002  2.0106E-002
VBAR= 2.0054E-002 -- CS SCALED BY 1.0026*000
2 CROEFF --- EFFECTIVE OBJECT RADIUS = .0793 METERS
50 POTENTIAL ITERATIONS COMPLETED.
RDOIT/RODMAX= 2.38-003/ 3.20-005
PCOND = -2.1205E-000  7.8795E-000
QCOND = -3.5585E-002  3.5581E-002
3 SMALL INTERCONDUCTOR CAPACITANCES:
    -2.72E001  2.72E001
```

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.
Figure 10.2. DETECT sample output.
PARAMETER DEFINITION SUMMARY FOR PARTICLE DETECTORS

NUMBER OF PARTICLE DETECTORS = 1

DETECTOR NUMBER 1:

SURFACE CELL LOCATION = 17C

ENERGY FLUX INTEGRAL PARAMETERS

DE = 10.00 %  NE = 1
DS = 500  NF = 1
DTH = 1.00 DEG  NHU2 = 1

ELECTRON CHARGE = -1.60200E-19 COUL  ELECTRON MASS = 9.10910E-031 KG
PROTON CHARGE = 1.60200E-19 COUL  PROTON MASS = 1.67252E-027 KG

INDEPENDENT VARIABLE FOR PLOT = THET
SCAN RANGE = 10 POINTS FROM -8.80E+001 DEG TO 8.80E+001 DEG

FIXED VARIABLES

ENERGY = 1.000E+000 EV
PHI = 0.00 DEG

PROTON ENERGY FLUX PLOT SEPARATION SCALE FACTOR = 1.00E+005
PROTON ENERGY FLUX PLOT PER LINE WIDTH = 1 MASTER INCREMENTS
PARTICLE VELOCITY = 100 MESH UNITS PER STEP
HIGHEST GRID IN WHICH I/V POTENTIAL TRACKING IS PERMITTED = 2
ENERGY FLUX SCALE RANGE IS DETERMINED AT EXECUTION TIME

**** PARTICLE TRAJECTORY PLOTS WILL BE PRODUCED FOR THIS DETECTOR ****

TRAJECTORY PLOT FRAME REPEATITION OPTION ACTIVE WITH PARAMETERS SET AS FOLLOW:

GRID BOUNDARY INDEX OF FIRST FRAME (NGRND) = 1
NUMBER OF FRAMES GENERATED (NGPLOT) = 1
GRID BOUNDARY INDEX INCREMENT (NGINC) = 0

Figure 10.2. (Continued).
Figure 10.2. (Continued).
**ASGFIL**

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<th>-- ORIGINAL VELOCITY:</th>
<th>-9625</th>
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<td>-7334</td>
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<tr>
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<td>437.8 EV</td>
<td>-- ORIGINAL VELOCITY:</td>
<td>-9574</td>
<td>-6967</td>
<td>5699</td>
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</table>

**PARTICLE TRACKING TOTALS FOR DETECTOR**

**1 SPECIES 1 AT CYCLE**

<table>
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<th>19.3 EV</th>
<th>Originated from spacecraft</th>
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</thead>
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<td>Originated from spacecraft</td>
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<tr>
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<td>11.8 EV</td>
<td>Originated from spacecraft</td>
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**PARTICLE TRACKING TOTALS FOR DETECTOR**

**1 SPECIES 2 AT CYCLE**

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<th>---</th>
</tr>
</thead>
</table>

**END**

**NASCAP**

**Figure 10.2. (Concluded).**
10.4. HIDCEL

Output is shown in Figure 10.3. The output is purely diagnostic.

![HIDCEL Output](image)

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 = -2000
PCOND = -1000
BOND = 0
KAPTON = -3000

END

TOTAL CHARGE FOR INITIALLY SPECIFIED POTENTIALS ESTIMATED TO BE  -1.10+005 COUL UNITS.

POTENTIALS TO BE SET BY SETALL TO -1.30+005/(4.40+PI*R)
AVERAGE RADIUS (RO) = 4.00+000 COUL UNITS

<table>
<thead>
<tr>
<th>SURFACE POTENTIALS - ALL 184 CELLS</th>
</tr>
</thead>
<tbody>
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<td>CELL NO.</td>
</tr>
<tr>
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</tr>
<tr>
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</tr>
<tr>
<td>3</td>
</tr>
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<td>17</td>
</tr>
<tr>
<td>18</td>
</tr>
<tr>
<td>19</td>
</tr>
</tbody>
</table>

19 POTENTIAL ITERATIONS COMPLETED.
ROOTR/ROOTMA = 4.65+003/ 4.85+009
PCOND = -1.000+001 -2.000+003
QCOND = 1.5210+009 -5.9287+005
NLX1RA = 0

EFFPPLP = 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.
<table>
<thead>
<tr>
<th>Property</th>
<th>Input Value</th>
<th>Code Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DISSIPATION CONSTANT</td>
<td>1.00-000 (NONE)</td>
<td>1.00-000 (NONE)</td>
</tr>
<tr>
<td>CONDUCTIVITY</td>
<td>1.00-000 Meters</td>
<td>1.00-000 MESH</td>
</tr>
<tr>
<td>ATOMIC NUMBER</td>
<td>7.90-001 (NONE)</td>
<td>7.90-001 (NONE)</td>
</tr>
<tr>
<td>DELTA HX Y COEFF</td>
<td>7.90-001 (NONE)</td>
<td>7.90-001 (NONE)</td>
</tr>
<tr>
<td>E-MAX EDEPTH</td>
<td>8.00-001 (NONE)</td>
<td>8.00-001 (NONE)</td>
</tr>
<tr>
<td>RANGE</td>
<td>9.00-001 (ANG)</td>
<td>9.00-001 (ANG)</td>
</tr>
<tr>
<td>EXPONENT</td>
<td>9.00-001 (ANG)</td>
<td>9.00-001 (ANG)</td>
</tr>
<tr>
<td>RADIUS EXPONENT</td>
<td>9.00-001 (ANG)</td>
<td>9.00-001 (ANG)</td>
</tr>
<tr>
<td>YIELD FOR I KEV PROTONS</td>
<td>4.13-001 (NONE)</td>
<td>4.13-001 (NONE)</td>
</tr>
<tr>
<td>MAX DEP FOR PROTONS</td>
<td>4.13-001 (NONE)</td>
<td>4.13-001 (NONE)</td>
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<tr>
<td>PHOTOCURRENT</td>
<td>4.13-001 (NONE)</td>
<td>4.13-001 (NONE)</td>
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<td>SURFACE RESISTIVITY</td>
<td>4.13-001 (NONE)</td>
<td>4.13-001 (NONE)</td>
</tr>
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<td>INTERNAL DISCHARGE POTENTIAL</td>
<td>4.13-001 (NONE)</td>
<td>4.13-001 (NONE)</td>
</tr>
<tr>
<td>RADON INDUCECOND Y COEFF</td>
<td>4.13-001 (NONE)</td>
<td>4.13-001 (NONE)</td>
</tr>
<tr>
<td>RADON INDUCECOND Y POWER</td>
<td>4.13-001 (NONE)</td>
<td>4.13-001 (NONE)</td>
</tr>
<tr>
<td>DENSITY</td>
<td>4.13-001 KG/M**3</td>
<td>4.13-001 KG/M**3</td>
</tr>
</tbody>
</table>

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

COMMENT WORKED EXAMPLE (CHAPTER 10)
COMMENT ZONE SIZE IS 0.02 M
COMMENT DEFINE MATERIAL GOLD AND SOLAR

GOLD
MATERIAL PROPERTIES
1.00E+00 1.00E+03 1.00E+00 -7.90E-01 6.00E-01 1.00E+01 1.00E+13 1.00E+06 1.00E+06 1.00E+06 1.00E+06 1.00E+06
2.90E+02 2.90E+02 2.90E+02 2.90E+02 2.90E+02 2.90E+02 2.90E+02 2.90E+02

SOLAR
MATERIAL PROPERTIES
3.00E+00 1.79E-04 1.00E-01 2.05E+00 9.10E-01 7.75E+00 9.50E-01 1.50E+03 1.73E+00 1.73E+00
2.44E+01 2.30E+02 2.00E-05 1.00E+19 1.00E+04 2.00E+03 1.00E+01 1.00E+06 1.00E+06 1.00E+06

COMMENT PROPERTIES OF KAPTON AND ALUMINUM FROM DEFAULT TABLE.

CONDUCTOR 1
COMMENT CENTRAL CUBOID

Figure 10.6. OBJDEF.
RECTAN
OBJECT NOW DEFINED.

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
EXTENDING PARALLEL TO THE Z AXIS TO 
RADI .05000
SURF ALUM

COMMENT BOOM TO SOLAR SPHERE

BOOM

BOOM DEFINED
BEGINNING AT
EXTENDING PARALLEL TO THE Z AXIS TO 
RADI .05000
SURF ALUM

COMMENT KAPTON SPHERE

QSPHERE

DEFINING Q-SPHERE
CENTER = 9 9 22
DIAMETER = 1
MATERIAL = KAPTON

OCTAGON DEFINED
AXIS = 1 9 22 10 1 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).
<table>
<thead>
<tr>
<th>SURFACE CELL LIST</th>
<th>CONDUCTOR</th>
<th>IX</th>
<th>IY</th>
<th>IZ</th>
<th>NORMAL</th>
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<th>CONDUCTOR</th>
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<th>IY</th>
<th>IZ</th>
<th>GRID AXIS</th>
<th>BOOM</th>
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<table>
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<th>LIST OF BOOM PROPERTIES</th>
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<th>CONDUC</th>
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<tr>
<td>BOOM</td>
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<td>ALUM</td>
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Figure 10.6. (Continued).
### MATERIAL 11: GOLD

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>INPUT VALUE</th>
<th>CODE VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric Constant</td>
<td>1.00+000 Inch</td>
<td>1.00+000 Inch</td>
</tr>
<tr>
<td>Thickness</td>
<td>0.00+000 Meters</td>
<td>0.00+000 Meters</td>
</tr>
<tr>
<td>Conductivity</td>
<td>0.00+000 Mhos/M</td>
<td>0.00+000 Mhos/M</td>
</tr>
<tr>
<td>Atomic Number</td>
<td>0.00+000</td>
<td>0.00+000</td>
</tr>
<tr>
<td>Delta Max 2</td>
<td>0.00+000</td>
<td>0.00+000</td>
</tr>
<tr>
<td>E-Max</td>
<td>8.00+000</td>
<td>8.00+000</td>
</tr>
<tr>
<td>Range</td>
<td>8.00+000</td>
<td>8.00+000</td>
</tr>
<tr>
<td>EXPONENT</td>
<td>9.20+000</td>
<td>9.20+000</td>
</tr>
<tr>
<td>Range &gt; EXPONENT</td>
<td>5.35+000</td>
<td>5.35+000</td>
</tr>
<tr>
<td>Yield for 1 keV Protons</td>
<td>8.17+000</td>
<td>8.17+000</td>
</tr>
<tr>
<td>Max Delta for Protons</td>
<td>8.17+000</td>
<td>8.17+000</td>
</tr>
<tr>
<td>PhotoCurrent</td>
<td>4.00+000</td>
<td>4.00+000</td>
</tr>
<tr>
<td>Surface Resistivity</td>
<td>1.00+000</td>
<td>1.00+000</td>
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<tr>
<td>Space Discharge Pot/L</td>
<td>2.00+000</td>
<td>2.00+000</td>
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<tr>
<td>Internal Discharge Pot/L</td>
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### MATERIAL 21: SOLA

<table>
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</tr>
</thead>
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<tr>
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<td>1.00+000 Inch</td>
</tr>
<tr>
<td>Thickness</td>
<td>0.00+000 Meters</td>
<td>0.00+000 Meters</td>
</tr>
<tr>
<td>Conductivity</td>
<td>0.00+000 Mhos/M</td>
<td>0.00+000 Mhos/M</td>
</tr>
<tr>
<td>Atomic Number</td>
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</tr>
<tr>
<td>Delta Max 2</td>
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<td>9.10+000</td>
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<td>7.50+000</td>
</tr>
<tr>
<td>EXPONENT</td>
<td>4.50+000</td>
<td>4.50+000</td>
</tr>
<tr>
<td>Range &gt; EXPONENT</td>
<td>1.75+000</td>
<td>1.75+000</td>
</tr>
<tr>
<td>Yield for 1 keV Protons</td>
<td>5.54+000</td>
<td>5.54+000</td>
</tr>
<tr>
<td>Max Delta for Protons</td>
<td>5.54+000</td>
<td>5.54+000</td>
</tr>
<tr>
<td>PhotoCurrent</td>
<td>2.00+000</td>
<td>2.00+000</td>
</tr>
<tr>
<td>Surface Resistivity</td>
<td>1.00+000</td>
<td>1.00+000</td>
</tr>
<tr>
<td>Space Discharge Pot/L</td>
<td>2.00+000</td>
<td>2.00+000</td>
</tr>
<tr>
<td>Internal Discharge Pot/L</td>
<td>1.00+000</td>
<td>1.00+000</td>
</tr>
<tr>
<td>RADIATION INDUCED COND * POWER</td>
<td>1.00+000</td>
<td>1.00+000</td>
</tr>
<tr>
<td>DENSITY</td>
<td>1.00+000</td>
<td>1.00+000</td>
</tr>
</tbody>
</table>

### MATERIAL 31: KAPT

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>INPUT VALUE</th>
<th>CODE VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric Constant</td>
<td>1.00+000 Inch</td>
<td>1.00+000 Inch</td>
</tr>
<tr>
<td>Thickness</td>
<td>0.00+000 Meters</td>
<td>0.00+000 Meters</td>
</tr>
<tr>
<td>Conductivity</td>
<td>0.00+000 Mhos/M</td>
<td>0.00+000 Mhos/M</td>
</tr>
<tr>
<td>Atomic Number</td>
<td>0.00+000</td>
<td>0.00+000</td>
</tr>
<tr>
<td>Delta Max 2</td>
<td>0.00+000</td>
<td>0.00+000</td>
</tr>
<tr>
<td>E-Max</td>
<td>1.50+000</td>
<td>1.50+000</td>
</tr>
<tr>
<td>Range</td>
<td>1.50+000</td>
<td>1.50+000</td>
</tr>
<tr>
<td>EXPONENT</td>
<td>6.00+000</td>
<td>6.00+000</td>
</tr>
<tr>
<td>Range &gt; EXPONENT</td>
<td>3.12+002</td>
<td>3.12+002</td>
</tr>
<tr>
<td>Yield for 1 keV Protons</td>
<td>4.55+000</td>
<td>4.55+000</td>
</tr>
<tr>
<td>Max Delta for Protons</td>
<td>4.55+000</td>
<td>4.55+000</td>
</tr>
<tr>
<td>PhotoCurrent</td>
<td>2.00+000</td>
<td>2.00+000</td>
</tr>
<tr>
<td>Surface Resistivity</td>
<td>1.00+000</td>
<td>1.00+000</td>
</tr>
<tr>
<td>Space Discharge Pot/L</td>
<td>2.00+000</td>
<td>2.00+000</td>
</tr>
<tr>
<td>Internal Discharge Pot/L</td>
<td>1.00+000</td>
<td>1.00+000</td>
</tr>
<tr>
<td>RADIATION INDUCED COND * POWER</td>
<td>1.00+000</td>
<td>1.00+000</td>
</tr>
<tr>
<td>DENSITY</td>
<td>1.00+000</td>
<td>1.00+000</td>
</tr>
</tbody>
</table>

Figure 10.6. (Continued).
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.
<table>
<thead>
<tr>
<th>KEYWORD INPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>KMEAN 0.02</td>
</tr>
<tr>
<td>NCFC 1</td>
</tr>
<tr>
<td>DELTA 5</td>
</tr>
<tr>
<td>SURFACE CELL 20</td>
</tr>
<tr>
<td>SURFACE CELL 129</td>
</tr>
<tr>
<td>SURFACE CELL 28</td>
</tr>
<tr>
<td>SURFACE CELL 77</td>
</tr>
<tr>
<td>SURFACE CELL 88</td>
</tr>
<tr>
<td>SURFACE CELL 167</td>
</tr>
<tr>
<td>SURFACE CELL 181</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LONGTIMESTEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUNINT 1.0</td>
</tr>
<tr>
<td>SUNDIR 1.10</td>
</tr>
<tr>
<td>BEST ELEC</td>
</tr>
<tr>
<td>ASGFIL -- BASG 10</td>
</tr>
<tr>
<td>ASGFIL -- BASG 15</td>
</tr>
<tr>
<td>ASGFIL -- BASG 20</td>
</tr>
<tr>
<td>ASGFIL -- BASG 25</td>
</tr>
<tr>
<td>ASGFIL -- BASG 30</td>
</tr>
<tr>
<td>ASGFIL -- BASG 35</td>
</tr>
<tr>
<td>ASGFIL -- BASG 40</td>
</tr>
<tr>
<td>ASGFIL -- BASG 45</td>
</tr>
<tr>
<td>ASGFIL -- BASG 50</td>
</tr>
<tr>
<td>ASGFIL -- BASG 55</td>
</tr>
</tbody>
</table>

Figure 10.7. RDOPT
TITLE = NASCAP

GRID SIZE OPTIONS: MX NY NZ NG
17 17 35 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: I0 IR05 IPOCGN ILTBL ICNGW IAREA
15 15 14 11 21 27
SCRATCH FILES: IAWN IHW IDIV IUP ISPARX I0BJ 000PLT IOPART
11 12 25 13 14 18 19 28

RUN MODE OPTIONS: ICREST IPREST NCYC MVC MCYC
0 0 1 1

DELTA DLFAC
5.00+000 1.00+000

DEADLINE = NONE
ADDITIONAL KEYWORD = (RESTART)

POTENTIAL SOLVER OPTIONS: POTCON MAXIT IOUTER SCALE
O NSUET 99 2 SCALE
SCALING KEYS: SCALE, NOSCALE, DSCALE

AMBIENT SPACE CHARGE OPTION (KEYWORD DEPENDS)

CONDUCTOR FIXING AND BIASING (KEYWORDS FIXP, RIAS, FLOAT)

INTERCONDUCTOR CAPACITANCES: KEYWORD C1, C2
THE CODE UNIT OF CHARGE IS 1.771-013 COULombs.
THE CODE UNIT OF CAPACITANCE IS 1.771-013 FARADS.
NO INTERCONDUCTOR CAPACITANCES SPECIFIED.

LONGTIMESTEP AND DISCHARGE OPTIONS
KEYWORDS: LONGTIMESTEP, DISCHARGE, FLASHOVER
LONGTIMESTEP REQUESTED WITH DVPLY= 1000.0 VOLTS.
DISCHARGE ANALYSIS OFF

ILLUMINATION SPECIFICATIONS:
NUMINT= 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 PHOTON SHEATH CONDUCTIVITY (EPSILON) = OFF
FIELD-EFFECTIVE BULK CONDUCTIVITY (PLOCON) = OFF
RADIATION-INDUCED BULK CONDUCTIVITY (PRAUSD) = OFF

OUTPUT OPTIONS:
NGPRT 1 CPRINT 1 TIMER ENOTIMER
NO ICON
ICWP (CONVERGENCE PLOTS) = 0
PRINT (ENOPRINT) POTENT LINCPR OBJDEF HIFCER
NO NO SOME NO
7 SURFACE CELLS SPECIFIED FOR I/O
20 28 77 80 129 167 181
KEYWORDS: (SURFACE CLI AS, SURFACE A13, SURFACE CORNER)

PLOT OPTIONS:
TITLE = NASCAP
NGPLOT 0 ICON REPEAT 1 IOPART 1 IIPR X CUR I0005 P
0 0 0

Figure 10.7. (Continued).
DEST = ELECT
NEON 0 NDIR 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 -5000 -5000
-2000 -6000 -2000
6 MATERIAL PLOT VIEWS REQUESTED:
VIEW FROM +X DIRECTION BETWEEN -8 AND 8
VIEW FROM +Y DIRECTION BETWEEN -8 AND 8
VIEW FROM +Z DIRECTION BETWEEN -8 AND 8
VIEW FROM -X DIRECTION BETWEEN -8 AND 8
VIEW FROM -Y 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 = 1
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 S
1   TIME =  7.0920 SECONDS
2   SUN ROTATED TO  1.8101  *1077  00000
     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
ISCFIL -- BASG
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.
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
ASGFIC -- BSG 2.0
AVERAGE SOLAR ILLUMINATION BEING OBTAINED
1 THE INITIAL SUN DIRECTION IS .707 .707 .000
2 VIEWS WILL BE GENERATED ABOUT THE AXIS .000 .000 1.000
DISTANCE EQUALS 999.99998
{FINAL NA1 = 62
 DISTANCE EQUALS 999.99999
3 FINAL NA1 = 62
 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

**ELECTRIC FIELD STRESS**

**CELLS 1 THROUGH 10 ON LIST OF DECREASING STRENGTH**

<table>
<thead>
<tr>
<th>Surface Cell No.</th>
<th>Code:</th>
<th>Location</th>
<th>Normal</th>
<th>Potential</th>
<th>Material</th>
<th>Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>005111270103</td>
<td>0 9 23</td>
<td>0 0 1</td>
<td>-1.006×10³ Volts</td>
<td>KAPT</td>
<td>1.582×10⁷ Volts/Meter</td>
</tr>
<tr>
<td>1</td>
<td>004607170303</td>
<td>6 7 15</td>
<td>0 0 -1</td>
<td>-1.006×10³ Volts</td>
<td>KAPT</td>
<td>1.582×10⁷ Volts/Meter</td>
</tr>
<tr>
<td>8</td>
<td>004607220103</td>
<td>6 7 10</td>
<td>0 0 1</td>
<td>-1.006×10³ Volts</td>
<td>KAPT</td>
<td>1.582×10⁷ Volts/Meter</td>
</tr>
<tr>
<td>23</td>
<td>004612170303</td>
<td>6 10 10</td>
<td>0 0 -1</td>
<td>-1.006×10³ Volts</td>
<td>KAPT</td>
<td>1.582×10⁷ Volts/Meter</td>
</tr>
<tr>
<td>30</td>
<td>004612220103</td>
<td>6 10 10</td>
<td>0 0 1</td>
<td>-1.006×10³ Volts</td>
<td>KAPT</td>
<td>1.582×10⁷ Volts/Meter</td>
</tr>
<tr>
<td>123</td>
<td>005307170303</td>
<td>11 7 10</td>
<td>0 0 -1</td>
<td>-1.006×10³ Volts</td>
<td>KAPT</td>
<td>1.582×10⁷ Volts/Meter</td>
</tr>
</tbody>
</table>

*Figure 10.11. STRESS sample output.*
<table>
<thead>
<tr>
<th>Surface Cell No.</th>
<th>Code</th>
<th>Location</th>
<th>Normal</th>
<th>Material</th>
<th>Potential</th>
<th>Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>130</td>
<td>005307220103</td>
<td>11 10 10</td>
<td>0 0 1</td>
<td>KAPT</td>
<td>-1.006+003 Volts</td>
<td>1.582+007 Volts/meter</td>
</tr>
<tr>
<td>145</td>
<td>005312170303</td>
<td>11 10 15</td>
<td>0 0 -1</td>
<td>KAPT</td>
<td>-1.006+003 Volts</td>
<td>1.582+007 Volts/meter</td>
</tr>
<tr>
<td>152</td>
<td>005312220103</td>
<td>11 10 10</td>
<td>0 0 1</td>
<td>KAPT</td>
<td>-1.006+003 Volts</td>
<td>1.582+007 Volts/meter</td>
</tr>
<tr>
<td>15</td>
<td>004610220103</td>
<td>6 8 10</td>
<td>0 0 1</td>
<td>KAPT</td>
<td>-1.006+003 Volts</td>
<td>1.582+007 Volts/meter</td>
</tr>
</tbody>
</table>

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.
Figure 10.12. TANK sample output.
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.
1 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+000/14*PI*R

AVERAGE RADIUS (R0) = 4.00+000 CODE UNITS

2 *** THE SYSTEM IS NOW AT TIME 0.000 SECONDS. 1 CYCLES HAVE BEEN REQUESTED.

BEGIN CYCLE NO. 1  TIME = 0.000 SECONDS.

QSUM FOUND QSUM: 1.00+000 CODE UNITS.
AFTER SCREENING CORRECTION (SCREENING LENGTH: 2.00+000 M.) QSUM: 1.00+000
QSCALE = 1.00+000 CORRECTED TO 1.00+000
QSUM = 1.00+000
PCOND = 1.989-002 1.989-002
QCOND = 0.000 0.000

--------------------

EXPLICITLY CALCULATED FLUXES FOR CYCLE 1  TIME = 0.000 SECONDS.
DURING THIS TIME STEP, NASCAP WILL TAKE INTO ACCOUNT SUCH ADDITIONAL EFFECTS AS SURFACE CONDUCTIVITY, DISCHARGES, EMMITER OPERATION, AND VARIATION OF LIMITING FACTORS FOR LOW-ENERGY EMMITED ELECTRONS.

--------------------

Figure 10.13. TRILIN output.
<table>
<thead>
<tr>
<th>SURFACE CELL NO.</th>
<th>20</th>
<th>CODE</th>
<th>00461216003</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LOCATION</td>
<td>6 9 17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NORMAL</td>
<td>-1 0 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MATERIAL</td>
<td>KAI</td>
</tr>
<tr>
<td>POTENTIAL</td>
<td>000</td>
<td>VOLTS</td>
<td></td>
</tr>
<tr>
<td>STRESS</td>
<td>1.566×1002</td>
<td>VOLTS/METER</td>
<td>0.000</td>
</tr>
<tr>
<td>EXTERNAL FIELD</td>
<td>0.000</td>
<td>VOLTS/METER</td>
<td></td>
</tr>
<tr>
<td>LIMITING FACTOR</td>
<td>1.000×1000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLUXES IN A/H++2</td>
<td></td>
<td>INCIDENT ELECTRONS</td>
<td>2.28-006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RESULTING SECONDARIES</td>
<td>9.75-007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RESULTING BACKSCATTER</td>
<td>6.01-007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>INCIDENT PROTONS</td>
<td>2.75-0008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RESULTING SECONDARIES</td>
<td>4.91-0008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BULK CONDUCTIVITY</td>
<td>1.57-014</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PHOTOCURRENT</td>
<td>0.00</td>
</tr>
<tr>
<td>NET FLUX</td>
<td></td>
<td></td>
<td>-6.27-0007</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SURFACE CELL NO.</th>
<th>28</th>
<th>CODE</th>
<th>00461210003</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LOCATION</td>
<td>6 10 11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NORMAL</td>
<td>0 1 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MATERIAL</td>
<td>KAI</td>
</tr>
<tr>
<td>POTENTIAL</td>
<td>000</td>
<td>VOLTS</td>
<td></td>
</tr>
<tr>
<td>STRESS</td>
<td>1.566×1002</td>
<td>VOLTS/METER</td>
<td>0.000</td>
</tr>
<tr>
<td>EXTERNAL FIELD</td>
<td>0.000</td>
<td>VOLTS/METER</td>
<td></td>
</tr>
<tr>
<td>LIMITING FACTOR</td>
<td>1.000×1000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLUXES IN A/H++2</td>
<td></td>
<td>INCIDENT ELECTRONS</td>
<td>2.28-006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RESULTING SECONDARIES</td>
<td>9.75-007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RESULTING BACKSCATTER</td>
<td>6.01-007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>INCIDENT PROTONS</td>
<td>2.75-0008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RESULTING SECONDARIES</td>
<td>4.91-0008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BULK CONDUCTIVITY</td>
<td>1.57-014</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PHOTOCURRENT</td>
<td>0.00</td>
</tr>
<tr>
<td>NET FLUX</td>
<td></td>
<td></td>
<td>1.35-0005</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SURFACE CELL NO.</th>
<th>77</th>
<th>CODE</th>
<th>005107211403</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LOCATION</td>
<td>9 7 11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NORMAL</td>
<td>0 -1 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MATERIAL</td>
<td>KAI</td>
</tr>
<tr>
<td>POTENTIAL</td>
<td>000</td>
<td>VOLTS</td>
<td></td>
</tr>
<tr>
<td>STRESS</td>
<td>1.566×1002</td>
<td>VOLTS/METER</td>
<td>0.000</td>
</tr>
<tr>
<td>EXTERNAL FIELD</td>
<td>0.000</td>
<td>VOLTS/METER</td>
<td></td>
</tr>
<tr>
<td>LIMITING FACTOR</td>
<td>1.000×1000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLUXES IN A/H++2</td>
<td></td>
<td>INCIDENT ELECTRONS</td>
<td>2.28-006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RESULTING SECONDARIES</td>
<td>9.75-007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RESULTING BACKSCATTER</td>
<td>6.01-007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>INCIDENT PROTONS</td>
<td>2.75-0008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RESULTING SECONDARIES</td>
<td>4.91-0008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BULK CONDUCTIVITY</td>
<td>1.57-014</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PHOTOCURRENT</td>
<td>0.00</td>
</tr>
<tr>
<td>NET FLUX</td>
<td></td>
<td></td>
<td>-6.27-0007</td>
</tr>
</tbody>
</table>

Figure 10.13. (Continued).
<table>
<thead>
<tr>
<th>Surface Cell No.</th>
<th>Code</th>
<th>Location</th>
<th>Normal</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>88</td>
<td>005111170103</td>
<td>9 9 23</td>
<td>0 0 1</td>
<td>KAP1</td>
</tr>
<tr>
<td>Potential</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volts</td>
<td>1.566 +002</td>
<td>Volts/Meter</td>
<td>1.000 +000</td>
<td></td>
</tr>
<tr>
<td>Fluxes in A/m**2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incident Electrons</td>
<td>6.96-004</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resulting Secondaries</td>
<td>6.01-007</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incident Protons</td>
<td>4.47-008</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resulting Secondaries</td>
<td>2.67-008</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk Conductivity</td>
<td>1.57-014</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photocurrent</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Flux</td>
<td>-6.27-007</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Surface Cell No.</th>
<th>Code</th>
<th>Location</th>
<th>Normal</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>129</td>
<td>005117212001</td>
<td>11 7 17</td>
<td>0 0 0</td>
<td>GOLD</td>
</tr>
<tr>
<td>Potential</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volts</td>
<td>1.000 +000</td>
<td>Volts/Meter</td>
<td>1.000 +000</td>
<td></td>
</tr>
<tr>
<td>Fluxes in A/m**2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incident Electrons</td>
<td>2.48-006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resulting Secondaries</td>
<td>1.46-006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incident Protons</td>
<td>2.75-008</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resulting Secondaries</td>
<td>2.05-005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk Conductivity</td>
<td>2.12-005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photocurrent</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Flux</td>
<td>2.12-005</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Surface Cell No.</th>
<th>Code</th>
<th>Location</th>
<th>Normal</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>167</td>
<td>011111120302</td>
<td>9 9 10</td>
<td>0 0 1</td>
<td>SOLA</td>
</tr>
<tr>
<td>Potential</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volts</td>
<td>1.114 +002</td>
<td>Volts/Meter</td>
<td>1.000 +000</td>
<td></td>
</tr>
<tr>
<td>Fluxes in A/m**2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incident Electrons</td>
<td>2.29-006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resulting Secondaries</td>
<td>1.63-006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incident Protons</td>
<td>7.77-007</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resulting Secondaries</td>
<td>2.69-008</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk Conductivity</td>
<td>1.11-015</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photocurrent</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Flux</td>
<td>3.01-007</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Boom Surface Cell No.</th>
<th>Code</th>
<th>Location</th>
<th>Normal</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>181</td>
<td>000011121723</td>
<td>9 9 19</td>
<td>1 1 1</td>
<td>ALUM</td>
</tr>
<tr>
<td>Potential</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volts</td>
<td>1.000 +000</td>
<td>Volts/Meter</td>
<td>1.000 +000</td>
<td></td>
</tr>
<tr>
<td>Fluxes in A/m**2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incident Electrons</td>
<td>2.79-006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resulting Secondaries</td>
<td>8.52-009</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incident Protons</td>
<td>8.51-007</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resulting Secondaries</td>
<td>2.69-008</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk Conductivity</td>
<td>1.27-005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photocurrent</td>
<td>1.21-005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Flux</td>
<td>1.21-005</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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; 8.03-012 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 3.05 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).
AVERAGE FLUX TO CELL 20 15 -8.752-007 A/M**2
AVERAGE FLUX TO CELL 25 15 -7.179-008 A/M**2
AVERAGE FLUX TO CELL 30 15 -6.352-008 A/M**2
AVERAGE FLUX TO CELL 35 15 -6.352-008 A/M**2
AVERAGE FLUX TO CELL 167 15 -9.740-008 A/M**2

NEW CONDUCTOR POTENTIALS

7

VNEW
3.0900+000
1.7236+000

DQ
1.6966+005
-9.7015-005

VOLD
.0000
.0000

CONDUCTOR
1
2

TOTAL CHANGE IN CHARGE = -1.966-002 CODE UNITS
-3.933011 COULOMPS

AVERAGE NET CHARGING CURRENT = -6.965-012 AMPERES
-3.933-011 CODE UNITS/SEC.

CONDUCTOR CURRENTS (AMPS; POSITIVE INTO CONDUCTORS):

1
2

NET CURRENT (AVG DQ/DT): 2.73-008 -3.49-018

CONDUCTIVITY CURRENT (NEW)
FROM INSULATING CELLS: -4.71-013 -1.98-018

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 = 5.0000000 SECONDS.

QSUM = -1.966-002

Figure 10.13. (Continued).

Figure 10.13. Continued.
<table>
<thead>
<tr>
<th>CELL NO.</th>
<th>Surface Potentials - All 18% Cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>-9.769+000 -9.768+000 -9.768+000 -9.768+000 -9.768+000 -9.768+000 -9.768+000 -9.768+000 -9.768+000</td>
</tr>
<tr>
<td>7</td>
<td>-9.770+000 -9.768+000 -9.768+000 -9.768+000 -9.768+000 -9.768+000 -9.768+000 -9.768+000 -9.768+000</td>
</tr>
</tbody>
</table>

**POTENTIAL ITERATIONS COMPLETED.**
- Root/RootMax: 5.27-005/1.01-004
- PCOND = 1.940+000
- QCQND = 7.486+004
- NEXTRA = 0

<table>
<thead>
<tr>
<th>IP = 12</th>
<th>IR = 14</th>
<th>IU = 10</th>
<th>ISPARE = 13</th>
<th>IPSAVe = 10</th>
</tr>
</thead>
</table>

**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 defined 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.
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:

<table>
<thead>
<tr>
<th>Part</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Globe diameter</td>
<td>63 mm</td>
</tr>
<tr>
<td>Boom length</td>
<td>41.5 mm</td>
</tr>
<tr>
<td>Cuboid</td>
<td>78 x 78 x 124 mm</td>
</tr>
<tr>
<td>Boom radius</td>
<td>1 mm</td>
</tr>
</tbody>
</table>

A choice of XMESH = 0.020 m (20 mm) allows these dimensions to be replaced by mesh units as follows:

<table>
<thead>
<tr>
<th>Part</th>
<th>Size (mesh units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Globe diameter</td>
<td>3 = (60 mm)</td>
</tr>
<tr>
<td>Boom length</td>
<td>2 = (40 mm)</td>
</tr>
<tr>
<td>Cuboid</td>
<td>4 x 4 x 6 (= 80 x 80 x 120 mm)</td>
</tr>
<tr>
<td>Boom radius</td>
<td>0.05 (= 1 mm)</td>
</tr>
</tbody>
</table>

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.
Let's suppose we are lucky and the plasma environment we have been given is in Maxwellian form, with the following parameters.

<table>
<thead>
<tr>
<th></th>
<th>Electrons</th>
<th>Ions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>$1.2 \times 10^6$ m$^{-3}$</td>
<td>$0.8 \times 10^6$ m$^{-3}$</td>
</tr>
<tr>
<td>Temperature</td>
<td>5.0 keV</td>
<td>3.0 keV</td>
</tr>
</tbody>
</table>

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.
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.

```
11XMESH 0.02
21NCYC 1
31DELTA 5
41SURFACE CELL 20
51SURFACE CELL 129
61SURFACE CELL 28
71SURFACE CELL 77
81SURFACE CELL 88
91SURFACE CELL 167
101SURFACE CELL 181
111LONGTIMESTEP
121SUNDIR 1.0
131SUNINT 1.0
141DEBT ELEC
151END
EOF:15
0:>
```

Figure 11.3. The OPTION file (first run).
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 +x and +y directions were chosen, along with cells pointing in the +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.
Figure 11.4. NASCAP runstream (first run).
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 USE
ADDITIONAL OPTION WORDS: OFFSET, TANKSIZE, ZTRUNC, TANK RADIUS, TANK AXI

LOGICAL UNIT NUMBERS
INPUT FILES:  KEYWD  ISAT  IFLUX  ISPCTR
26  20  22  9
RESTART FILES:  IR  IROUS  IPOQND  ITBL  IBNOW  IAREA
10  16  17  21  27
SCRATCH FILES:  IAUN  IR  IDIV  IU  ISPARE  IOBJ  IOPLT  IPART
11  12  25  13  14  18  19  20
RUN MODE OPTIONS:  ICREST  IPREST  NCYC  MCYC
0  0  1  1
DELTA DLEFA
5.0D+000  1.0D+000
DEADLINE = NONE
ADDITIONAL KEYWORD = CRESTART3

POTENTIAL SOLVER OPTIONS:  POTCON  MAXITR  IOUTER  SCALE
NOTSET  99  2  SCALE
SCALING KEYWORDS:  SCALE, NOSCALE, DISSCALE
AMBIENT SPACE CHARGE OPTION (KEYWORD DEBEY=NONE

CONDUCTOR FIXING AND BIASING: KEYWORDS FIXP, RIAS, FLOAT

INTERCONDUCTOR CAPACITANCES:  KEYWORD Cl-
THE CODE UNIT OF CHARGE IS 1.771-011 COULOMBS.
THE CODE UNIT OF CAPACITANCE IS 1.771-013 FARADS.
NO INTERCONDUCTOR CAPACITANCES SPECIFIED.

LONGTENSTEP AND DISCHARGE OPTIONS
KEYWORDS:  LONGTENSTEP, NOLONGTENSTEP, DISCHARGE, FLASHOVER
LONGTENSTEP REQUESTED WITH DLIM= 1000.0 VOLTS.
DISCHARGE ANALYSIS OFF

ILLUMINATION SPECIFICATIONS:
SUMINT= 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 (FLOCON) = OFF
RADIATION-INDUCED BULK CONDUCTIVITY (RADCON) = OFF

OUTPUT OPTIONS:
NOPRINT CRTM23 TINTER (NOTIMER)
0  NO
ICNVP (CONVERGENCE PLOTS)= 0
PRINT ENPRINT=33  POTENT  LIPCEL  OBJDEF  HIDCEL
NO  NO  SOME  NO
7 SURFACE CELLS SPECIFIED FOR I/O:
20  20  20  77  88  129  167  18
KEYWORDS:  [SURFACE CELLS], [SURFACE AT], [SURFACE CORNER]

PLOT OPTIONS:
TITLE = NASCAP
NGPLOT  ICON  REPEAT  ITPART  ITCUR  IROUSP
0  0  1  0  0  0

Figure 11.5. (Continued).
BEST = ELEC
KCON = NOIR
0 3
ADDITIONAL KEYSWDS: TANKCUR TANKTRAJ 3D-VIEW HATVIEW CONTOUR
NO. OF ADDITIONAL CONTOUR PLOT CUTS = 0
NO. OF 3-D PLOT VIEWS = 3
VECTORS FROM SATELLITE CENTER TOWARD VIEWER ARE
-5000 -5000 -5000
-5000 -5000 -5000
-2000 -2000 -5000

6 MATERIAL PLOT VIEWS REQUESTED:
VIEW FROM +X DIRECTION BETWEEN -A AND 0
VIEW FROM +Y DIRECTION BETWEEN -A AND 0
VIEW FROM +Y DIRECTION BETWEEN -A AND 0
VIEW FROM +Z DIRECTION BETWEEN -16 AND 16
VIEW FROM +Z DIRECTION BETWEEN -16 AND 16

PARTICLE TRACKING OPTIONS:
KEYWORDS: Emitter, N0EMITTER, SHEATH, SHEATH SELF-CONSISTENT
NO EMITTERS REQUESTED

MAGNETIC FIELD OPTIONS:
KEYWORDS [FIELD], [DIPOLE]
CONSTANT MAGNETIC FIELD = 1 .00 .00 .00 1 W/H**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 + 000 1.00 + 000 1.00 + 000 1.00 + 000 1.00 + 000 1.00 + 000 9.20 + 001 9.20 + 001 5.15 + 001 1.73 + 000
4.13 + 001 1.00 + 000 1.00 + 000 1.00 + 000 1.00 + 000 1.00 + 000 1.00 + 000 1.00 + 000 1.00 + 000 1.00 + 000 1.00 + 000 1.00 + 000

SOLAR
MATERIAL PROPERTIES
3.80 + 000 1.72 + 000 1.00 + 017 1.00 + 001 7.05 + 000 4.40 + 001 7.75 + 001 4.60 + 001 1.50 + 003 1.66 + 003 1.72 + 001
2.44 + 001 2.30 + 002 2.00 + 005 1.00 + 019 7.00 + 004 2.06 + 008 7.70 + 013 1.60 + 008 1.56 + 008 1.67 + 001

COMMENT PROPERTIES OF KAPTON AND ALUMINUM FROM DEFAULT TABLE.

CONDUCTOR 1
COMMENT CENTRAL CUBOID

RECTANGULAR
OBJECT NOW DEFINED.

SURFACE +X GOLD 12
SURFACE -X KAPTON 13
SURFACE +Y KAPTON 14
SURFACE -Y KAPTON 15
SURFACE +Z KAPTON 16
SURFACE -Z KAPTON 17
ENDBJ

COMMENT BOOM TO KAPTON SPHERE

BOOM

BOOM DEFINED
BEGINNING AT
EXTENDING PARALLEL TO THE Z AXIS TO 21
RADI 0.05000

SURF ALUM 9

COMMENT BOOM TO SOLAR SPHERE

BOOM

BOOM DEFINED
BEGINNING AT
EXTENDING PARALLEL TO THE Z AXIS TO 15
RADI 0.05000

SURF ALUM 9

COMMENT KAPTON SPHERE

QSPHERE

DEFINING O-SPHERE
CENTER = 22 9 9
DIAMETER = 3
MATERIAL = KAPT

OCTAGON DEFINED
AXIS = 22 1 10 1 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

<table>
<thead>
<tr>
<th>CELL NO.</th>
<th>CODE</th>
<th>CONDUCTOR</th>
<th>IX</th>
<th>IY</th>
<th>IZ</th>
<th>NORMAL</th>
<th>MATERIAL</th>
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<td>11</td>
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<td>17</td>
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<td>12</td>
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### BOOM SURFACE CELL LIST

<table>
<thead>
<tr>
<th>CELL NO.</th>
<th>CODE</th>
<th>CONDUCTOR</th>
<th>IX</th>
<th>IY</th>
<th>IZ</th>
<th>GRID AXIS</th>
<th>BOOM INT</th>
<th>MATERIAL</th>
</tr>
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<tbody>
<tr>
<td>181</td>
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### LIST OF BOOM PROPERTIES

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<tr>
<th>BOOM RADIUS</th>
<th>AXIS</th>
<th>MATERIAL</th>
<th>CONDUCTOR</th>
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<tr>
<td>1</td>
<td>0.50</td>
<td>ALUM</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0.50</td>
<td>ALUM</td>
<td>2</td>
</tr>
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</table>

Figure 11.5. (Continued).
### Preprocessing of Material Properties

#### Material 1: Gold

<table>
<thead>
<tr>
<th>Property</th>
<th>Input Value</th>
<th>Code Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric constant</td>
<td>1.00*000 (NONE)</td>
<td>1.00*000 (NONE)</td>
</tr>
<tr>
<td>Thickness</td>
<td>1.00-005 Meters</td>
<td>-1.00-005 Meters</td>
</tr>
<tr>
<td>Conductivity</td>
<td>-1.00*000 MHO/M</td>
<td>-1.00*000 MHO/M</td>
</tr>
<tr>
<td>Atomic number</td>
<td>7.90*001 (NONE)</td>
<td>7.90*001 (NONE)</td>
</tr>
<tr>
<td>Delta max scoeff</td>
<td>8.80*001 (NONE)</td>
<td>2.93*000 (NONE)</td>
</tr>
<tr>
<td>E-max</td>
<td>8.88*001 ANG.</td>
<td>9.47*001 ANG.</td>
</tr>
<tr>
<td>Range</td>
<td>8.88*001 ANG.</td>
<td>9.47*001 ANG.</td>
</tr>
<tr>
<td>Exponent (&gt;) Range</td>
<td>9.47*001 ANG.</td>
<td>9.47*001 ANG.</td>
</tr>
<tr>
<td>Exponent (&gt;) Exponent</td>
<td>1.73*000 (NONE)</td>
<td>1.73*000 (NONE)</td>
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<tr>
<td>Yield for Ikek Protons</td>
<td>4.13*001 (NONE)</td>
<td>4.13*001 (NONE)</td>
</tr>
<tr>
<td>Max dE/dx for Protons</td>
<td>4.13*001 (NONE)</td>
<td>4.13*001 (NONE)</td>
</tr>
<tr>
<td>Photocurrent</td>
<td>7.47*001 (NONE)</td>
<td>7.47*001 (NONE)</td>
</tr>
<tr>
<td>Surface resistivity</td>
<td>1.00*005 OHMS</td>
<td>1.77*013 V-SY0</td>
</tr>
<tr>
<td>Space discharge pot'</td>
<td>1.00*003 VOLTS</td>
<td>1.00*003 VOLTS</td>
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<tr>
<td>Internal discharge pot'</td>
<td>2.00*003 VOLTS</td>
<td>2.00*003 VOLTS</td>
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<tr>
<td>Radon induced cond'y power</td>
<td>1.00-013 MMH53</td>
<td>1.00-013 MMH53</td>
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<tr>
<td>Density</td>
<td>1.00*003 KG/M3</td>
<td>1.00*003 KG/M3</td>
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#### Material 2: Sola

<table>
<thead>
<tr>
<th>Property</th>
<th>Input Value</th>
<th>Code Value</th>
</tr>
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<tbody>
<tr>
<td>Dielectric constant</td>
<td>3.00*000 (NONE)</td>
<td>3.00*000 (NONE)</td>
</tr>
<tr>
<td>Thickness</td>
<td>3.00-000 Meters</td>
<td>3.00-000 Meters</td>
</tr>
<tr>
<td>Conductivity</td>
<td>3.00-000 MHO/M</td>
<td>3.00-000 MHO/M</td>
</tr>
<tr>
<td>Atomic number</td>
<td>3.00-000 MHO/M</td>
<td>3.00-000 MHO/M</td>
</tr>
<tr>
<td>Delta max scoeff</td>
<td>3.00-000 MHO/M</td>
<td>3.00-000 MHO/M</td>
</tr>
<tr>
<td>E-max</td>
<td>3.00-000 MHO/M</td>
<td>3.00-000 MHO/M</td>
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<td>Range</td>
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<td>3.00-000 MHO/M</td>
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<tr>
<td>Exponent (&gt;) Range</td>
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<td>3.00-000 MHO/M</td>
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<td>Exponent (&gt;) Exponent</td>
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<td>3.00-000 MHO/M</td>
</tr>
<tr>
<td>Yield for Ikek Protons</td>
<td>3.00-000 MHO/M</td>
<td>3.00-000 MHO/M</td>
</tr>
<tr>
<td>Max dE/dx for Protons</td>
<td>3.00-000 MHO/M</td>
<td>3.00-000 MHO/M</td>
</tr>
<tr>
<td>Photocurrent</td>
<td>3.00-000 MHO/M</td>
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<tr>
<td>Surface resistivity</td>
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<tr>
<td>Space discharge pot'</td>
<td>3.00-000 MHO/M</td>
<td>3.00-000 MHO/M</td>
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<tr>
<td>Internal discharge pot'</td>
<td>3.00-000 MHO/M</td>
<td>3.00-000 MHO/M</td>
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<td>Radon induced cond'y power</td>
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<td>3.00-000 MHO/M</td>
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<tr>
<td>Density</td>
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<td>3.00-000 MHO/M</td>
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#### Material 3: Kappt

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<tr>
<th>Property</th>
<th>Input Value</th>
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<tbody>
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<td>Dielectric constant</td>
<td>3.50*000 (NONE)</td>
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<td>Thickness</td>
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<td>Conductivity</td>
<td>1.00-016 MHO/M</td>
<td>1.00-016 MHO/M</td>
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<td>Atomic number</td>
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<td>5.00*000 (NONE)</td>
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<td>E-max</td>
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<td>Yield for Ikek Protons</td>
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<td>Max dE/dx for Protons</td>
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<td>Space discharge pot'</td>
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Figure 11.5. (Continued).
20

MATERIAL 4: ALUM

PROPERTY

1  DIELECTRIC CONSTANT  
2  THICKNESS  
3  CONDUCTIVITY  
4  ATOMIC NUMBER  
5  DELTA MAX J0F80E  
6  E-MAX > DEPTH**1

INPUT VALUE  
1.00*000 (NONE)  
1.00*000 (NONE)  
1.00*003 (NONE)  
1.00*000 (NONE)  
1.00*000 (NONE)  
3.00*000 (NONE)

CODE VALUE  
1.00*000 (NONE)  
5.00*002 MESH  
1.00*000 MESH  
1.00*000 MESH  
1.00*000 MESH  
1.00*000 MESH

180 VOLUME CELLS NUMBERED BY NUMV.

INSLST -- 164 INSULATING SURFACE CELLS FOUND

SOLA HAS SURFACE RESISTIVITY OF 1.0*019 OHMS
RAFT HAS SURFACE RESISTIVITY OF 1.0*016 OHMS

FNDSC -- 328 SURFACE CONDUCTING EDGES FOUND

ROOMEJ -- 328 EDGES FOUND

668 ENTRIES IN REVISED VTXL

******SATPLT

ASGFIL -- BAG
DISTANCE EQUALS 999.99998

FINAL NAI = 95
DISTANCE EQUALS 999.99998

FINAL NAI = 95
DISTANCE EQUALS 999.99999

FINAL NAI = 93

******CAPACI

POSSIBILITIES TO BE SET BY SETALL TO 1.00*000/IT**P3*RI

AVERAGE RADIUS (RD) = 4.00*000 CODE UNITS

147 POTENTIAL ITERATIONS COMPLETED.

RPIE R0/I/B0RMAX = 1.05*997  2.16*001

PCOND = 2.0106-002  2.0106-002

QCOND = 2.0105-002  2.0105-002

VBAR = 2.0054-002 -- CS SCALED BY 1.0026*000

Figure 11.5. (Continued).
CROEFF --- EFFECTIVE OBJECT RADIUS = .0793 METERS
50 POTENTIAL ITERATIONS COMPLETED
ROOTR/RORMAX = 2.38-003/ 3.42-005
PCOND = -2.1205+000 3.6979+000
QCOND = -3.5858+002 5.5861+002
SMALL INTERCONDUCTOR CAPACITANCES:
  -2.73+001 2.72+001

****HIDCEL
DISTANCE EQUALS 999.99998
FINAL NAI =  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 (RO) = 4.00+000 CODE UNITS

*** THE SYSTEM IS NOW AT TIME 5.00+000 SECONDS, 1 CYCLES HAVE BEEN REQUESTED.
   DELTA= 5.00+000 SECONDS, DELFAC= 1.00+000.

Figure 11.5. (Continued).
BEGIN CYCLE NO. 1  \hspace{1cm} \text{TIME = \cdot000 SECONDS.}

QSUM ERROR FOUND QSUM = 1.00\times10^4 CODE UNITS.
AFTER SCREENING CORRECTION (SCREENING LENGTH = 2.00\times10^2 M.) QSUM = 1.00\times10^4
QSCALE = 1.00\times10^0  
QSUM = 1.00\times10^2
QCOND = 1.00\times10^{-2}  \hspace{1cm} 1.00\times10^2
QCOND = 1.00\times10^0

-----------------------------------------------

EXPLICITLY CALCULATED FLUXES FOR CYCLE 1  \hspace{1cm} \text{TIME = \cdot000 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

\hspace{1cm} \text{CODE = O0461116003}
\hspace{1cm} \text{LOCATION = 6 9 17}
\hspace{1cm} \text{NORMAL = 0 0 0}
\hspace{1cm} \text{MATERIAL = KAPT}

\text{POTENTIAL = \cdot600 VOLTS}
\text{STRESS = \cdot566\times10^2 VOLTS/METER}
\text{LIMITING FACTOR = \cdot1000\times10^0}

\begin{tabular}{ll}
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 & 0.00 \\
\end{tabular}

\text{NET FLUX = -6.27-007}

-----------------------------------------------

SURFACE CELL NO. 28

\hspace{1cm} \text{CODE = O04612210403}
\hspace{1cm} \text{LOCATION = 6 9 17}
\hspace{1cm} \text{NORMAL = 0 0 0}
\hspace{1cm} \text{MATERIAL = KAPT}

\text{POTENTIAL = \cdot600 VOLTS}
\text{STRESS = \cdot566\times10^2 VOLTS/METER}
\text{LIMITING FACTOR = \cdot1000\times10^0}

\begin{tabular}{ll}
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 \\
\end{tabular}

\text{NET FLUX = 1.35-005}

-----------------------------------------------

SURFACE CELL NO. 77

\hspace{1cm} \text{CODE = 00510721403}
\hspace{1cm} \text{LOCATION = 9 7 17}
\hspace{1cm} \text{NORMAL = 0 0 0}
\hspace{1cm} \text{MATERIAL = KAPT}

\text{POTENTIAL = \cdot600 VOLTS}
\text{STRESS = \cdot566\times10^2 VOLTS/METER}
\text{LIMITING FACTOR = \cdot1000\times10^0}

\begin{tabular}{ll}
INCIDENT ELECTRONS & 2.28-006 \\
RESULTING SECONDARIES & 9.75-007 \\
RESULTING BACKSCATTER & 6.01-007 \\
\end{tabular}

\text{Figure 11.5. (Continued).}
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<th>BULK CONDUCTIVITY</th>
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**SURFACE CELL NO. 88**

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**SURFACE CELL NO. 129**

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**BOOM SURFACE CELL NO. 181**

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Figure 11.5. (Continued).
DIRECTION = Z
MATERIAL = ALUM

POTENTIAL = 0.000 VOLTS
FIELD = 0.000 VOLTS/METER
LIMITING FACTOR = 1.000+000

FLUXES IN A/M**2
INCIDENT ELECTRONS
RESULTING SECONDARIES
RESULTING BACKSCATTER
INCIDENT PROTONS
RESULTING SECONDARIES
PHOTOCURRENT

NET FLUX

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; 8.03-012 FARADS.

ICCG --- RDOTR/RDOTR = 1.16-014/ 4.16+011
LEAVING ICCG1 -- VCTRI = 2.067+005 1.939+005
ICCG --- RDOTR/RDOTR = 3.53-025/ 1.95+006
LEAVING ICCG1 -- VCTRI = 0.000 0.000
ICCG --- RDOTR/RDOTR = 2.71-025/ 1.94+006
LEAVING ICCG1 -- VCTRI = 0.000 0.000

VFIX --- 59 out of 164 NODES FIXED.
CONDUCTOR 1 FIXED TO 3.03 VOLTS.

ICCG --- RDOTR/RDOTR = 1.65-025/ 1.14+006
LEAVING ICCG1 -- VCTRI = 3.034+000 1.721+000
NO DISCHARGE ANALYSIS
NO DISCHARGE ANALYSIS

ICCG --- RDOTR/RDOTR = 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 29 IS -4.173-006 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 4.790-008 A/M**2

NEW CONDUCTOR POTENTIALS

VNEW DQ VOLDC CONDUCTOR
3.040+000 3.696+005 +0000
1.7256+000 -9.7015-005 +0000

TOTAL CHANGE IN CHARGE = -1.964+002 CODE UNITS
-3.482-011 COULOMNS

AVERAGE NET CHARGING CURRENT = -6.965-012 AMPERES
-3.933+001 CODE UNITS/SEC.

CONDUCTOR CURRENTS (AMPS; POSITIVE INTO CONDUCTORS):

NET CURRENT(AVG DQ/DT):
2.73-008 -3.49-018

Figure 11.5. (Continued).
Figure 11.5. (Concluded).
Figure 11.6(a). 3D-VIEW of object produced by SATPLT (Hidden lines).
Figure 11.6(c). 3D-VIEW of object produced by SATPLT (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).
SURFACE CELL MATERIAL COMPOSITION AS VIEWED FROM THE NEGATIVE Y DIRECTION

FOR Y VALUES BETWEEN 1 AND 17

MATERIAL LEGEND

2 SOLA

3 KAPT

Figure 11.6(i). MATVIEW produced by SATPLT.
SURFACE CELL MATERIAL COMPOSITION AS VIEWED FROM THE POSITIVE Y DIRECTION

FOR Y VALUES BETWEEN 1 AND 17

MATERIAL LEGEND

2 SOLA
3 KPL

Figure 11.6(j). MATVIEW produced by SATPLT.
SURFACE CELL MATERIAL COMPOSITION AS VIEWED FROM THE NEGATIVE X DIRECTION

FOR X VALUES BETWEEN 1 AND 17

MATERIAL LEGEND

2 SOLA

3 KAPL

Figure 11.6(k). 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 x 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).
Figure 11.7. The Run Options file (second run).
**AXGT**

*****RDOP**

**KEYWORD INPUT**

XMESH 0.02  
NCYC 5  
DELTA 200  
SURFACE CELL 20  
SURFACE CELL 129  
SURFACE CELL 28  
SURFACE CELL 77  
SURFACE CELL 88  
SURFACE CELL 167  
SURFACE CELL 181  
LONGTIMESTEP 500  
SUNINT 1.0  
SUNDIR 1.0  
OEST ELEC CIJ 1 2 1.E-12  
CIJE 1, 2) SET TO 1.00-012 FARADS  
CONTORS STANDARD MOD 5  
RESTART END  
ASGFIL -- ASG 10  
ASGFIL -- ASG 12  
ASGFIL -- ASG 25  
ASGFIL -- ASG 19  
ASGFIL -- ASG 16  
ASGFIL -- ASG 16  
ASGFIL -- ASG 10  
ASGFIL -- ASG 10  
ASGFIL -- ASG 10  
ASGFIL -- ASG 21  
ASGFIL -- ASG 26  
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: IDAT ISAT TFLUX ISPCTR
26 42 22 9
RESTART FILES: IP IQUS IPGCD ITBL ICMD IAERA
10 15 16 17 21 27
SCRATCH FILES: IAUN IR IDIV IU ISPARE I0BJ I0BPL I0PART
11 12 25 13 14 18 19 20
RUN MODE OPTIONS: ICNST IPREST NCYC NCYC
1 1 5 1
DELTA DELFAC
2.00-000 1.00-000
DEADLINE = NONE
ADDITIONAL KEYWORD = [RESTART]

POTENTIAL SOLVER OPTIONS: POTCON MAXITR IOUTER SCALE
NOTSET 99 2 SCALE
SCALING KEYWORDS: SCALE, NOSCALE, DESCAL
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 771.013 COULOMBS.
THE CODE UNIT OF CAPACITANCE IS 1.17-013 FARADS.

CIJ:

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</tbody>
</table>

LONGITIMSTEP AND DISCHARGE OPTIONS
KEYWORDS: LONGITIMSTEP, NOLONGITIMSTEP, DISCHARGE, FLASHOVER
LONGITIMSTEP REQUESTED WITH OVLIM = 500.0 VOLTS.
DISCHARGE ANALYSIS OFF

ILLUMINATION SPECIFICATIONS
SUMINT = 1.0000 SUMDIR = 1.0711 .000000
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 = TANGENT MODE.
EFFECTIVE PHOTOELECTRIC CONDUCTIVITY (EFFCON) = OFF
FIELD-ENHANCED BULK CONDUCTIVITY (FLCON) = OFF
RADIATION-INDUCED BULK CONDUCTIVITY (RADCON) = OFF

OUTPUT OPTIONS:
- NGPRT [APRINT] TIMER [TOMITR] = 0
- ICNV [CONVERGENCE PLOTS] = 0
- PRINT [NPRINT]  PLOIT  LINCEL  OBJDEF  HIDCEL = NO  NO  NO  NO
- 7 SURFACE CELLS SPECIFIED FOR I/O:
  20  29  77  99  129  167  186
- KEYWORDS: [SURFACE CELLS], [SURFACE AT], [SURFACE CORNER]

PLOT OPTIONS:
- TITLE: NASCAP
- NGPLOT ICON REPEAT 1 PRT 1  C  0  0  0  0
- DECT = ELECT
- NCON = 6
- 3 ADDITIONAL KEYWORDS: TANKCUR TANKTRAJ 3D-VIEW MATVIEW CONTOUR

CONTOUR PLOTS TABLE

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<tr>
<th>DIRECTION</th>
<th>CUT VALUE</th>
<th>NO. GRIDS</th>
<th>MOD</th>
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<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Y</td>
<td>0</td>
<td>1</td>
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</tr>
<tr>
<td>Z</td>
<td>0</td>
<td>1</td>
<td>5</td>
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<tr>
<td>X</td>
<td>0</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Y</td>
<td>0</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

NO. OF 3-D PLOT VIEWS = 3
VECTORS FROM SATELLITE CENTER TOWARD VIEWER ARE

6 MATERIAL PLOT VIEWS REQUESTED:
- VIEW FROM +X DIRECTION BETWEEN -8 AND 8
- VIEW FROM +Y DIRECTION BETWEEN -8 AND 8
- VIEW FROM +Z DIRECTION BETWEEN -8 AND 8
- VIEW FROM -X DIRECTION BETWEEN -16 AND 16
- VIEW FROM -Y 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], [DIPOL]
- CONSTANT MAGNETIC FIELD = 0.000 0.000 0.000 1 W/M**2,
- NO MAGNETIC DIPOLES

ASGFI = 2

*****TRILIN

OBJECT DEFINITION INFORMATION BEING READ FROM FILE

A SHADING TABLE WAS PREVIOUSLY GENERATED
FOR THIS OBJECT USING THE HIDE OPTION
FLUX DEFINITION SINGLE MAXWELLIAN

ELECTRON TEMPERATURE = 5.00E03 ELECTRON VOLTS

Figure 11.8. (Continued).
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, DISCHARGE, 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 = KAP1

POTENTIAL = -9.768+000 VOLTS
STRESS = 1.009+000 VOLTS/METER
EXTERNAL FIELD = 1.694+002 VOLTS/METER
LIMITING FACTOR = 1.000+000

FLUXES IN A/M**2

  INCIDENT ELECTRONS
  RESULTING SECONDARIES  2.98-006
  RESULTING BACKSCATTER  1.79-007
  INCIDENT PROTONS
  RESULTING SECONDARIES  2.76-008
  RESULTING BACKSCATTER  4.91-008
  BULK CONDUCTIVITY
  PHOTOCURRENT

NET FLUX

-6.25-007

SURFACE CELL NO. 28  CODE = 004612210903
                       LOCATION = 6 10 17
                       NORMAL = 1 0 0
                       MATERIAL = KAP1

POTENTIAL = 1.570+000 VOLTS
STRESS = 1.158+004 VOLTS/METER
EXTERNAL FIELD = 1.694+002 VOLTS/METER
LIMITING FACTOR = 1.037-001

FLUXES IN A/M**2

  INCIDENT ELECTRONS
  RESULTING SECONDARIES  2.98-006
  RESULTING BACKSCATTER  1.79-007 [ 9.76-0073]
  INCIDENT PROTONS
  RESULTING SECONDARIES  2.76-008
  RESULTING BACKSCATTER  4.91-008 [ 4.91-0081]
  BULK CONDUCTIVITY
  PHOTOCURRENT

NET FLUX

1.13-006

SURFACE CELL NO. 77  CODE = 005107211403
                       LOCATION = 9 7 17
                       NORMAL = 0 1 0
                       MATERIAL = KAP1

POTENTIAL = -9.769+000 VOLTS
STRESS = 1.009+005 VOLTS/METER
EXTERNAL FIELD = -1.135+002 VOLTS/METER
LIMITING FACTOR = 1.000+000

FLUXES IN A/M**2

  INCIDENT ELECTRONS
  RESULTING SECONDARIES  2.28-006
  RESULTING BACKSCATTER  9.76-007
  INCIDENT PROTONS
  RESULTING SECONDARIES  2.28-006
  RESULTING BACKSCATTER  5.99-007

Figure 11.8. (Continued).
<table>
<thead>
<tr>
<th>Surface Cell No.</th>
<th>Code</th>
<th>Location</th>
<th>Potential</th>
<th>Stress</th>
<th>External Field</th>
<th>Limiting Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>88</td>
<td>005111170103</td>
<td>9 9 21</td>
<td>-9.763 kV</td>
<td>1.008 V/m</td>
<td>-2.943 V/m</td>
<td>1.000 V/m</td>
</tr>
<tr>
<td>129</td>
<td>005307212001</td>
<td>11 7 17</td>
<td>3.040 kV</td>
<td>2.029 V/m</td>
<td>1.032 V/m</td>
<td></td>
</tr>
<tr>
<td>167</td>
<td>011111120302</td>
<td>9 9 10</td>
<td>4.642 kV</td>
<td>7.049 V/m</td>
<td>1.402 V/m</td>
<td>7.929 V/m</td>
</tr>
</tbody>
</table>

**Figure 11.8. (Continued).**
DIRECTION = Z
MATERIAL = ALUM

\[ \text{POTENTIAL} = 3.000 \times 10^2 \text{ VOLTS} \]
\[ \text{LEAKING} = 2.774 \times 10^2 \text{ VOLTMETER} \]
\[ \text{LIMITING FACTOR} = 3.107 \times 001 \]

\[ \text{FLUXES IN A/M}^2 \]
\[ \text{INCIDENT ELECTRONS} = 2.28 \times 006 \]
\[ \text{RESULTING SECONDARIES} = 2.53 \times 009 \]
\[ \text{RESULTING BACKSCATTER} = 8.53 \times 007 \]
\[ \text{INCIDENT PROTONS} = 2.30 \times 008 \]
\[ \text{RESULTING SECONDARIES} = 6.38 \times 011 \]
\[ \text{PHOTOCURRENT} = 3.93 \times 008 \]
\[ \text{TOTAL} = 2.02 \times 008 \]

\[ \text{NET FLUX} = -1.36 \times 006 \]

\[ \text{INITIAL NET CHARGING CURRENT (WITHOUT LIMITING)} = 3.60 \times 007 \text{ AMPERES} \]
\[ \text{INITIAL NET CHARGING CURRENT (WITH LIMITING)} = 5.92 \times 010 \text{ AMPERES} \]

\[ \text{TOTAL CAPACITANCE TO INFINITY} = 49.9 \text{ CODE UNITS} \quad 8.03 \times 012 \text{ FARADS} \]

\[ \text{ICCG} = \frac{R\text{OOTR/RDO}TR_1}{R\text{OOTR/RDO}TR_1} = 5.52 \times 022 \quad 7.96 \times 007 \]
\[ \text{LEAVING ICCG} = \frac{R\text{OOTR/RDO}TR_1}{R\text{OOTR/RDO}TR_1} = -3.707 \times 000 \quad -2.700 \times 000 \]
\[ \text{LEAVING ICCG} = \frac{R\text{OOTR/RDO}TR_1}{R\text{OOTR/RDO}TR_1} = 5.52 \times 022 \quad 7.96 \times 007 \]
\[ \text{LEAVING ICCG} = \frac{R\text{OOTR/RDO}TR_1}{R\text{OOTR/RDO}TR_1} = -3.707 \times 000 \quad -2.700 \times 000 \]
\[ \text{LEAVING ICCG} = \frac{R\text{OOTR/RDO}TR_1}{R\text{OOTR/RDO}TR_1} = 1.03 \times 022 \quad 5.93 \times 007 \]
\[ \text{LEAVING ICCG} = \frac{R\text{OOTR/RDO}TR_1}{R\text{OOTR/RDO}TR_1} = -3.707 \times 000 \quad -2.323 \times 000 \]

\[ \text{VFIX} = 59 \text{ OUT OF} 164 \text{ NODES FIXED}. \]

\[ \text{CONDUCTOR 1 FIXED TO} \quad 2.26 \text{ VOLTS} \]
\[ \text{ICCG} = \frac{R\text{OOTR/RDO}TR_1}{R\text{OOTR/RDO}TR_1} = 8.16 \times 023 \quad 5.80 \times 007 \]
\[ \text{LEAVING ICCG} = \frac{R\text{OOTR/RDO}TR_1}{R\text{OOTR/RDO}TR_1} = 2.264 \times 000 \quad 4.392 \times 001 \]

\[ \text{NO DISCHARGE ANALYSIS} \]

\[ \text{NO DISCHARGE ANALYSIS} \]
\[ \text{ICCG} = \frac{R\text{OOTR/RDO}TR_1}{R\text{OOTR/RDO}TR_1} = 1.56 \times 019 \quad 8.60 \times 009 \]
\[ \text{LEAVING ICCG} = \frac{R\text{OOTR/RDO}TR_1}{R\text{OOTR/RDO}TR_1} = 2.361 \times 000 \quad 5.127 \times 001 \]

\[ \text{AVERAGE FLUXES (ONLY AVAILABLE FOR INSULATING CELLS)} \]
\[ \text{AVERAGE FLUX TO CELL 20} = -4.658 \times 007 \text{ A/M}^2 \]
\[ \text{AVERAGE FLUX TO CELL 20} = 3.114 \times 009 \text{ A/M}^2 \]
\[ \text{AVERAGE FLUX TO CELL 77} = -4.658 \times 007 \text{ A/M}^2 \]
\[ \text{AVERAGE FLUX TO CELL 68} = -4.658 \times 007 \text{ A/M}^2 \]
\[ \text{AVERAGE FLUX TO CELL 167} = 1.201 \times 009 \text{ A/M}^2 \]

\[ \text{NEW CONDUCTOR POTENTIALS} \]
\[ \text{VNEW} = 2.309 \times 000 \quad 2.498 \times 007 \quad 3.004 \times 000 \quad 5.126 \times 001 \quad -3.116 \times 003 \quad 1.726 \times 000 \]

\[ \text{TOTAL CHANGE IN CHARGE} = -9.72 \times 003 \text{ CODE UNITS} \]
\[ \text{TOTAL CHANGE IN CHARGE} = -1.722 \times 009 \text{ COULOMBS} \]

\[ \text{AVERAGE NET CHARGING CURRENT} = -4.609 \times 012 \text{ AMPERES} \]
\[ \text{AVERAGE NET CHARGING CURRENT} = -4.862 \times 001 \text{ CODE UNITS/SEC.} \]

\[ \text{CONDUCTOR CURRENTS (AMPS; POSITIVE INTO CONDUCTORS):} \]
\[ \text{1} \quad 2 \quad 1 \quad 2 \quad 1 \quad 2 \quad 1 \quad 2 \]

\[ \text{NET CURRENT (AVG Q/Q)} = 1.99 \times 008 \quad -2.76 \times 008 \]

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.
GSUM = -9.9219*003

SURFACE POTENTIALS - ALL 184 CELLS

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<tr>
<th>CELL NO.</th>
<th>Potential</th>
<th>CELL NO.</th>
<th>Potential</th>
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<tr>
<td>1</td>
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<td>10</td>
<td>3.920*002</td>
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<tr>
<td>2</td>
<td>3.921*002</td>
<td>11</td>
<td>3.922*002</td>
</tr>
<tr>
<td>3</td>
<td>3.921*002</td>
<td>12</td>
<td>3.920*002</td>
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<tr>
<td>...</td>
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<td>...</td>
</tr>
</tbody>
</table>

16 POTENTIAL ITERATIONS COMPLETED.

PCOND = 2.3609*000 5.2265*001
QCOND = 2.3608*001 3.1342*002

NEXTRA = 0
EFREP -- 1 GRIDS OUT OF 1 READ IN.
BEGIN CYCLE NO.  3  TIME =  2.050+002 SECONDS.

QSUM: 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 = -9.991+003
QCOND = 2.361+000  5.177-001
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.

<table>
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<th>CODE = 004611216003</th>
<th>LOCATION = 0 0 0</th>
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<tbody>
<tr>
<td>POTENTIAL = -3.921+002 VOLTS</td>
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<tr>
<td>STRESS = 3.106+006 VOLTS/METER</td>
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<td>EXTERNAL FIELD = -5.695+003 VOLTS/METER</td>
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<tr>
<td>LIMITING FACTOR = 1.000+000</td>
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<tr>
<td>INCIDENT ELECTRONS</td>
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<td></td>
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<tr>
<td>RESULTING SECONDARIES</td>
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<td>RESULTING BACKSCATTER</td>
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<td>STRESS = -8.511+003 VOLTS/METER</td>
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<td>EXTERNAL FIELD = 6.009+003 VOLTS/METER</td>
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<tr>
<td>LIMITING FACTOR = 8.020-027</td>
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<tr>
<td>INCIDENT ELECTRONS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RESULTING SECONDARIES</td>
<td></td>
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<tr>
<td>RESULTING BACKSCATTER</td>
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<td></td>
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<tr>
<td>INCIDENT PROTONS</td>
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<td></td>
</tr>
<tr>
<td>RESULTING SECONDARIES</td>
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<tr>
<td>BULK CONDUCTIVITY</td>
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<td></td>
</tr>
<tr>
<td>PHOTOCURRENT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NET FLUX</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.28-006</td>
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<tr>
<td>7.83-033</td>
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<td>6.01-007</td>
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<td>2.76-008</td>
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<tr>
<td>3.93-034</td>
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<tr>
<td>1.11-051</td>
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<tr>
<td>-1.65-006</td>
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</table>

<table>
<thead>
<tr>
<th>SURFACE CELL NO.  77</th>
<th>CODE = 005107211403</th>
<th>LOCATION = 9 7 17</th>
</tr>
</thead>
<tbody>
<tr>
<td>POTENTIAL = -3.922+002 VOLTS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STRESS = 3.106+006 VOLTS/METER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXTERNAL FIELD = -4.229+003 VOLTS/METER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LIMITING FACTOR = 1.000+000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>INCIDENT ELECTRONS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RESULTING SECONDARIES</td>
<td></td>
<td></td>
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<td>RESULTING BACKSCATTER</td>
<td></td>
<td></td>
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<tr>
<td>2.11-006</td>
<td></td>
<td></td>
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<tr>
<td>9.02-007</td>
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<tr>
<td>5.55-007</td>
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<td></td>
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</tbody>
</table>

Figure 11.8. (Continued).
| INCIDENT PROTONS | 3.11-004 |
| BULK CONDUCTIVITY | 5.60-008 |
| PHOTOCURRENT | 3.11-010 |

<table>
<thead>
<tr>
<th>NET FLUX</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5.63-007</td>
</tr>
</tbody>
</table>

**SURFACE CELL NO. 88**

| CODE | 005111720103 |
| LOCATION | 0 0 2 |
| NORMAL | 0 0 1 |
| MATERIAL | KAPT |

**POTENTIAL** = -3.919*002 VOLTS
**STRESS** = 3.10*006 VOLTS/METER
**EXTERNAL FIELD** = -1.02*008 VOLTS/METER
**LIMITING FACTOR** = 1.000-000

**FLUXES IN A/M**

| INCIDENT ELECTRONS | 2.11-006 |
| RESULTING SECONDARIES | 9.02-007 |
| RESULTING BACKSCATTER | 5.55-007 |
| INCIDENT PROTONS | 8.59-008 |
| RESULTING SECONDARIES | 3.10-010 |
| BULK CONDUCTIVITY |
| PHOTOCURRENT |

<table>
<thead>
<tr>
<th>NET FLUX</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5.63-007</td>
</tr>
</tbody>
</table>

**SURFACE CELL NO. 129**

| CODE | 005305521001 |
| LOCATION | 11 7 17 |
| NORMAL | 0 0 0 |
| MATERIAL | GOLD |

**POTENTIAL** = 2.761*000 VOLTS
**EXTERNAL FIELD** = 6.01*003 VOLTS/METER
**LIMITING FACTOR** = 7.588-027

**FLUXES IN A/M**

| INCIDENT ELECTRONS | 2.29-006 |
| RESULTING SECONDARIES | 3.11-032 |
| RESULTING BACKSCATTER | 1.48-006 |
| INCIDENT PROTONS | 3.79-008 |
| RESULTING SECONDARIES | 1.56-031 |
| BULK CONDUCTIVITY |
| PHOTOCURRENT |

<table>
<thead>
<tr>
<th>NET FLUX</th>
</tr>
</thead>
<tbody>
<tr>
<td>-7.76-007</td>
</tr>
</tbody>
</table>

**SURFACE CELL NO. 167**

| CODE | 011111120302 |
| LOCATION | 0 0 10 |
| NORMAL | 0 0 -1 |
| MATERIAL | SOLA |

**POTENTIAL** = 5.287-001 VOLTS
**STRESS** = -8.95*001 VOLTS/METER
**EXTERNAL FIELD** = 1.65*003 VOLTS/METER
**LIMITING FACTOR** = 6.582-008

**FLUXES IN A/M**

| INCIDENT ELECTRONS | 2.29-006 |
| RESULTING SECONDARIES | 1.20-013 |
| RESULTING BACKSCATTER | 1.77-007 |
| INCIDENT PROTONS | 2.79-008 |
| RESULTING SECONDARIES | 1.77-015 |
| BULK CONDUCTIVITY |
| PHOTOCURRENT |

<table>
<thead>
<tr>
<th>NET FLUX</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1.64-006</td>
</tr>
</tbody>
</table>

**BOOM SURFACE CELL NO. 181**

| CODE | 000061111123 |
| LOCATION | 9 9 19 |

Figure 11.8. (Continued).
DIRECTION = Z
MATERIAL = ALUM

\[ \text{POTENTIAL} = 2.354 \times 10^4 \text{ VOLTS} \]
\[ \text{FIELD} = 1.751 \times 10^4 \text{ VOLTS/HOUR} \]

LIMITING FACTOR = 0.000

FLUXES IN A/M**2

<table>
<thead>
<tr>
<th>INCIDENT ELECTRONS</th>
<th>RESULTING SECONDARIES</th>
<th>LIMITING</th>
<th>RESULTING BACKSCATTER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.28 - 056</td>
<td>9.53 - 073</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INCIDENT PROTONS</th>
<th>RESULTING SECONDARIES</th>
<th>LIMITING</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.75 - 006</td>
<td>6.69 - 008</td>
</tr>
</tbody>
</table>

\[ \text{NET FLUX} = -1.40 - 006 \]

\[ \text{INITIAL NET CHARGING CURRENT (WITHOUT LIMITING)} = 3.63 - 007 \text{ AMPERES} \]
\[ \text{INITIAL NET CHARGING CURRENT (WITH LIMITING)} = -7.05 - 008 \text{ AMPERES} \]

TOTAL CAPACITANCE TO INFINITY = 99.9 CODE UNITS; 8.03 - 012 FARADS.

\[ \text{ICCG} \rightarrow \text{RDOT1/RDOT1} = 7.94 - 022/1.21 - 008 \]
\[ \text{LEAVING ICCG1} \rightarrow \text{VCRI1} = -1.732 - 002/1.313 - 002 \]
\[ \text{ICCG} \rightarrow \text{RDOT1/RDOT1} = 7.94 - 022/1.21 - 008 \]
\[ \text{LEAVING ICCG1} \rightarrow \text{VCRI1} = -1.732 - 002/1.313 - 002 \]
\[ \text{ICCG} \rightarrow \text{RDOT1/RDOT1} = 1.69 - 002/9.27 - 007 \]
\[ \text{LEAVING ICCG1} \rightarrow \text{VCRI1} = -1.732 - 002/1.259 - 002 \]

\[ \text{VFIX} \rightarrow \text{59 OUT OF 164 NODES FIXED.} \]

CONDUCTOR 1 FIXED TO -166.79 VOLTS.

\[ \text{ICCG} \rightarrow \text{RDOT1/RDOT1} = 1.59 - 022/9.08 - 007 \]
\[ \text{LEAVING ICCG1} \rightarrow \text{VCRI1} = -1.668 - 002/1.225 - 002 \]

NO DISCHARGE ANALYSIS

\[ \text{ICCG} \rightarrow \text{RDOT1/RDOT1} = 6.22 - 018/5.97 - 009 \]
\[ \text{LEAVING ICCG2} \rightarrow \text{VCRI1} = -1.667 - 002/1.225 - 002 \]

AVERAGE FLUXES (ONLY AVAILABLE FOR INSULATING CELLS)

| AVERAGE FLUX TO CELL  15 | -1.529 - 007 A/M**2 |
| AVERAGE FLUX TO CELL  28 | -1.371 - 008 A/M**2 |
| AVERAGE FLUX TO CELL  77 | -1.521 - 007 A/M**2 |
| AVERAGE FLUX TO CELL  86 | -1.520 - 007 A/M**2 |
| AVERAGE FLUX TO CELL 167 | 6.340 - 008 A/M**2 |

NEW CONDUCTOR POTENTIALS

\[ \text{VNEW} = -1.667 - 009, \quad \text{DO} = 1.876 - 007, \quad \text{VOLD} = 2.369 - 000 \]

\[ \text{CONDUCTOR} = 1 \quad \text{VOLD} = 2.369 - 000 \]

\[ \text{TOTAL CHANGE IN CHARGE} = 1.603 - 004 \text{ CODE UNITS} \]
\[ \text{2.839 - 009 COULOMBS} \]

\[ \text{AVERAGE NET CHARGING CURRENT} = -1.909 - 011 \text{ AMPERES} \]
\[ -8.014 - 001 \text{ CODE UNITS/SEC.} \]

CONDUCTOR CURRENTS (AMPS; POSITIVE INTO CONDUCTORS):

\[ \text{NET CURRENT(AVG} \text{ DO/DT)}: 1.66 - 008, \quad 1.55 - 016 \]

Figure 11.8. (Continued).
<table>
<thead>
<tr>
<th>Description</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity current (new)</td>
<td>-2.57-011</td>
<td>7.67-017</td>
</tr>
<tr>
<td>(from insulating cells)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasma current (initial)</td>
<td>-5.67-009</td>
<td>0.00</td>
</tr>
<tr>
<td>(to bare cells)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remainder current</td>
<td>2.23-008</td>
<td>7.79-017</td>
</tr>
</tbody>
</table>

Figure 11.8. (Continued).
### Surface Potentials - All 184 Cells

<table>
<thead>
<tr>
<th>Cell No.</th>
<th>Potential Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-8.740 E+002</td>
</tr>
<tr>
<td>10</td>
<td>-8.740 E+002</td>
</tr>
<tr>
<td>19</td>
<td>-8.740 E+002</td>
</tr>
<tr>
<td>28</td>
<td>-8.740 E+002</td>
</tr>
<tr>
<td>37</td>
<td>-8.740 E+002</td>
</tr>
<tr>
<td>46</td>
<td>-8.740 E+002</td>
</tr>
<tr>
<td>55</td>
<td>-8.740 E+002</td>
</tr>
<tr>
<td>64</td>
<td>-8.740 E+002</td>
</tr>
<tr>
<td>73</td>
<td>-8.740 E+002</td>
</tr>
<tr>
<td>82</td>
<td>-8.740 E+002</td>
</tr>
<tr>
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<tr>
<td>109</td>
<td>-8.740 E+002</td>
</tr>
<tr>
<td>118</td>
<td>-8.740 E+002</td>
</tr>
</tbody>
</table>

### 16 Potential Iterations Completed

- COND = -1.667E+002
- QCOND = 4.086E+007

**Figure 11.8.** (Continued).
BEGIN CYCLE NO. 4  
TIME = 0.050+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 = -2.60+004
QCOND = -1.267+002 -1.225+002
QCOND = 4.088+007 -4.171+003

EXPLICITLY CALCULATED FLUXES FOR CYCLE 4  
TIME = 0.050+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.

<table>
<thead>
<tr>
<th>SURFACE CELL NO.</th>
<th>CODE</th>
<th>LOCATION</th>
<th>NORMAL</th>
<th>MATERIAL</th>
</tr>
</thead>
<tbody>
<tr>
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<td>00461216003</td>
<td>6 9 17</td>
<td>-1 0 0</td>
<td>KAP1</td>
</tr>
<tr>
<td>POTENTIAL</td>
<td>-9.742+002 VOLTS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STRESS</td>
<td>5.571+006 VOLTS/METER</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXTERNAL FIELD</td>
<td>-1.155+004 VOLTS/METER</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LIMITING FACTOR</td>
<td>1.000+000</td>
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</table>

**FLUXES IN A/M**

<table>
<thead>
<tr>
<th>INCIDENT ELECTRONS</th>
<th>RESULTING SECONDARIES</th>
<th>RESULTING BACKSCATTER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.91-006</td>
<td>2.00-007</td>
<td>5.04-007</td>
</tr>
</tbody>
</table>

**NET FLUX**

| -4.89-007 |

<table>
<thead>
<tr>
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<th>CODE</th>
<th>LOCATION</th>
<th>NORMAL</th>
<th>MATERIAL</th>
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</thead>
<tbody>
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<td>POTENTIAL</td>
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<td>STRESS</td>
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<tr>
<td>EXTERNAL FIELD</td>
<td>7.927+003 VOLTS/METER</td>
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</tr>
<tr>
<td>LIMITING FACTOR</td>
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**FLUXES IN A/M**

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<tr>
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<th>RESULTING BACKSCATTER</th>
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<td>9.39-007</td>
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**NET FLUX**

| -1.59-006 |

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<th>MATERIAL</th>
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<td>KAP1</td>
</tr>
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<td>POTENTIAL</td>
<td>-8.742+002 VOLTS</td>
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<tr>
<td>STRESS</td>
<td>5.571+006 VOLTS/METER</td>
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</tr>
<tr>
<td>EXTERNAL FIELD</td>
<td>-1.000+000 VOLTS/METER</td>
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</tr>
<tr>
<td>LIMITING FACTOR</td>
<td>1.000+000</td>
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**FLUXES IN A/M**

<table>
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<th>RESULTING BACKSCATTER</th>
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<tr>
<td>1.91-006</td>
<td>5.04-007</td>
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Figure 11.8. (Continued).
<table>
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<tr>
<th>INCIDENT PROTONS</th>
<th>RESULTING SECONDARIES</th>
<th>BULK CONDUCTIVITY</th>
<th>PHOTOCURRENT</th>
<th>NET FLUX</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>3.79-000</td>
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<td>-4.89-007</td>
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**SURFACE CELL NO. 88**

<table>
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<th>NORMAL</th>
<th>MATERIAL</th>
</tr>
</thead>
<tbody>
<tr>
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<td>9 9 25 0</td>
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<td>KAPT</td>
</tr>
</tbody>
</table>

**POTENTIAL** = -0.716 x 10^2 VOLTS

**STRESS** = 5.564 x 10^6 VOLTS/METER

**EXTERNAL FIELD** = -2.144 x 10^4 VOLTS/METER

**LIMITING FACTOR** = 1.000 x 10^0

**FLUXES IN A/M**

<table>
<thead>
<tr>
<th>INCIDENT ELECTRONS</th>
<th>RESULTING SECONDARIES</th>
<th>RESULTING BACKSCATTER</th>
<th>INCIDENT PROTONS</th>
<th>RESULTING SECONDARIES</th>
<th>BULK CONDUCTIVITY</th>
<th>PHOTOCURRENT</th>
<th>NET FLUX</th>
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<tbody>
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<td>-4.89-007</td>
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**SURFACE CELL NO. 129**

<table>
<thead>
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<th>NORMAL</th>
<th>MATERIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>005397212001</td>
<td>11 1 0 0</td>
<td>0 0</td>
<td>GOLD</td>
</tr>
</tbody>
</table>

**POTENTIAL** = -1.667 x 10^2 VOLTS

**STRESS** = 3.773 x 10^6 VOLTS/METER

**EXTERNAL FIELD** = 9.081 x 10^3 VOLTS/METER

**LIMITING FACTOR** = 1.000

**FLUXES IN A/M**

<table>
<thead>
<tr>
<th>INCIDENT ELECTRONS</th>
<th>RESULTING SECONDARIES</th>
<th>RESULTING BACKSCATTER</th>
<th>INCIDENT PROTONS</th>
<th>RESULTING SECONDARIES</th>
<th>BULK CONDUCTIVITY</th>
<th>PHOTOCURRENT</th>
<th>NET FLUX</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.20-006</td>
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<td>2.90-008</td>
<td>6.70-008</td>
<td>2.05-005</td>
<td>-7.48-007</td>
<td></td>
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**SURFACE CELL NO. 167**

<table>
<thead>
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<th>CODE</th>
<th>LOCATION</th>
<th>NORMAL</th>
<th>MATERIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>011111120302</td>
<td>9 9 10 0</td>
<td>0 0 1</td>
<td>SOLA</td>
</tr>
</tbody>
</table>

**POTENTIAL** = -5.499 x 10^1 VOLTS

**STRESS** = 3.773 x 10^6 VOLTS/METER

**EXTERNAL FIELD** = 3.647 x 10^3 VOLTS/METER

**LIMITING FACTOR** = 1.448 x 10^-1

**FLUXES IN A/M**

<table>
<thead>
<tr>
<th>INCIDENT ELECTRONS</th>
<th>RESULTING SECONDARIES</th>
<th>RESULTING BACKSCATTER</th>
<th>INCIDENT PROTONS</th>
<th>RESULTING SECONDARIES</th>
<th>BULK CONDUCTIVITY</th>
<th>PHOTOCURRENT</th>
<th>NET FLUX</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.25-006</td>
<td></td>
<td>1.81-006</td>
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<td></td>
<td>-1.46-006</td>
<td></td>
</tr>
</tbody>
</table>

**BOOM SURFACE CELL NO. 181**

<table>
<thead>
<tr>
<th>CODE</th>
<th>LOCATION</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>000061111123</td>
<td>9 9 19</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Figure 11.8. (Continued).
DIRECTION = Z
MATERIAL = ALUM

POTENTIAL = -1.667 x 002 VOLTS
FIELD = 3.190 x 004 VOLTS/METER
LIMITING FACTOR = .000

FLUXES IN A/M**2

INCIDENT ELECTRONS 2.20 x 006 8.24 x 007
RESULTING SECONDARIES 2.20 x 006
RESULTING BACKSCATTER 2.20 x 006
INCIDENT PROTONS 2.20 x 006
RESULTING SECONDARIES 2.20 x 006
PHOTOCURRENT 2.20 x 006

NET FLUX

-1.35 x 006

INITIAL NET CHARGING CURRENT (WITHOUT LIMITING) = 3.66 x 007 AMPERES
INITIAL NET CHARGING CURRENT (WITH LIMITING) = 0.58 x 006 AMPERES

TOTAL CAPACITANCE TO INFINITY = 49.9 CODE UNITS; 8.03 x 012 FARADS.

ICCG --- RDTR/RDTR1 = 1.06 x 021/ 1.30 x 008
LEAVING ICCG1 -- VCTRI = -4.233 x 002 -3.291 x 002
ICCG --- RDTR/RDTR1 = 1.06 x 021/ 1.30 x 008
LEAVING ICCG1 -- VCTRI = -4.233 x 002 -3.291 x 002
ICCG --- RDTR/RDTR1 = 1.64 x 022/ 1.03 x 008
LEAVING ICCG1 -- VCTRI = -4.233 x 002 -3.291 x 002

VFIX --- 59 OUT OF 164 NODES FIXED.
CONDUCTOR 1 FIXED TO -416.40 VOLTS.

ICCG --- RDTR/RDTR1 = 1.53 x 022/ 1.01 x 008
LEAVING ICCG1 -- VCTRI = -4.164 x 002 -3.214 x 002
NO DISCHARGE ANALYSIS

ICCG --- RDTR/RDTR1 = 1.76 x 017/ 4.16 x 009
LEAVING ICCG2 -- VCTRI = -4.163 x 002 -3.213 x 002

AVERAGE FLUXES (ONLY AVAILABLE FOR INSULATING CELLS)

AVERAGE FLUX TO CELL 20 [0] = 1.437 x 008 A/M**2
AVERAGE FLUX TO CELL 28 [0] = 1.437 x 008 A/M**2
AVERAGE FLUX TO CELL 27 [0] = 1.437 x 008 A/M**2
AVERAGE FLUX TO CELL 27 [0] = 1.437 x 008 A/M**2
AVERAGE FLUX TO CELL 27 [0] = 1.437 x 008 A/M**2

NEW CONDUCTOR POTENTIALS

VNEW = -4.1632 x 002 1.5449 x 007 -1.667 x 002
VOLD = -3.2133 x 002 3.0019 x 001 -1.2253 x 002

TOTAL CHANGE IN CHARGE = -1.842 x 004 CODE UNITS
-3.262 x 009 COULOMBS

AVERAGE NET CHARGING CURRENT = -1.631 x 011 AMPERES
-9.211 x 001 CODE UNITS/SEC.

CONDUCTOR CURRENTS (AMPS; POSITIVE INTO CONDUCTORS):

1 2

NET CURRENT(avg dq/dt) = 1.37 x 008 2.66 x 016

Figure 11.8. (Continued).
CONTINUE CYCLE NO. 4 AT UPDATED TIME = 6.050×10^{-2} SECONDS.

SURFACE POTENTIALS - ALL 184 CELLS

<table>
<thead>
<tr>
<th>CELL NO.</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-1.387×10^{-3}</td>
</tr>
<tr>
<td>2</td>
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</tr>
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<td>14</td>
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<tr>
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</tr>
<tr>
<td>16</td>
<td>-1.387×10^{-3}</td>
</tr>
</tbody>
</table>

16 POTENTIAL ITERATIONS COMPLETED.

PCOND = 4.163×10^{-2} /

QCOND = 5.591×10^{-3} /

FPREP -- 1 GRIDS OUT OF 1 READ IN.

Figure 11.8. (Continued)
BEGIN CYCLE NO. 5  TIME = 6.050+002 SECONDS.

QSUM ER FOUND QSUM = -4.46+004 CODE UNITS.
AFTER SCREENING CORRECTION (SCREENING LENGTH = 2.00+002 M.) QSUM = -4.46+004
QSCALE = -4.46+004   CORRECTED TO   -4.46+004
PCOND = -4.163+002    -3.213+002
QCOND = 5.591+004    -8.356+003

EXPLICITLY CALCULATED FLUXES FOR CYCLE 5  TIME = 6.050+002 SECONDS.
DURING THIS TIMESTEP, NASEF WILL TAKE INTO ACCOUNT SUCH ADDITIONAL EFFECTS AS SURFACE CONDUCTIVITY, DISSOLVING, EMITTER OPERATION, AND VARIATION OF LIMITING FACTORS FOR LOW-ENERGY EMITTED ELECTRONS.

SURFACE CELL NO. 20  CODE = 004611216003
LOCATION = 9 0 17
NORMAL = 0 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/M²:²
INCIDENT ELECTRONS  1.73-006
RESULTING SECONDARIES  1.39-007
RESULTING BACKSCATTER  3.35-007
INCIDENT PROTONS  4.01-006
RESULTING SECONDARIES  7.69-009
BULK CONDUCTIVITY  7.65-010
PHOTOCURRENT  0.00
NET FLUX  -4.15-007

SURFACE CELL NO. 28  CODE = 004612210043
LOCATION = 9 10 17
NORMAL = 0 1 0
MATERIAL = KAPT

POTENTIAL = -4.549+002 VOLTS
STRESS = 3.038+005 VOLTS/METER
EXTERNAL FIELD = -8.911-003 VOLTS/METER
LIMITING FACTOR = 0.000

FLUXES IN A/M²:²
INCIDENT ELECTRONS  2.08-006
RESULTING SECONDARIES  0.00  E  8.91-0073
RESULTING BACKSCATTER  3.98-007
INCIDENT PROTONS  5.16-006
RESULTING SECONDARIES  3.07-011  E  5.71-0083
BULK CONDUCTIVITY  3.09-011  E  1.41-0053
PHOTOCURRENT  0.00
NET FLUX  -1.50-006

SURFACE CELL NO. 77  CODE = 005107211103
LOCATION = 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/M²:²
INCIDENT ELECTRONS  1.73-006
RESULTING SECONDARIES  1.39-007
RESULTING BACKSCATTER  3.35-007

Figure 11.8. (Continued).
<table>
<thead>
<tr>
<th>INCIDENT PROTONS</th>
<th>4.01-000</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESULTING SECONDARIES</td>
<td>7.69-000</td>
</tr>
<tr>
<td>BULK CONDUCTIVITY</td>
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<tr>
<td>PHOTOCURRENT</td>
<td>.00</td>
</tr>
<tr>
<td>NET FLUX</td>
<td>-4.15-007</td>
</tr>
</tbody>
</table>

**SURFACE CELL NO. 88**

<table>
<thead>
<tr>
<th>FLUXES IN A/M**2</th>
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</thead>
<tbody>
<tr>
<td>INCIDENT ELECTRONS</td>
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<tr>
<td>RESULTING SECONDARIES</td>
</tr>
<tr>
<td>RESULTING BACKSCATTER</td>
</tr>
<tr>
<td>INCIDENT PROTONS</td>
</tr>
<tr>
<td>RESULTING SECONDARIES</td>
</tr>
<tr>
<td>BULK CONDUCTIVITY</td>
</tr>
<tr>
<td>PHOTOCURRENT</td>
</tr>
<tr>
<td>NET FLUX</td>
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**SURFACE CELL NO. 129**

<table>
<thead>
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<tbody>
<tr>
<td>INCIDENT ELECTRONS</td>
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<tr>
<td>RESULTING SECONDARIES</td>
</tr>
<tr>
<td>RESULTING BACKSCATTER</td>
</tr>
<tr>
<td>INCIDENT PROTONS</td>
</tr>
<tr>
<td>RESULTING SECONDARIES</td>
</tr>
<tr>
<td>BULK CONDUCTIVITY</td>
</tr>
<tr>
<td>PHOTOCURRENT</td>
</tr>
<tr>
<td>NET FLUX</td>
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</tbody>
</table>

**SURFACE CELL NO. 167**

<table>
<thead>
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<tbody>
<tr>
<td>INCIDENT ELECTRONS</td>
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<tr>
<td>RESULTING SECONDARIES</td>
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<tr>
<td>RESULTING BACKSCATTER</td>
</tr>
<tr>
<td>INCIDENT PROTONS</td>
</tr>
<tr>
<td>RESULTING SECONDARIES</td>
</tr>
<tr>
<td>BULK CONDUCTIVITY</td>
</tr>
<tr>
<td>PHOTOCURRENT</td>
</tr>
<tr>
<td>NET FLUX</td>
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</tbody>
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**BOOM SURFACE CELL NO. 181**

<table>
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<td>INCIDENT ELECTRONS</td>
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<tr>
<td>RESULTING SECONDARIES</td>
</tr>
<tr>
<td>RESULTING BACKSCATTER</td>
</tr>
<tr>
<td>INCIDENT PROTONS</td>
</tr>
<tr>
<td>RESULTING SECONDARIES</td>
</tr>
<tr>
<td>BULK CONDUCTIVITY</td>
</tr>
<tr>
<td>PHOTOCURRENT</td>
</tr>
<tr>
<td>NET FLUX</td>
</tr>
</tbody>
</table>

**CODE:** 0051111270103
**LOCATION:** 9 9 23
**NORMAL:** 0 0 0
**MATERIAL:** KAPT

**FLUXES IN A/M**

| INCIDENT ELECTRONS | 1.73-006 |
| RESULTING SECONDARIES | 7.39-007 |
| RESULTING BACKSCATTER | 4.05-007 |
| INCIDENT PROTONS | 4.01-000 |
| RESULTING SECONDARIES | 7.69-008 |
| BULK CONDUCTIVITY | 7.64-010 |
| PHOTOCURRENT | .00 |
| NET FLUX | -4.15-007 |

**CODE:** 005307212001
**LOCATION:** 1 1 17
**NORMAL:** 0 0 0
**MATERIAL:** GOLD

**FLUXES IN A/M**

| INCIDENT ELECTRONS | 2.20-006 |
| RESULTING SECONDARIES | 1.36-006 |
| RESULTING BACKSCATTER | 9.33-008 |
| INCIDENT PROTONS | 9.31-008 |
| RESULTING SECONDARIES | .00 |
| BULK CONDUCTIVITY | .00 |
| PHOTOCURRENT | .00 |
| NET FLUX | -7.08-007 |

**CODE:** 11111120302
**LOCATION:** 9 9 10
**NORMAL:** 0 0 0
**MATERIAL:** SOAP

**FLUXES IN A/M**

| INCIDENT ELECTRONS | 2.20-006 |
| RESULTING SECONDARIES | 8.67-027 |
| RESULTING BACKSCATTER | 7.50-007 |
| INCIDENT PROTONS | 7.91-008 |
| RESULTING SECONDARIES | 1.40-028 |
| BULK CONDUCTIVITY | 7.99-012 |
| PHOTOCURRENT | .00 |
| NET FLUX | -1.42-006 |

**CODE:** 000061111123
**LOCATION:** 9 9 19

**Figure 11.8. (Continued).**
DIRECTION = Z
MATERIAL = ALUM

POTENTIAL = -4.163 x 10^2 VOLTS
FIELD = 4.293 x 10^4 VOLTS/METER
LIMITING FACTOR = .000

FLUXES IN A/M**2
INCIDENT ELECTRONS = 2.10 - 0D6
RESULTING SECONDARIES = 0.00
RESULTING BACKSCATTER = 7.83 - 0D7
INCIDENT PROTONS = 3.13 - 0D6
RESULTING SECONDARIES = 0.00
PHOTOCURRENT = 0.00

NET FLUX
INITIAL NET CHARGING CURRENT [WITHOUT LIMITING] = 3.70 - 0D7 AMPERES
INITIAL NET CHARGING CURRENT [WITH LIMITING] = -6.06 - 0D8 AMPERES

TOTAL CAPACITANCE TO INFINITY = 49.9 CODE UNITS; 8.03 - 0D2 FARADS.

ICCG --- RDOT/RDOT1 = 9.32 - 022/ 1.21 + 008
LEAVING ICCG1 -- VCTR1 = -7.062 - 002 - 5.600 + 002
ICCG --- RDOT/RDOT1 = 9.32 - 022/ 1.21 + 008
LEAVING ICCG1 -- VCTR1 = -7.062 - 002 - 5.600 + 002
ICCG --- RDOT/RDOT1 = 1.53 - 022/ 9.90 + 007
LEAVING ICCG1 -- VCTR1 = -7.062 - 002 - 5.555 + 002

VFIX --- 59 OUT OF 164 NODES FIXED.
CONDUCTOR 1 FIXED TO -698.88 VOLTS.

ICCG --- RDOT/RDOT1 = 1.69 - 022/ 9.67 + 007
LEAVING ICCG1 -- VCTR1 = -6.989 - 002 - 5.521 + 002
NO DISCHARGE ANALYSIS
NO DISCHARGE ANALYSIS

ICCG --- RDOT/RDOT1 = 1.94 - 017/ 3.10 + 009
LEAVING ICCG2 -- VCTR1 = -6.988 + 002 - 5.521 + 002

AVERAGE FLUXES [ONLY AVAILABLE FOR INSULATING CELLS]
AVERAGE FLUX TO CELL 20 15 = -2.747 - 007 A/M**2
AVERAGE FLUX TO CELL 99 15 = -2.749 - 007 A/M**2
AVERAGE FLUX TO CELL 80 15 = -2.746 - 007 A/M**2
AVERAGE FLUX TO CELL 167 15 = -2.788 - 008 A/M**2

NEW CONDUCTOR POTENTIALS
VNEW = -6.9885 - 002 1.3488 + 007 4.4231 + 002
.DQ = -5.5208 + 002 4.4231 - 001 3.2133 + 002

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).
<table>
<thead>
<tr>
<th>Conductivity Current (New)</th>
<th>-4.33E-011</th>
<th>2.54E-016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasma Current (Initial)</td>
<td>-5.18E-009</td>
<td>.00</td>
</tr>
<tr>
<td>(To Bare Cells)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remainder Current:</td>
<td>1.72E-008</td>
<td>1.40E-016</td>
</tr>
</tbody>
</table>

Figure 11.8. (Continued).
BEGIN CYCLE NO.  6  TIME =  8.050+002 SECONDS.

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 -6.39+004
QCOND = -6.868+004 -5.521+002
QCON =  6.004+002 -1.229+004

EXPLICITLY CALCULATED FLUXES FOR CYCLE  6  TIME =  8.050+002 SECONDS.
DURING THIS TIMESTEP, NSCAP 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 =  OD4612196003
LOCATION = 6 9 17  NORMAL = 1 0 0
MATERIAL = KAPT

POTENTIAL =  -1.895+003 VOLTS
STRESS =  9.188+006 VOLTS/METER
EXTERNAL FIELD = 2.310+004 VOLTS/METER
LIMITING FACTOR =  1.000+000

FLUXES IN A/M**2
INCIDENT ELECTRONS
RESULTING SECONDARIES
RESULTING BACKSCATTER
INCIDENT PROTONS
RESULTING SECONDARIES
RESULTING BACKSCATTER
BULK CONDUCTIVITY
PHOTOCURRENT

1.56-006
6.48-007
4.11-007
4.40-008
6.91-008
9.82-010
0.00

NET FLUX
-3.47-007

SURFACE CELL NO.  28  CODE =  OD4612194003
LOCATION = 6 10 17  NORMAL = 0 1 0
MATERIAL = KAPT

POTENTIAL =  -7.520+002 VOLTS
STRESS =  9.188+006 VOLTS/METER
EXTERNAL FIELD = 9.151+003 VOLTS/METER
LIMITING FACTOR =  0.000

FLUXES IN A/M**2
INCIDENT ELECTRONS
RESULTING SECONDARIES
RESULTING BACKSCATTER
INCIDENT PROTONS
RESULTING SECONDARIES
RESULTING BACKSCATTER
BULK CONDUCTIVITY
PHOTOCURRENT

1.96-006
0.00
5.37-007
3.41-008
0.00
4.19-011
0.00

NET FLUX
-1.41-006

SURFACE CELL NO.  77  CODE =  OD5107211403
LOCATION = 9 7 17  NORMAL = 0 1 0
MATERIAL = KAPT

POTENTIAL =  -1.895+003 VOLTS
STRESS =  9.188+006 VOLTS/METER
EXTERNAL FIELD = -1.003+004 VOLTS/METER
LIMITING FACTOR =  1.000+000

FLUXES IN A/M**2
INCIDENT ELECTRONS
RESULTING SECONDARIES
RESULTING BACKSCATTER

1.56-006
6.88-007
4.11-007

Figure 11.8. (Continued).
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<thead>
<tr>
<th>Surface Cell No. 88</th>
<th>Code: 005111270103</th>
<th>Location: 9 9 25</th>
<th>Normal: 0 0 1</th>
<th>Material: NAPF</th>
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</thead>
<tbody>
<tr>
<td>Potential: -1.694*10^{-3} Volts</td>
<td>Stress: -9.407*10^{-6} Volts/Meter</td>
<td>External Field: -9.309*10^{-4} Volts/Meter</td>
<td>Limiting Factor: 1.000*10^{0}</td>
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</tr>
<tr>
<td>Fluxes in A/H**2</td>
<td>Incident Electrons</td>
<td>Resulting Secondaries</td>
<td>Resulting Backscatter</td>
<td>Incident Protons</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------</td>
<td>---------------------</td>
<td>---------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Incident Electrons</td>
<td>1.56*10^{-4}</td>
<td>6.66*10^{-7}</td>
<td>4.47*10^{-8}</td>
<td>9.91*10^{-9}</td>
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<tr>
<td>Resulting Secondaries</td>
<td>6.66*10^{-7}</td>
<td>4.47*10^{-8}</td>
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<td>9.91*10^{-9}</td>
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<td>Resulting Backscatter</td>
<td>4.47*10^{-8}</td>
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<td>9.91*10^{-9}</td>
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<td>9.91*10^{-9}</td>
<td>9.91*10^{-9}</td>
<td>9.91*10^{-9}</td>
<td>9.91*10^{-9}</td>
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<tr>
<td>Net Flux</td>
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<table>
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<th>Surface Cell No. 129</th>
<th>Code: 005307212001</th>
<th>Location: 1 7 17</th>
<th>Normal: 0 0 0</th>
<th>Material: GOLD</th>
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<tbody>
<tr>
<td>Potential: -6.988*10^{-2} Volts</td>
<td>Stress: -1.17*10^{-4} Volts/Meter</td>
<td>External Field: -1.17*10^{-4} Volts/Meter</td>
<td>Limiting Factor: 0.000</td>
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</tr>
<tr>
<td>Fluxes in A/H**2</td>
<td>Incident Electrons</td>
<td>Resulting Secondaries</td>
<td>Resulting Backscatter</td>
<td>Incident Protons</td>
</tr>
<tr>
<td>---------------------</td>
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<td>---------------------</td>
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<tr>
<td>Incident Electrons</td>
<td>1.98*10^{-4}</td>
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<td>5.61*10^{-8}</td>
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<tr>
<td>Resulting Backscatter</td>
<td>1.27*10^{-6}</td>
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<td>5.61*10^{-8}</td>
<td>5.61*10^{-8}</td>
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<td>Incident Protons</td>
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<table>
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<th>Surface Cell No. 167</th>
<th>Code: 011111120302</th>
<th>Location: 9 9 10</th>
<th>Normal: 0 0 1</th>
<th>Material: SOLA</th>
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<tbody>
<tr>
<td>Potential: -1.467*10^{-2} Volts</td>
<td>Stress: -1.20*10^{-4} Volts/Meter</td>
<td>External Field: -4.873*10^{-3} Volts/Meter</td>
<td>Limiting Factor: 6.865*10^{-2}</td>
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</tr>
<tr>
<td>Fluxes in A/H**2</td>
<td>Incident Electrons</td>
<td>Resulting Secondaries</td>
<td>Resulting Backscatter</td>
<td>Incident Protons</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------</td>
<td>---------------------</td>
<td>---------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Incident Electrons</td>
<td>4.13*10^{-6}</td>
<td>1.71*10^{-6}</td>
<td>1.71*10^{-6}</td>
<td>1.71*10^{-6}</td>
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<tr>
<td>Resulting Secondaries</td>
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<td>3.01*10^{-8}</td>
<td>3.01*10^{-8}</td>
</tr>
<tr>
<td>Resulting Backscatter</td>
<td>1.71*10^{-6}</td>
<td>3.01*10^{-8}</td>
<td>3.01*10^{-8}</td>
<td>3.01*10^{-8}</td>
</tr>
<tr>
<td>Incident Protons</td>
<td>3.01*10^{-8}</td>
<td>3.01*10^{-8}</td>
<td>3.01*10^{-8}</td>
<td>3.01*10^{-8}</td>
</tr>
<tr>
<td>Net Flux</td>
<td>-1.37*10^{-6}</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Boom Surface Cell No. 181 | Code: 000061111123 | Location: 9 9 19 | Normal: 0 0 1 |

Figure 11.8. (Continued).
DIRECTION: Z
MATERIAL: ALUM

POTENTIAL: -4.988*002 VOLTS
FIELD: 5.277*004 VOLTS/METER
LIMITING FACTOR: 0.000

FLUXES IN A/M**2
INCIDENT ELECTRONS
RESULTING SECONDARIES 1.98-006
RESULTING BACKSCATTER
INCIDENT PROTONS 7.49-007
RESULTING SECONDARIES 3.38-000
PHOTOCURRENT

---
---
---

NET FLUX
INITIAL NET CHARGING CURRENT (WITHOUT LIMITING) = 3.33-007 AMPERES;
INITIAL NET CHARGING CURRENT (WITH LIMITING) = -5.33-008 AMPERES:

TOTAL CAPACITANCE TO INFINITY = 49.9 CODE UNITS; 8.03-012 FARADS.

ICCG --- RDOTR/RDOTRI = 8.90-022/ 1.04*008
LEAVING ICCG1 -- VCTRI = -9.964*002 -7.989*002
ICCG --- RDOTR/RDOTRI = 8.90-022/ 1.04*008
LEAVING ICCG1 -- VCTRI = -9.964*002 -7.989*002
ICCG --- RDOTR/RDOTRI = 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/RDOTRI = 1.46-022/ 8.54*007
LEAVING ICCG1 -- VCTRI = -9.886*002 -7.914*002

NO DISCHARGE ANALYSIS
NO DISCHARGE ANALYSIS
ICCG --- RDOTR/RDOTRI = 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 15 -2.353*007 A/M**2
AVERAGE FLUX TO CELL 26 15 -1.641*008 A/M**2
AVERAGE FLUX TO CELL 47 15 -2.152*007 A/M**2
AVERAGE FLUX TO CELL 86 15 -2.350*007 A/M**2
AVERAGE FLUX TO CELL 167 15 6.964*008 A/M**2

NEW CONDUCTOR POTENTIALS

<table>
<thead>
<tr>
<th>VNLY</th>
<th>DO</th>
<th>VOLD</th>
<th>CONDUCTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>-9.985*002</td>
<td>1.129*003</td>
<td>5.990*002</td>
<td>0.000</td>
</tr>
<tr>
<td>-7.913*002</td>
<td>6.414*001</td>
<td>5.320*002</td>
<td></td>
</tr>
</tbody>
</table>

TOTAL CHANGE IN CURRENT = -1.858*004 CODE UNITS
-3.291.007 COULOMBS

AVERAGE NET CHARGING CURRENT = -1.645*011 AMPERES
-9.292*001 CODE UNITS/SEC.

CONDUCTOR CURRENTS (AMPS; POSITIVE INTO CONDUCTORS):

<table>
<thead>
<tr>
<th>CONDUCTOR</th>
<th>CURRENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00-008</td>
</tr>
<tr>
<td>2</td>
<td>5.68-016</td>
</tr>
</tbody>
</table>

Figure 11.8. (Continued).
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  \hspace{1cm} TIME = 1.805\times 0.003 SECONDS.

QSUM (FIND QSUM) = -1.43\times 0.005 \hspace{1cm} CODE UNITS.
AFTER SCREENING CORRECTION (SCREENING LENGTH = 2.00\times 0.002 m) QSUM = -1.43\times 0.005
QSCALE = -1.43\times 0.005 \hspace{1cm} CORRECTED TO -1.43\times 0.005
QSUM = -1.43\times 0.005
QCOND = -1.980\times 0.003 \hspace{1cm} -1.621\times 0.003
QCOND = 1.098\times 0.008 \hspace{1cm} -2.633\times 0.004

EXPLICITLY CALCULATED FLUXES FOR CYCLE 11  \hspace{1cm} TIME = 1.805\times 0.003 SECONDS.
DURING THIS TIME STEP, NO DEPOSITS WILL BE TAKEN INTO ACCOUNT SUCH AS ADDITIONAL EFFECTS AS SURFACE CONDUCTIVITY, DISCHARGES, EMITTER OPERATION, AND VARIATION OF LIMITING FACTORS FOR LOW-ENERGY EMITTED ELECTRONS.

---

SURFACE CELL NO. 20

<table>
<thead>
<tr>
<th>CODE</th>
<th>D0N61216003</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOCATION</td>
<td>6 9 17</td>
</tr>
<tr>
<td>NORMAL</td>
<td>0 0 0</td>
</tr>
<tr>
<td>MATERIAL</td>
<td>KAPT</td>
</tr>
</tbody>
</table>

POTENTIAL = -3.083\times 0.003 VOLTS
STRESS = 1.999\times 0.007 VOLTS/METER
EXTERNAL FIELD = -9.922\times 0.004 VOLTS/METER
LIMITING FACTOR = 1.000\times 0.000

FLUXES IN A/M^2

| INCIDENT ELECTRONS | 1.05E-06 |
| RESULTING SECONDARIES | 1.39E-07 |
| INCIDENT PROTONS | 2.76E-01 |
| RESULTING SECONDARIES | 9.56E-08 |
| BULK CONDUCTIVITY | 1.7E-09 |
| PHOTOCURRENT | 1.0E-00 |

NET FLUX

-1.15E-07

---

SURFACE CELL NO. 28

<table>
<thead>
<tr>
<th>CODE</th>
<th>D0N612120403</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOCATION</td>
<td>6 10 17</td>
</tr>
<tr>
<td>NORMAL</td>
<td>0 1 0</td>
</tr>
<tr>
<td>MATERIAL</td>
<td>KAPT</td>
</tr>
</tbody>
</table>

POTENTIAL = -2.576\times 0.003 VOLTS
STRESS = 6.419\times 0.005 VOLTS/METER
EXTERNAL FIELD = -5.999\times 0.003 VOLTS/METER
LIMITING FACTOR = 2.512\times 0.026

FLUXES IN A/M^2

| INCIDENT ELECTRONS | 1.50E-06 |
| RESULTING SECONDARIES | 1.61E-03 |
| INCIDENT PROTONS | 4.65E-06 |
| RESULTING SECONDARIES | 2.36E-03 |
| BULK CONDUCTIVITY | 8.82E-01 |
| PHOTOCURRENT | 3.55E-01 |

NET FLUX

-1.06E-06

---

SURFACE CELL NO. 77

<table>
<thead>
<tr>
<th>CODE</th>
<th>D0S107211403</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOCATION</td>
<td>9 7 17</td>
</tr>
<tr>
<td>NORMAL</td>
<td>0 1 0</td>
</tr>
<tr>
<td>MATERIAL</td>
<td>KAPT</td>
</tr>
</tbody>
</table>

POTENTIAL = 3.883\times 0.003 VOLTS
STRESS = 1.499\times 0.007 VOLTS/METER
EXTERNAL FIELD = -1.512\times 0.004 VOLTS/METER
LIMITING FACTOR = 1.600\times 0.000

FLUXES IN A/M^2

| INCIDENT ELECTRONS | 1.05E-06 |
| RESULTING SECONDARIES | 4.49E-07 |
| RESULTING BACKSCATTER | 2.76E-07 |

Figure 11.10a. Trilin Output for cycle 11.
DIRECTION = Z
MATERIAL = ALUM

POTENTIAL = -1.980 x 10^3 VOLTS
LIMITING FACTOR = 2 x 10^4 VOLTS/AMPERE

FLUXES IN A/H#2
INCIDENT ELECTRONS 1.53 x 10^6 [5.74 x 10^7]
RESULTING SECONDARIES 0.0 [5.00 x 10^3]
RESULTING BACKSCATTER 5.73 x 10^7 [5.00 x 10^3]
INCIDENT PROTONS 4.55 x 10^8 [1.37 x 10^3]
RESULTING SECONDARIES 0.0 [5.00 x 10^3]
PHOTOCURRENT 0.0

NET FLUX
INITIAL NET CHARGING CURRENT (WITHOUT LIMITING) = 3.80 x 10^7 AMPERES
INITIAL NET CHARGING CURRENT (WITH LIMITING) = 1.56 x 10^8 AMPERES

TOTAL CAPACITANCE TO INFINITY = 49.9 CODE UNITS; 8.83 x 10^3 FARADS

ICCG -- RDOTR/RDOTRI = 2.29-022/2.63 x 10^7
LEAVING ICCG1 -- VCTRI = -2.174 x 10^03 -1.783 x 10^03
ICCG -- RDOTR/RDOTRI = 2.29-022/2.63 x 10^7
LEAVING ICCG1 -- VCTRI = -2.174 x 10^03 -1.783 x 003
ICCG -- RDOTR/RDOTRI = 1.10-022/2.93 x 10^07
LEAVING ICCG1 -- VCTRI = -2.174 x 10^03 -1.780 x 003

VFIX --- 59 OUT OF 169 NODES FIXED,
CONDUCTOR 1 FIXED TO -2164.04 VOLTS.
ICCG -- RDOTR/RDOTRI = 8.64-023/2.27 x 10^7
LEAVING ICCG1 -- VCTRI = -2.164 x 10^03 -1.777 x 003
NO DISCHARGE ANALYSIS
NO DISCHARGE ANALYSIS
ICCG -- RDOTR/RDOTRI = 1.24-018/3.35 x 10^08
LEAVING ICCG2 -- VCTRI = -2.164 x 10^03 -1.776 x 003
AVERAGE FLUXES (ONLY AVAILABLE FOR INSULATING CELLS)
AVERAGE FLUX TO CELL 20 15 = -8.849 x 10^08 A/H#2
AVERAGE FLUX TO CELL 20 15 = -8.840 x 10^08 A/H#2
AVERAGE FLUX TO CELL 97 15 = -8.840 x 10^08 A/H#2
AVERAGE FLUX TO CELL 98 15 = -8.805 x 10^08 A/H#2
AVERAGE FLUX TO CELL 167 15 = 3.968 x 10^08 A/H#2
NEW CONDUCTOR POTENTIALS
VNEW
-2.164 x 10^03 4.372 x 10^06 1.976 x 10^03
VOLD
-1.776 x 10^03 1.053 x 10^06 1.620 x 10^03

TOTAL CHANGE IN CHARGE = -1.069 x 10^04 CODE UNITS
-1.893 x 10^09 COULOMBS
AVERAGE NET CHARGING CURRENT = -9.465 x 10^12 AMPERES
-5.395 x 10^01 CODE UNITS/SFC.
CONDUCTOR CURRENTS (AMPS; POSITIVE INTO CONDUCTORS):
1 2
NET CURRENT(AVG DQ/DT):
3.87 x 10^9 9.33 x 10^16

Figure 11.10a. (Continued)
INCIDENT PROTONS
RESULTING SECONDARIES
BULK CONDUCTIVITY
PHOTOCURRENT

---

NET FLUX

SURFACE CELL NO. 88

INCIDENT PROTONS
RESULTING SECONDARIES
BULK CONDUCTIVITY
PHOTOCURRENT

---

NET FLUX

SURFACE CELL NO. 129

INCIDENT PROTONS
RESULTING SECONDARIES
BULK CONDUCTIVITY
PHOTOCURRENT

---

NET FLUX

SURFACE CELL NO. 167

INCIDENT PROTONS
RESULTING SECONDARIES
BULK CONDUCTIVITY
PHOTOCURRENT

---

NET FLUX

BOOM SURFACE CELL NO. 181

INCIDENT PROTONS
RESULTING SECONDARIES
BULK CONDUCTIVITY
PHOTOCURRENT

---

NET FLUX

Figure 11.10a. (Continued).
| CONDUCTIVITY CURRENT (NEW) FROM INSULATING CELLS | -7.16-011 |
| PLASMA CURRENT (INITIAL) ITO BARE CELLS | -3.63-009 |
| REMAINDER CURRENT | 7.57-009 |

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:

<table>
<thead>
<tr>
<th>Type of cell</th>
<th>Potential (kv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shaded KAPTON</td>
<td>- 5.1</td>
</tr>
<tr>
<td>Sunlit KAPTON</td>
<td>~ -3</td>
</tr>
<tr>
<td>GOLD</td>
<td>~ -3</td>
</tr>
<tr>
<td>SOLAR sphere</td>
<td>~ -2 ± -3</td>
</tr>
</tbody>
</table>

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→3 kV range are likely.
BEGIN CYCLE NO. 21  TIME = 6.505003 SECONDS.

QSUMH FOUND QSUM: -1.960005 CODE UNITS.
AFTER SCREENING CORRECTION (SCREENING LENGTH = 2.000000 M) QSUM: -1.960005
QSCALE = -1.960005 CONNECTED TO -1.960005
QSUM = -1.960005
PEOUD = -2.930003 -2.930003
QCOND = 1.261008 1.261008

EXPLICITLY CALCULATED FLUXES FOR CYCLE 21  TIME = 6.505003 SECONDS.
DURING THIS TIME STEP, NASA 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

<table>
<thead>
<tr>
<th>CODE</th>
<th>LOCATION</th>
<th>NORMAL</th>
<th>MATERIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q04612114003</td>
<td>6 9 17</td>
<td>0 0</td>
<td>KAPT</td>
</tr>
</tbody>
</table>

POTENTIAL = -5.113003 VOLTS
STRESS = 1.719007 VOLTS/METER
EXTERNAL FIELD = 5.613004 VOLTS/METER
LIMITING FACTOR = 1.000000

FLUXES IN A/M**2

INCIDENT ELECTRONS 8.200007
RESULTING SECONDARIES 3.510007
RESULTING BACKSCATTER 2.100007
INCIDENT PROTONS 7.430008
RESULTING SECONDARIES 7.610008
BULK CONDUCTIVITY 1.720009
PHOTOCURRENT 0.00

NET FLUX 6.070009

SURFACE CELL NO. 2A

<table>
<thead>
<tr>
<th>CODE</th>
<th>LOCATION</th>
<th>NORMAL</th>
<th>MATERIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q046102100403</td>
<td>6 10 17</td>
<td>0 1 0</td>
<td>KAPT</td>
</tr>
</tbody>
</table>

POTENTIAL = -3.071003 VOLTS
STRESS = 1.115004 VOLTS/METER
EXTERNAL FIELD = 2.349002 VOLTS/METER
LIMITING FACTOR = 9.598002

FLUXES IN A/M**2

INCIDENT ELECTRONS 1.230006
RESULTING SECONDARIES 5.070008
RESULTING BACKSCATTER 3.950007
INCIDENT PROTONS 5.850008
RESULTING SECONDARIES 5.950008
BULK CONDUCTIVITY 1.160008
PHOTOCURRENT 1.710008

NET FLUX 5.670007

SURFACE CELL NO. 77

<table>
<thead>
<tr>
<th>CODE</th>
<th>LOCATION</th>
<th>NORMAL</th>
<th>MATERIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q051D7211403</td>
<td>9 7 17</td>
<td>0 0</td>
<td>KAPT</td>
</tr>
</tbody>
</table>

POTENTIAL = -5.113003 VOLTS
STRESS = 1.719007 VOLTS/METER
EXTERNAL FIELD = 4.516004 VOLTS/METER
LIMITING FACTOR = 1.000000

FLUXES IN A/M**2

INCIDENT ELECTRONS 8.200007
RESULTING SECONDARIES 3.510007
RESULTING BACKSCATTER 2.160007

Figure 11.11. Trilin output for cycle 21.
<table>
<thead>
<tr>
<th>INCIDENT PROTONS</th>
<th>RESULTING SECONDARIES</th>
<th>BULK CONDUCTIVITY</th>
<th>PHOTOCURRENT</th>
<th>NET FLUX</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.81-004</td>
<td>1.83-007</td>
<td>1.72-009</td>
<td>0.00</td>
<td>6.00-009</td>
</tr>
</tbody>
</table>

**Surface Cell No. 88**

- **Code:** 005111270103
- **Location:** 9 9 23
- **Normal:** 0 0 1
- **Material:** KAP1
- **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/H**

- **Incident Electrons:** 0.21-007
- **Resulting Secondaries:** 1.52-007
- **Resulting Backscatter:** 9.16-007
- **Incident Protons:** 1.80-007
- **Resulting Secondaries:** 1.07-009
- **Bulk Conductivity:** 0.00
- **Photocurrent:** 0.00
- **Net Flux:** 5.17-009

**Surface Cell No. 129**

- **Code:** 0053012712001
- **Location:** 11 7 17
- **Normal:** 0 0 0
- **Material:** GOLD
- **Potential:** -2.930*003 Volts
- **External Field:** 3.835*005 Volts/Meter
- **Limiting Factor:** 2.249-017

**Fluxes in A/H**

- **Incident Electrons:** 1.27-006
- **Resulting Secondaries:** 1.81-023
- **Resulting Backscatter:** 8.25-007
- **Incident Protons:** 5.34-008
- **Resulting Secondaries:** 4.43-024
- **Bulk Conductivity:** 4.55-022
- **Photocurrent:** 0.00
- **Net Flux:** 3.93-007

**Surface Cell No. 167**

- **Code:** 011111120303
- **Location:** 9 9 10
- **Normal:** 0 0 1
- **Material:** SOLA
- **Potential:** -1.700*003 Volts
- **Stress:** -4.007*006 Volts/Meter
- **External Field:** 5.629*001 Volts/Meter
- **Limiting Factor:** 5.698-001

**Fluxes in A/H**

- **Incident Electrons:** 1.62-006
- **Resulting Secondaries:** 1.42-007
- **Resulting Backscatter:** 5.53-007
- **Incident Protons:** 4.30-008
- **Resulting Secondaries:** 2.63-008
- **Bulk Conductivity:** -4.00-011
- **Photocurrent:** 0.00
- **Net Flux:** -2.58-007

**BooM Surface Cell No. 101**

- **Code:** 00006111123
- **Location:** 9 9 14

Figure 11.11. (Continued).
Figure 11.11. (Continued).
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. $\phi$ 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:INE 12
9:AUTOS
10:IMDXAR=THETA
11:FJNEMU 88
12:IN 46
13:PLPART
14:INGBND 1
15:LINGRD 2
16:END
```

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.
Figure 11.14. DETECT runstream.
ENERGY FLUX IN EV/(CM²-SEC-SR-EV) AT CYCLE 21 MEASURED BY DETECTOR LOCATED AT CELL NUMBER 170 (INTERPOLATED AT 40 POINTS) PROTON FLUX (HEAVY) SCALED BY 1.00E+05 ELECTRON FLUX (LIGHT) UNSCALED.

**Figure 11.15.** Detector plot for charged spacecraft.
Figure 11.16a. Trajectory plots for charged spacecraft.
TRAJECTORIES AT CYCLE 21 FOR ELECTRONS IN 1 GRIDS RECEIVED BY DETECTOR LOCATED AT CELL NUMBER 170 PROJECTED ONTO THE Y-Z PLANE.

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 TOSETH.

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 receives 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 BOOMDO
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 Poisson'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 determining how the charge was distributed among the surface cells.
SUBROUTINE CAPERR
   This subroutine 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 integration 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 CELGST
   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 100 surface which points into a partially filled volume element. Called during OBJDEF.

SUBROUTINE CHARGE
   High level routine called by TRILIN which calculates explicit particle fluxes and predicts the 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 CNDFSET
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 calculation.
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 DEADSET
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 detector routines.
SUBROUTINE DVLIMIT
   Called during the current integration to restrict the difference between trial potentials and original potentials to DVLIM.

SUBROUTINE ECUBE
   Element stiffness 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 EFREP
   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 FASTRN
    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 FILASS
    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 FILIII
    Creates a III 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 F-TITLE
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 algorithms.

SUBROUTINE GENMFA
Sets markers for interface boom cells.

SUBROUTINE GENMTL
High level which generates the skeleton of the
LONGTIMESTEP matrix and initializes 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 SUNSHD
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
Implicit flux routine which calculates the charge required to change the surface voltage from \( V_0 \) to \( V_{\text{TRIal}} \).

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 inverter.

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 IPSCHO
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 initialization 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 LOUADV
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 coordinates 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 necessary 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 QEQN2
    Low level routine to solve for maximum yield energy during 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 QUSUMER
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.

SUBROUTINEREWIND
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 SACTCR
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 matrices for particle pushing initial 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 FIL11 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 FIL11 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 photoelectron 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 integration 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 vertices of a surface cell from NASCAP coordinates to plotter raster coordinates.

SUBROUTINE UXXY
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 ICCCG 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 surfaces 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 (MOVEDAT, 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, FT47FO01 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:

<table>
<thead>
<tr>
<th>Permanent Name</th>
<th>Local Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>prefix02</td>
<td>FT02</td>
</tr>
<tr>
<td>prefix10</td>
<td>FT10</td>
</tr>
<tr>
<td>prefix15</td>
<td>FT15</td>
</tr>
<tr>
<td>prefix16</td>
<td>FT16</td>
</tr>
<tr>
<td>prefix17</td>
<td>FT17</td>
</tr>
<tr>
<td>prefix21</td>
<td>FT21</td>
</tr>
<tr>
<td>prefix27</td>
<td>FT27</td>
</tr>
<tr>
<td>prefixOBJ</td>
<td>FT20</td>
</tr>
<tr>
<td>prefixOPT</td>
<td>FT26</td>
</tr>
<tr>
<td>prefixFLX</td>
<td>FT22</td>
</tr>
<tr>
<td>prefix19</td>
<td>FT19</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Routine</th>
<th>LUN(S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLOTREAD</td>
<td>2</td>
</tr>
<tr>
<td>CONTOURS</td>
<td>10, 17, 21.</td>
</tr>
<tr>
<td>TERMTALK</td>
<td>16, 17, 21.</td>
</tr>
</tbody>
</table>
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.
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 OBJDE0 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.IBMPL0T, and their objects in LIB.TERMTALK, LIB.CONTOURS, and LIB.IBMPL0T. 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


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.


**Title and Subtitle**

NASCAP Programmer's Reference Manual

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**Abstract**

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.