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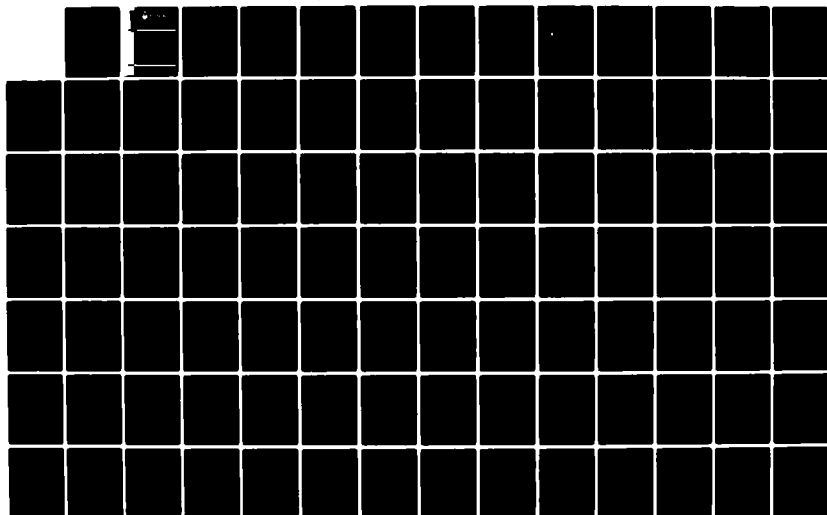
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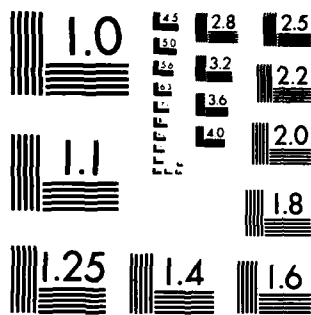
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NUMERICAL SIMULATION OF SPACECRAFT CHARGING
PHENOMENA AT HIGH ALTITUDE

J.G. Laframboise, M. Kamitsuma, S.M.L. Prokopenko,
Jen-Shih Chang, and R. Godard

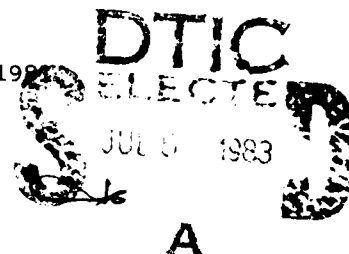
Physics Department and Centre for Research in Experimental Space Science
York University
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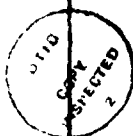
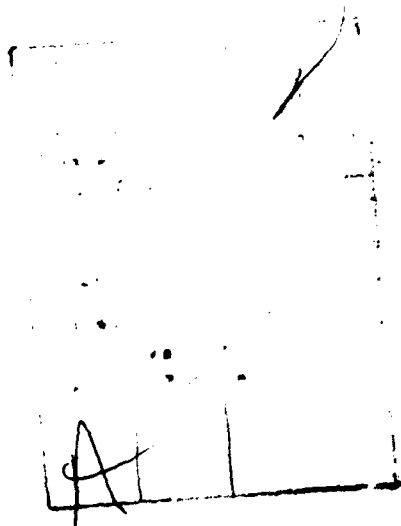
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and the "barrier" effect. Also included is a derivation of two results which appear likely to be of use in future simulation studies: an analytic expression for photoelectron currents on surfaces with variable illumination in electric fields, and a perturbation technique for calculating space-charge density and flux along particle orbits.



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PHENOMENA AT HIGH ALTITUDE

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Chief, Technical Information Division

Prepared for

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ABSTRACT

This report describes work done under grant AFOSR-76-2962. This work has included the development of computer programs for simulating spacecraft charging at three levels of complexity: LOCHG, a relatively simple local-charging calculation; CYLVIA, a two-dimensional simulation program for treating cylindrical spacecraft cross-sections, and XYCIC, a simulation program for the treatment of a larger variety of two-dimensional geometries. This work has also included studies of two physical phenomena which are fundamental to an improved understanding of spacecraft charging: the "threshold temperature" effect and the "barrier" effect. Also included is a derivation of two results which appear likely to be of use in future simulation studies: an analytic expression for photoelectron currents on surfaces with variable illumination in electric fields, and a perturbation technique for calculating space-charge density and flux along particle orbits.



1. INTRODUCTION

The performance of many satellites in geostationary orbit has been degraded by anomalous events which include frequent spurious spacecraft commands and in some cases permanent damage [Rosen, 1975; McPherson and Schober, 1976]. These events invariably appear to involve electrical discharges caused by differential charging of spacecraft surfaces to large relative potentials. The latter condition is known to result from the large average energies (up to a few keV) of the charged-particle environment at geostationary-orbit altitude, particularly in disturbed magnetospheric conditions. In order to be able to design spacecraft in future which do not suffer from such difficulties, it is important to be able to make reliable predictions of them on proposed spacecraft configurations. The ability to make such predictions requires improved understanding of the plasma sheath which connects a spacecraft with its environment in such conditions. This sheath is more complex in many ways than those which usually surround lower-altitude spacecraft because at geostationary-orbit altitude, the fluxes of incident electrons, secondary and backscattered electrons, and photoelectrons can all have comparable magnitudes and usually vary by large amounts over the surface of a spacecraft, and the relative weakness of space-charge shielding (large Debye length) means that electric fields due to charging of one part of a spacecraft surface can readily extend around the spacecraft to other parts, including those on its other sides, exerting strong influences on charged-particle collection by them and hence on their charging.

Because of the magnitude of the spacecraft-charging problem, a joint USAF-NASA programme was commenced during the 1970-1980 decade to study it, including the launching of the P78-2 (SCATHA) satellite, which was specifically devoted to the study of the high-altitude charging process, and also including theoretical work on the nature of the spacecraft-environment interface problem: this work was to be closely coordinated with analysis of SCATHA observations.

The work described in this report is part of this theoretical effort.

This work has been conducted using a number of different approaches. In Sec. 2, we describe a relatively simple local-current-balance calculation of charging which formed the first phase of it, and led to the discovery that floating potentials (voltages) of many spacecraft surface materials can have more than one possible value in certain, frequently-occurring, space environments; the possibility that this might occur had been earlier predicted by Whipple (1965). Attempts to gain further understanding of the conditions in which this might occur led to the realization that this was one of several closely-related phenomena which could all be explained in terms of a newly-defined property of spacecraft surface materials, the threshold material temperature for high-voltage charging (Sec. 3). We present herein a table of these threshold temperatures, calculated for a variety of spacecraft surface materials. A second phase of our effort was the development of a more elaborate, two-dimensional spacecraft charging simulation program called CYLVIA, which treats the regions around circular spacecraft cross-sections (Sec. 4). We have also begun development of another two-dimensional simulation program, called XYCIC (Sec. 5), which treats a wider class of two-dimensional geometries than does CYLVIA. The effort to develop CYLVIA, together with efforts by other workers (Sec. 4.6), led gradually to an understanding of the importance of the barrier effect, an example of which is presented in Sec. 4.6.

A related phase of our work has been an effort to develop efficient numerical techniques, and analytical replacements for some numerical procedures, which will be of general use not only in our own simulation programs but also in other spacecraft-charging simulations. To this end, we have developed an analytic expression for the electric current produced by photoelectron migration on a surface with spatially-varying illumination in an electric field (Sec. 6), and a perturbation technique for calculating current

density and space-charge density carried by collisionless charged-particle orbits (Sec. 7).

Listings of computer programs developed as part of this work appear in Appendices A-E.

2. LOCHG: A LOCAL-CHARGING CALCULATION

2.1 INTRODUCTION

In order for high-voltage differential charging of a spacecraft to occur, some of its surfaces must charge to large (usually negative) potentials (voltages) relative to space. The amount of such "absolute" charging, for the surface at the largest potential, is generally simpler to estimate than are the differential potentials between this surface and others. On the sunlit side of a spacecraft, photoelectron emission tends to compensate for incident electron fluxes. Sunlit-side surface potentials therefore are generally less negative than shaded-side potentials, and may be slightly positive if photoemission flux $>$ ambient random electron flux. Therefore, an approximate upper bound on differential charging magnitudes can be obtained by simply calculating floating potentials of electrically-isolated shaded surfaces, relative to space potential. In the present work, we have attempted to obtain upper bounds on these floating potentials, which in cases of interest are usually highly negative, because these bounds constitute "worst cases" for design purposes, and also because unlike more exact calculations, they can be obtained from simple current-balance calculations. Furthermore, it is sufficient to consider local current balance only, because this corresponds to an electrically-isolated surface element, which is also a "worst case" for differential charging. To calculate these bounds, we have constructed a computer program called LOCHG (LOCAL CHARGING), which extends a previous calculation by Knott [1972], of the floating potential of a spherically-symmetric geostationary-altitude satellite in eclipse. A listing of LOCHG appears in Appendix A. To investigate geometrical effects, we have replaced Knott's use of the Mott-Smith and Langmuir [1926] orbit-limited current expression for collection of Maxwellian ions by a unipotential sphere, by the corresponding expression for an infinite cylinder;

both expressions have been shown [Laframboise and Parker, 1973] to be upper bounds for collisionless ion collection as a function of local surface potential, for three- and two-dimensional collectors, respectively, regardless of collector shape, sheath potential, or potential of other parts of the collector. This replacement causes a large decrease in ion collection and a correspondingly large increase in negative shaded-side floating potentials (Sec. 2.3). Another important ion-current restriction may be caused by "effective-potential barrier" or "angular-momentum selection" effects [Bernstein and Rabinowitz, 1959; Laframboise, 1966; Laframboise and Parker, 1973], in which the presence of less-negative sunlit-side potentials produces dipole and higher moments in the sheath potential [Fahleson, 1973], causing steepening and contraction of the potential well surrounding the shaded side (Fig. 2.1). A similar steepening effect will also occur if an isolated shaded surface element is surrounded by adjacent shaded surfaces which for any reason have less-negative potentials (Fig. 2.2). The most extreme possibility would be a potential profile which was equal to space potential almost to the spacecraft surface, then fell discontinuously to surface potential. This limit would correspond to a "planar sheath" situation in which the ion collection on any shaded convex surface would be given by just the ion random flux. This amounts to a further ion-current restriction which produces even larger increases in negative shaded-side floating potentials (Sec. 2.3). This situation corresponds to a velocity-space cutoff boundary for incident ions which is "one-dimensional"; the cutoff boundaries corresponding to spherical and infinite cylindrical collectors are, respectively, "three-dimensional" and "two-dimensional" (Sec. 2.2) [Laframboise and Parker, 1973].

We also show (Sec. 2.3) that if shaded cavities containing isolated surfaces exist on a spacecraft, negative potentials on such surfaces may surpass even these predictions. In some cases, more than one possible floating potential results from the calculation. This has several implications (Sec. 2.3), including the possibility

(a) of "bifurcation phenomena" in which adjacent isolated surfaces of the same material may arrive at different floating potentials as a result of differences in their charging histories (b) that large and relatively sudden changes in surface potentials may result from gradual changes in ambient velocity distributions (c) that such changes may also result from relatively gradual changes in beam emission currents in a beam experiment. In Sec. 2.4 we calculate effects of ion drift motion on floating potentials.

We have also modified Knott's calculation in another way, by including currents due to electron backscattering (Sec. 2.2). These currents will tend to decrease net electron collection, thereby making floating potentials less negative than otherwise (Sec. 2.3). A process not included by either Knott or ourselves is secondary electron emission due to ion impacts; this will also tend to make floating potentials less negative. Ion-produced secondaries have been included in a calculation by DeForest [1972] of the floating potential of a shaded aluminum surface. However, no direct comparison is possible between his result and ours (Sec. 2.3) because we have used different ambient velocity distributions than his.

2.2 THEORY

The ambient electron energy distributions used in the present work are a model quiet-time spectrum (Knott [1972], Figure 1) and a model disturbed spectrum (Knott [1972], Figure 2b) based on measurements by Shield and Frank [1970] and DeForest and McIlwain [1971], respectively. Both of these distributions, and also the ambient ion distribution, are assumed isotropic. The disturbed spectrum was chosen from the three used by Knott because it has a higher average electron energy (~ 4 keV) than the others. In using it, we have changed it as follows: in the energy ranges $0.5 \text{ keV} \leq E \leq 10 \text{ keV}$ and $10 \text{ keV} \leq E \leq 40 \text{ keV}$, we have replaced Knott's differential energy spectrum by $\sqrt{2} \times 10^8 E^{-1/2}$ and $\sqrt{2} \times 10^9 E^{-3/2}$ electrons/cm² sec steradian keV, respectively, where E is

energy. These relations are simpler than those indicated by Knott, and they also bring the model spectrum into closer agreement with the data on which it is based. We therefore believe that they may have been the ones actually used by Knott, and that the corresponding parts of Figure 2b in his paper may be incorrectly plotted. For any spacecraft surface having a negative potential $\phi_s < 0$, or for a three-dimensional (e.g. spherical) surface having $\phi_s > 0$, the orbit-limited flux (particle current density) J_e of ambient electrons is given by [Laframboise and Parker, 1973]:

$$\begin{aligned}
 J_e &= \int f v_n d^3 \vec{v} \\
 &= \int_{E=\max(0, -e\phi_s)}^{E=\infty} \int_{\theta=0}^{\theta=\pi/2} \int_{\psi=0}^{\psi=2\pi} f(E) (v \cos \theta) (v^2 \sin \theta dv d\theta d\psi) \\
 &= \int_{\max(0, -e\phi_s)}^{\infty} (1 + e\phi_s/E) (dJ_{eo}/dE) dE \quad (2.1)
 \end{aligned}$$

where e is magnitude of unit electronic charge, ϕ_s is local surface potential, dJ_{eo}/dE is the ambient energy-differential flux incident on one side of an arbitrarily oriented surface element, v_n is the inward velocity component normal to the same surface element, (v, θ, ψ) are spherical coordinates in velocity space with v_n as polar axis, and $E = \frac{1}{2} m_e v^2 - e\phi$. dJ_{eo}/dE is π times the energy-differential flux per steradian used by Knott [1972], and is given in terms of the ambient electron velocity distribution $f = d^3 N_{\infty} / d^3 \vec{v}$ by the relation $dJ_{eo}/dE = 2\pi f E / m_e^2$, where m_e is electron mass and N_{∞} is ambient ion or electron number density. Since f is isotropic, $f \equiv f(E)$. The factor $(1 + e\phi_s/E)$ in (2.1), which appears to have been neglected by Knott, leads to a divergent integration in (2.1) if $\phi_s > 0$, unless $dJ_{eo}/dE \rightarrow 0$ as $E \rightarrow 0$, i.e. $f(E)$ remains finite as $E \rightarrow 0$. This implies that the differential fluxes in Knott's Figures 1-3 must approach zero linearly with E at E values smaller than those shown in these Figures. In the present work we have introduced a linear rise in dJ_{eo}/dE from 0 to 1 eV. We have also introduced a sharp upper cutoff at 50 keV in the quiet-time spectrum, also in order to avoid a divergent integration when calculating average energy for use in backscattering calculations (see below). The resulting values of N_{∞} are 5.43 cm^{-3} and 5.39 cm^{-3} for the quiet-time

and disturbed spectra, respectively. These values are consistent with those quoted by Knott [1972] for the corresponding spectra. The resulting values of the average ambient electron energy $\bar{E}$ are 0.176 keV and 4.17 keV, respectively. The incorporation of these changes has a relatively minor influence on Knott's results [Prokopenko and Laframboise, 1977, Table 1].

In order to obtain the orbit-limited electron flux expression for an arbitrary cylindrical collector, the lower integration limit in (2.1) must be replaced by the two-dimensional velocity-space cutoff boundary $E_1 = \max(0, -e\phi_s)$, where E_1 is the total energy of transverse motion $\frac{1}{2}m_e(v_x^2 + v_y^2) - e\phi$, and we have chosen a z coordinate perpendicular to the cylinder cross-section. If $\phi_s > 0$, this complicates the integration in (2.1), which may then be done in either of two ways. The first [Laframboise and Parker, 1973, Eq. (6)] is to convert (2.1) into an integration using cylindrical coordinates in velocity space. A more convenient method [Mott-Smith and Langmuir, 1926; Polychronopoulos, 1973] is as follows. We choose rectangular coordinates (v_n, v_t, v_z) in velocity space, such that v_n is the velocity component in the inward normal direction at the collector surface. Then v_t and v_z become tangential coordinates, with v_t in the plane of the cylinder cross-section. We then transform to spherical coordinates (v, θ, ψ) with v_z as polar axis. Then: $v_z = v \cos \theta$, $v_n = v \sin \theta \cos \psi$, and $v_t = v \sin \theta \sin \psi$. The condition $E_1 \geq 0$ is equivalent to $\sin \theta \geq [e\phi_s / (E + e\phi_s)]^{1/2}$. For $\phi_s > 0$, Eq. (2.1) is then replaced by:

$$\begin{aligned}
 J_e &= \int f v_n d^3 \vec{v} \\
 &= 2 \int_{E=0}^{\infty} \int_{\psi=-\pi/2}^{\pi/2} \int_{\theta=\text{Arc sin}[e\phi_s/(E+e\phi_s)]^{1/2}}^{\pi/2} f(E) (v \sin \theta \cos \psi) (v^2 \sin \theta dv d\theta d\psi) \\
 &= \int_0^{\infty} \frac{2}{\pi} \left[\text{Arc sin} \left(\frac{E}{E+e\phi_s} \right)^{1/2} + \frac{(Ee\phi_s)^{1/2}}{E+e\phi_s} \right] \left(1 + \frac{e\phi_s}{E} \right) \frac{dJ_{e0}}{dE} dE \quad (2.2)
 \end{aligned}$$

In comparison with Eq. (2.1), we see that the integrand in (2.2) contains an extra, energy-dependent weighting factor, which arises from integration of v_n over the fractional solid angle over which ambient electrons can reach the collector at each energy.

A similar procedure is advantageous in obtaining the one-dimensional (Sec. 2.1) orbit-limited flux expression. In this case, the lower limit in (2.1) must be replaced by: $E_n = \max(0, -e\phi_s)$, where $E_n = \frac{1}{2} m_e v_n^2 - e\phi$. This time we transform (v_n, v_t, v_z) to spherical coordinates (v, θ, ψ) with v_n as polar axis. The condition $E_n \geq 0$ is equivalent to $\cos \theta \geq [e\phi_s / (E + e\phi_s)]^{1/2}$. For $\phi_s > 0$, Eq. (2.1) is now replaced by:

$$J_e = \int_{E=0}^{E=\infty} \int_{\theta=\text{Arc cos}[e\phi_s/(E+e\phi_s)]^{1/2}}^{\theta=\text{Arc cos}[e\phi_s/(E+e\phi_s)]^{1/2}} f(E) (v \cos \theta) (2\pi v^2 \sin \theta dv d\theta) \\ = \int_0^{\infty} \frac{dJ_{e0}}{dE} dE \quad (2.3)$$

independently of collector potential, as expected.

The corresponding expressions for ion flux J_i are simpler because the ions are assumed to be Maxwellian. Corresponding to the three-, two-, and one-dimensional velocity-space cutoffs described above, we obtain, respectively [Mott-Smith and Langmuir, 1926; Laframboise and Parker, 1973], for ion-attracting surface potentials $\chi_{is} > 0$:

$$J_i = J_{i0} \begin{cases} (1 + \chi_{is}) & (2.4) \\ [2(\chi_{is}/\pi)^{1/2} + \exp(\chi_{is}) \text{erfc}(\chi_{is}^{1/2})] & (2.5) \\ (1) & (2.6) \end{cases}$$

where $\chi_{is} = -e\phi_s/kT_i$, k is Boltzmann's constant, T_i is ion temperature and J_{i0} is the ion random flux $N_{\infty}(kT_i/2\pi m_i)^{1/2}$. For ion-retarding surface potentials $\chi_{is} < 0$, we obtain:

$$J_i = J_{i0} \exp(\chi_{is}). \quad (2.7)$$

We have assumed, following Knott [1972], that $T_i = 1$ keV, and that the random ion-to-electron flux ratio $J_{io}/J_{eo} = 0.025$. Making these two assumptions simultaneously causes ambient charge neutrality to be violated in general. Large apparent violations of charge neutrality are frequently observed in measurements made by particle energy analyzers. Such discrepancies are believed to result from failure to measure particles outside the energy ranges of these analyzers, especially at energies of a few volts or less [DeForest and McIlwain, 1971]. Our calculations therefore neglect any current contributions which may be made by such particles.

For the secondary electron fractional yield $\delta(E)$, we have used, following Knott [1972], the relation of Sternglass [1954a]:

$$\delta(E) = 7.4 \delta_{\max} (E/E_{\max}) \exp \left[-2(E/E_{\max})^{\frac{1}{2}} \right]. \quad (2.8)$$

We have used values of $\delta_{\max}$ and $E_{\max}$ from Gibbons [1966], Hachenberg and Brauer [1959], and Willis and Skinner [1973].

The process of electron backscattering, which was not included in Knott's calculations, becomes important at incident electron kinetic energies larger than those for which secondary emission is dominant. For the backscattered electron fractional yield η , we have fitted the results of Sternglass [1954b] and Palluel [1947] with a relation of the form:

$$\eta(E) = A - B \exp(-CE) \quad (2.9)$$

where the coefficients A , B , and C are functions of the atomic number Z of the surface material. We have evaluated A , B and C for each surface material considered (Sec. 2.3) by substituting Sternglass' and Palluel's values of η at 0, 1 and 16 keV, into Eq. (2.9). For compound surface materials, we have used an atomic number given by a weighted average of those of each constituent. There exist more recent measurements of η [Thomas and Pattinson, 1970; Darlington and Cosslett, 1972] which give generally larger values than those of Sternglass or Palluel, especially for electrons having near-tangential incidence.

Increased values of δ have also been measured for electrons having non-normal incidence [Allen, 1939; Dekker, 1958]. In a separate calculation (Sec. 3), we have included angle-of-incidence effects on η and δ , but here we have ignored these. We have therefore underestimated both δ and η , and our predicted floating potentials in Sec. 2.3 will therefore be somewhat more negative than more realistic corresponding values.

When $\phi_s > 0$, not all secondary and backscattered electrons will escape. To calculate flux escaping, we assume [Sternglass, 1954b; Chung and Everhart, 1974] that both secondary and backscattered electrons are emitted with Maxwellian velocity distributions having thermal energies $E_{\text{sec}} = kT_{\text{sec}} = 3 \text{ eV}$, and $E_{\text{scat}} = kT_{\text{scat}} = (0.45 + 2 \times 10^{-3}Z)(E + e\phi_s) \text{ eV}$, respectively, regardless of the form of the incident velocity distribution. Here, $(E + e\phi_s)$ is the average incident electron kinetic energy. We further assume that escape of emitted electrons is orbit-limited, i.e. that no barriers of effective potential [Bernstein and Rabinowitz, 1959; Laframboise, 1966; Laframboise and Parker, 1973] or negative barriers of electric potential exist on the shaded side. {Fahleson [1973] has pointed out that such a barrier is likely to exist on the sunlit side independently of any space-charge effects, if substantial shaded-sunlit differences exist in ϕ_s . Such a barrier would cause most electrons emitted from the sunlit side to be recollected, driving sunlit-side potential just negative enough to almost destroy the barrier [Sec. 4.5]; [Katz et al, 1979, Figs. 17-21]}). The expressions for the escaping secondary and backscattered fluxes J_{sec} and J_{scat} therefore are:

$$J_{\text{sec}} = \int_{-e\phi_s}^{\infty} \delta(E + e\phi_s) (1 + e\phi_s/E) (dJ_{e0}/dE) dE \quad (2.10)$$

$$J_{\text{scat}} = \int_{-e\phi_s}^{\infty} \eta(E + e\phi_s) (1 + e\phi_s/E) (dJ_{e0}/dE) dE \quad (2.11)$$

if $\phi_s < 0$. If $\phi_s > 0$, the three-, two-, and one-dimensional cases must be considered separately. We define $\chi_{\text{sec}} = e\phi_s/kT_{\text{sec}}$ and $\chi_{\text{scat}} = e\phi_s/kT_{\text{scat}}$. For brevity, we consider only the secondary fluxes; the corresponding results for backscattered fluxes may be obtained by replacing δ by η and χ_{sec} by χ_{scat} throughout. If J_s is the emitted flux of secondaries,

then their velocity distribution at the surface is $f_s = (J_s/2\pi)(m_e/kT_{sec})^{3/2} \exp(-\frac{1}{2}m_e v^2/kT_{sec})$. In the three-dimensional case, the cutoff condition for their escape is $E = \frac{1}{2}m_e v^2 - e\phi_s > 0$. We redefine v_n as velocity component in the outward normal direction, and we use spherical coordinates as defined in connection with (2.3). We obtain, for the escaping secondary flux:

$$\begin{aligned} J_{sec} &= \int f_s v_n d^3\vec{v} \\ &= \frac{J_s}{2\pi} \left(\frac{m_e}{kT_{sec}} \right)^{3/2} \int_{E=0}^{\infty} \int_{\theta=0}^{\pi/2} \exp(-\frac{1}{2}m_e v^2/kT_{sec}) (v \cos \theta) (2\pi v^2 \sin \theta dv d\theta) \\ &= (1 + \chi_{sec}) \exp(-\chi_{sec}) \int_0^{\infty} \delta(E + e\phi_s) (1 + e\phi_s/E) (dJ_{eo}/dE) dE. \quad (2.12) \end{aligned}$$

The factor $(1 + \chi_{sec})$ is noteworthy, because it is specific to three-dimensional, as opposed to planar, sheath geometry. In the two-dimensional case, the cutoff condition for escape is $\frac{1}{2}m_e(v_n^2 + v_t^2) - e\phi_s > 0$, and the integral for J_s contains the extra weighting factor which appears in Eq. (2.2). It is convenient to use spherical coordinates as defined in connection with (2.2). We obtain:

$$\begin{aligned} J_{sec} &= \left[2(\chi_{sec}/\pi)^{1/2} + \exp(\chi_{sec}) \operatorname{erfc}(\chi_{sec}^{1/2}) \right] \exp(-\chi_{sec}) \\ &\quad \times \int_0^{\infty} \frac{2}{\pi} \left[\operatorname{Arc sin} \left(\frac{E}{E + e\phi_s} \right)^{1/2} + \frac{(Ee\phi_s)^{1/2}}{E + e\phi_s} \right] \left(1 + \frac{e\phi_s}{E} \right) \delta(E + e\phi_s) \frac{dJ_{eo}}{dE} dE. \quad (2.13) \end{aligned}$$

In the one-dimensional case, the escape condition is $\frac{1}{2}m_e v_n^2 - e\phi_s > 0$, and we again use spherical coordinates as defined in connection with (2.3). We obtain:

$$J_{sec} = \exp(-\chi_{sec}) \int_0^{\infty} \delta(E + e\phi_s) (dJ_{eo}/dE) dE. \quad (2.14)$$

The floating potential(s) of an isolated shaded surface element is (are) now given by the zero(s) of the function:

$$J_{net} = J_i - J_e + J_{sec} + J_{scat}. \quad (2.15)$$

2.3 RESULTS AND DISCUSSION: SHADED CAVITIES AND MULTIPLE FLOATING POTENTIALS

Table 1 shows floating potential values obtained using the program LOCHG, which performs numerical solution of the equation $J_{net} = 0$, where J_{net} is given by Eq. (2.15). An important feature of Table 1 is the very

large floating potentials which are evident in disturbed conditions in the presence of the two- and one-dimensional velocity-space cutoffs. The dramatic differences among these results are evidence that spacecraft geometry and sheath potential shape are important influences in determining floating potentials. As floating potential becomes more negative, it also becomes more sensitive to the presence of small amounts of high-energy electrons. This means that if a spacecraft should encounter conditions that are "more disturbed" than those given by Knott's spectrum 2b, the values in Table 1 most likely to be significantly exceeded are those for the one-dimensional cutoff. This implies that for design purposes in which worst-case information is desired, it is important to do calculations with the "most disturbed" electron spectra available. In obtaining these results, we have made no attempt to calculate the charging times involved.

Also evident in Table 1 are situations in which the current-voltage characteristic of the surface has three roots. For these to occur, it is necessary that $\delta_{\max}$ be substantially greater than one, and that the ambient electron spectrum be at least slightly non-Maxwellian (Sec. 3). The latter requirement arises because if the incident electrons are Maxwellian and ion-produced secondaries are ignored, the ratio of total secondary emission current to incident electron current will then be independent of ϕ_s for $\phi_s < 0$, and the total secondary emission will therefore be a monotonic function of ϕ_s for $\phi_s < 0$. (An exception to this, in which a triple-root situation occurs with Maxwellian ambient electrons, has been found by Meyer-Vernet (1982), but this exception applies only when $T_e < T_{\text{sec}}$, a condition which is not applicable here; see also Sec. 3). The centre root never represents a possible floating potential, because it is "unstable" in the sense that a small change in surface potential would cause a net current collection of a sign which would drive the surface potential away from this root to one on either side. Various consequences of such a situation are discussed later in this Section. A similar phenomenon in electronic image storage devices has been discussed by Kazan and Knoll [1968, pp. 17-19].

In comparison with the results of Knott [1972], Table 1 includes the further addition of backscattered electron flux (Sec. 2.2). In most cases, the effect is a moderate reduction of negative floating potentials. In some cases, the reduction is large, as in the case of a gold surface

exposed to the "quiet" spectrum. In several other cases, all associated with the quiet spectrum, backscattering changes a multiple-root to a single-root situation [Prokopenko and Laframboise, 1977]. As indicated in Sec. 2.2, we have probably underestimated secondary and backscattered fluxes caused by electron impacts, and we have also (Sec. 2.1) ignored secondary electron emission caused by ion impacts. Both of these effects would tend to further reduce negative potentials. For ion-produced secondaries, fractional yields at energies from 5 to 50 keV are generally of order unity to several times unity for metallic surfaces [Cousinie et al, 1959; Ray and Barnett, 1971; Baragiola et al, 1979] so substantial reductions due to this cause can be expected whenever ion collection plays an important role in total current balance. In comparison with the results of Table 1, potentials reaching -19 kV on the ATS 6 spacecraft in eclipse have been observed (E.C. Whipple, Jr., private communication).

Figures 2.3 - 2.7 show current-voltage characteristics for some of the situations in Table 1. Figure 2.3 shows a "typical" single-root situation in which secondary and backscatter contributions do not change the general shape of the net current curve. Figure 2.4 shows the above-mentioned case of gold exposed to the quiet spectrum, in which the backscatter contribution changes a large predicted negative floating potential to a much smaller value. Figure 2.5 shows a triple-root situation. Figure 2.6 shows the disappearance of a triple-root situation because of backscatter. In Fig. 2.7, secondary electron current is sufficient by itself to prohibit a negative floating potential.

We now examine situations which may arise in the case of spacecraft which have shaded cavities containing electrically-isolated interior surfaces. Figure 2.8 shows an idealization of such a spacecraft. We wish to show that the effects of surface concavity may cause ion collection to be reduced more than net electron collection at an interior point such as B, relative to an exterior point A; such a situation would result in floating potentials more negative than those of Table 1. To demonstrate this possibility, we first note that in the presence of an isotropic ambient plasma, incident fluxes to any surface depend only [Laframboise and Parker, 1973] on the locations, in velocity space, of

the cutoff boundaries inside of which the orbits of ambient particles can connect "from infinity" to the surface. Figure 2.8 shows a set of the associated "cutoff orbits". We see from Fig. 2.8 that the included angle between cutoff orbits has been reduced in going from A to B for ions but not for electrons, for which orbits tangential to the surface are shown as reaching both A and B and the range of allowable directions remains 180° . Accordingly, the incident ion current contribution for the energy shown will also be reduced, but the electron contribution will not. This picture is invalid for higher-energy electrons at B, whose orbits are straighter and will have a greater tendency to connect back to the interior surfaces of the cavity. Even though such higher-energy orbits will generally have lower populations than lower-energy orbits, it is not clear whether the relative current reduction at B will be greater for ions or for electrons. Therefore, this argument demonstrates only the possibility that the bounds in Table 1 will be exceeded. On the other hand, this possibility will be enhanced by the effects of secondary and backscattered electrons, which will tend to be recollected inside any cavity, rather than escaping into space, thus tending to increase net electron collection and driving floating potentials more negative. This effect will be strongest for backscattered electrons because their higher emission energies will cause them to have straighter orbits. The detailed numerical simulation required to draw firm conclusions remains to be done. An additional feature of cavities is their generally higher outgassing pressures, which will increase any tendencies for arcing to occur. More negative floating potentials may also result if the ambient electron distribution contains beam-like constituents [DeForest, 1977] which happen to be directed into a cavity. Severe arcing problems are known to have occurred between electronic components mounted inside a cavity at one end of the DSCS spacecraft.

Finally, we discuss some further implications of the multiple-root results shown in Table 1 and Fig. 2.5. We first consider a situation involving a shaded, isolated spacecraft surface whose external conditions change with time, as in the case of time-varying ambient distributions,

in such a way as to produce an evolution from a multiple-root to a single-root situation. If a spacecraft surface were floating at a potential corresponding to a root which disappeared, a large and relatively sudden change in surface potential would occur, even if external changes were gradual. In many situations, rapid redistribution of potentials on other parts of the spacecraft would result. In order to examine this situation in more detail, we illustrate it schematically in Fig. 2.9.

In Fig. 2.9a, the current-voltage curve at an earlier time t_1 has three roots. The two roots furthest apart, ϕ_{1a} and ϕ_{1b} , correspond to stable floating surface potentials; these are typically from one to ten kilovolts apart. As a result of a changing environment, this curve evolves continuously into the one shown for the later time t_2 , which has only the single root ϕ_2 . If the surface happened to be floating at the voltage ϕ_{1a} at time t_1 , then a sudden positive change in surface voltage, toward the voltage ϕ_2 , would occur as soon as the two left-hand roots disappeared.

In Fig. 2.9b, a spacecraft surface floating at the more positive root (at ϕ_{1b}) would undergo a sudden negative change in voltage, toward ϕ_2 , as soon as the two right-hand roots disappeared. Sudden voltage changes have been observed both on the SCATHA (P78-2) satellite and in numerical simulations (Sec. 3.1; Schnuelle et al, 1981; Stannard et al, 1982).

Similar sudden changes could occur on a spacecraft which was emitting a changing ion or electron gun current, if an increase or decrease in gun current were to provide enough net current to a surface to cause it to change from one stable floating potential to another. Again, such a change would be relatively sudden even if beam current changes were gradual.

A different effect could arise if the situation evolved in reverse fashion, so that t_2 were now the earlier time. Consider a spacecraft whose rotation carries a number of independently-floating surface panels from sunlight into shade, one after another. Suppose the situation evolves as in Fig. 2.9b. A surface already in the shade when the environment changed would go from voltage ϕ_2 to ϕ_{1a} . However, a surface which was

still in the sun, and whose photoemission current held its voltage close to ϕ_{1b} , would go to ϕ_{1b} when it entered the shade. As a result, two adjacent surfaces made of the same material could easily come to quite different voltages in the same environment, with a resulting danger of arcing between them.

In Sec. 3, we examine in detail the conditions in which multiple roots can occur.

2.4 PREDICTION OF ION DRIFT EFFECTS ON SPACECRAFT FLOATING POTENTIALS

2.4.1 INTRODUCTION

The plasma environment of high-altitude spacecraft has been observed to involve ion velocity anisotropies which sometimes become comparable to ion mean thermal speeds. These anisotropies are varied in nature, but a qualitative estimate of their effects on spacecraft charging may be obtained by considering the effects of a relatively simple anisotropy, namely the addition of a drift to a Maxwellian velocity distribution. Such drifts may cause an electrically-isolated spacecraft surface to float at a substantially increased negative potential if it is simultaneously shaded and downstream relative to the drift direction. In this Section, we present a calculation of upper and lower bounds on such potentials for a spherical spacecraft, based on the fact that ion collection on the spacecraft at its downstream point is bounded above by the corresponding current which would be collected if the spacecraft were an equipotential (i.e. were more attractive for ions elsewhere on its surface than it is in reality) and bounded below by the corresponding result for a sphere at space potential. The results show that (1) the ion speed ratio at which drift effects become "important" (i.e. change the floating potential by at least 10%) can be as low as 0.1, and may be decreased if the ambient electrons are non-Maxwellian; (2) the effects of ion speed ratio increase with increasing ion-to-electron temperature ratio; (3) negative floating potentials for drifting Maxwellian ion velocity distributions with speed ratio unity are typically about twice as large as the corresponding potentials for nondrifting conditions. We now examine the effects of ion drift in detail.

If a spacecraft is exposed to ambient ions whose drift velocity U is comparable to or larger than their most probable thermal speed [ion speed ratio $S_i = U/(2kT_i/m_i)^{1/2} \gtrsim 1$, where k is Boltzmann's constant and m_i and T_i are ion mass and assumed ion temperature], a large decrease in ion flux J_i to downstream surfaces will occur. Unless such surfaces are able to expel surplus incident electron fluxes, e.g. by photoemission,

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their floating potentials will become substantially more negative as a result. If the ambient electron temperature T_e is simultaneously large, or more generally the ambient electron energy distribution has a significant high-energy component, then large absolute increases in negative floating potentials will occur, with correspondingly increased arcing hazards. Even if T_e is relatively small, such effects may influence surface potentials enough to disturb particle and field measurements. S_i values of order unity may be reached in the Earth's outer magnetosphere (Mauk 1975; DeForest 1977, Figs. 6 and 8); larger values are likely in the outer Jovian magnetosphere and magnetosheath (Goldstein and Divine 1977), and in the solar wind (Dessler 1967; Axford 1968; Manka 1973). In both outer magnetospheres, electron distributions having substantial high-energy components have been observed (DeForest and McIlwain 1971; Goldstein and Divine 1977).

A calculation of ion drift effects on the floating potential of the lunar surface has been done by Manka (1973), using a local-current-balance formulation. Parker (1978) has done exact numerical calculations of floating surface potentials for nonconductive finite cylindrical objects, including photoemission due to illumination of one end and ion drift parallel to the axis of symmetry.

In this Section we have done an approximate calculation of ion drift effects on the floating potential of a shaded, downstream, electrically-isolated surface element on a spherical spacecraft (Fig. 2.10), using a local-current-balance formulation which yields upper and lower bounds on such potentials. This formulation is an adaptation of that of Secs. 2.1 to 2.3. The basis of the calculation is as follows: if one compares, on one hand, a situation wherein the entire spacecraft is at the same potential as the surface element in question, with, on the other hand, a more realistic situation wherein the rest of the spacecraft is at a less negative potential (Fig. 2.11), then in the latter case, the potential well surrounding the surface element will be steeper and less spatially extended, and the ion collection will in general be

decreased. When $S_i \neq 0$, this argument is subject to qualifications not present in the nondrifting case, for which it is rigorously true in a wide range of conditions (Laframboise and Parker 1973; Laframboise and Godard 1974). In particular, one can envision hypothetical asymmetric sheath potentials which would cause a high-speed-ratio ambient ion distribution to be focused onto the downstream point. We exclude such cases in what follows.

The most extreme example of steepening would be a potential profile which was equal to space potential almost to the spacecraft surface, then fell discontinuously to surface potential. In this limit, the surface element in question would collect just the downstream space-potential current corresponding to the given ion speed ratio. The downstream-point current-density values corresponding to a unipotential sphere at, respectively, the potential of the surface element and space potential may therefore be regarded as upper and lower bounds on the actual current collection at that potential, the upper bound being subject to the above-mentioned qualifications. The resulting values of local floating surface potential may correspondingly be regarded as upper and lower bounds on more realistic values of this quantity. The above-mentioned upper and lower bounds on current correspond, respectively, to the "three-dimensional" and "one-dimensional" velocity-space cutoffs considered in Secs. 2.1 to 2.3 for nondrifting situations.

2.4.2 THEORY OF LOCAL ION COLLECTION ON A UNIPOTENTIAL SPHERE

We assume a collisionless plasma with a drifting Maxwellian ion velocity distribution and negligible magnetic field, containing a fully charge-absorbing, unipotential, spherical electrode. We assume that Debye length $\lambda_D \gg$ electrode radius r_s . In the resulting spherically-symmetric Laplace potential $\phi(r) = \phi_s r_s/r$, the nondimensional ion current density at the electrode surface is (Godard 1975, p. 31)

$$j_i = \int_{\max(0, \chi_s)}^{\infty} \int_0^{3-\chi_s} \exp(-\beta - 2S_i \beta^2 \cos \mu \cos \theta - S_i^2) I_0(2S_i \beta^2 \sin \mu \sin \theta) d\Omega d\beta \quad (2.16)$$

where $\chi_s = q\phi_s/kT$, $\beta = E/kT$, $\Omega = L^2/(2mr_s^2kT)$, $j = J/[N_\infty q(kT/2\pi m)^{1/2}]$,

I_0 is the modified Bessel function of zero order, N_∞ is number density far from the electrode, μ is angular surface position coordinate measured from the upstream direction, θ is change in direction of the radius vector of a particle as it moves from infinity to radial distance r_s , and θ is related to particle energy E , angular momentum L , charge q and the potential profile $\phi(r)$ by the following expression (Goldstein 1950, Ch. 3):

$$\theta = \int_{r_s}^{\infty} Ldr / \{r^2 [2mE - 2mq\phi(r) - L^2/r^2]\}^{1/2} \quad (2.17)$$

We have computed j_i by integrating Eq. (2.16) numerically. For the given Laplace potential, Eq. (2.17) can be integrated analytically. We obtain:

$$\theta = \sin^{-1}[(2\Omega + \chi_s)/(\chi_s^2 + 4\Omega)^{1/2}] - \sin^{-1}[\chi_s/(\chi_s^2 + 4\Omega)^{1/2}] \quad (2.18)$$

For space potential ($\chi_s = 0$), Eq. (2.16) can be integrated analytically. The result is (Tsien 1946)

$$j_i = \pi^{1/2} S_i \cos \mu [1 + \operatorname{erf}(S_i \cos \mu)] + \exp(-S_i^2 \cos^2 \mu) \quad (2.19)$$

Figure 2.12 shows results obtained for the ion current density $j_{i\pi}$ at the downstream point $\mu = \pi$, as a function of S_i , with χ_s as a parameter, where $\chi_s = e\phi_s/kT_i \leq 0$ and $e \equiv q_i$. As expected, $j_{i\pi}$ decreases with increasing S_i and increases with increasing $|\chi_s|$. In Figure 2.13 the same results are graphed logarithmically as functions of χ_s . Figure 2.13 shows that these results may be approximated with an error $\lesssim 5\%$ by power-law relations of the form

$$j_{i\pi}(\chi_s) = j_{i\pi}(\chi_s = 0) + A_\pi |\chi_s|^{\alpha_\pi}; \quad \chi_s \leq 0 \quad (2.20)$$

The resulting S_i dependence of the coefficients A_π , α_π and $B_\pi \equiv j_{i\pi}(\chi_s = 0)$ is shown in Fig. 2.14.

2.4.3 RESULTS AND DISCUSSION

Upper and lower bounds on negative downstream-point floating potentials for a shaded, isolated surface element, obtained by numerical solution of the equation $J_i + J_e = 0$, are shown in Fig. 2.15 for various ion-to-electron temperature ratios $\epsilon = T_i/T_e$. Here we have assumed that ambient electrons are Maxwellian, and that J_i is given alternatively by Eq. (2.20) with Fig. 2.14 and by Eq. (2.19), yielding upper and lower bounds on ion current, corresponding respectively to "three-dimensional" and "one-dimensional" ion velocity-space cutoffs (Sec. 2.4.1). We have also assumed that secondary, backscattered, and photoemitted electron currents are zero. The lower-bound results are subject to the qualifications noted in Sec. 2.4.1. The dashed lines in Fig. 2.15 represent floating potentials for the nondrifting case $S_i = 0$. At ion speed ratios larger than those shown, the situation becomes complicated by electron speed ratio effects, especially at larger values of ϵ . In Fig. 2.15 we see that at larger values of ϵ , effects of S_i become important at smaller S_i values.

In Fig. 2.16, upper and lower bounds are shown which are similar to those of Fig. 2.15, except that instead of Maxwellian electron velocity distributions, we have used the "quiet" and "disturbed" electron distributions measured by Shield and Frank (1970) and DeForest and McIlwain (1971) respectively in the Earth's outer magnetosphere, and approximated by Knott (1972), as described in Sec. 2.2; see also Prokopenko and Laframboise (1977) and Laframboise and Prokopenko (1978). The ion temperatures used are 111.6 eV and 2.43 keV, respectively. These values were obtained by integrating the electron velocity distributions to find $N_{e\infty}$, equating $N_{i\infty}$ to the result, then assuming that the ions were Maxwellian and that the ratio of ion to electron random fluxes was 0.025. This procedure differs from that used by Knott (1972) and in Secs. 2.1 - 2.3 in which an ion-to-electron random flux ratio of 0.025 and an ion temperature of 1 keV were assumed simultaneously, thereby violating ambient charge neutrality in general. The corresponding electron mean energies are 270 eV and 8.78 keV. The method used for calculating electron currents is described in Sec. 2.2. We see that S_i effects become important at smaller S_i values in "quiet" magnetospheric conditions. The ratio of ion to electron mean energies implied by the

above data is also larger in "quiet" conditions, corresponding to the dependence of S_i effects on ϵ noted in Fig. 2.15. The "quiet" and "disturbed" distributions also differ substantially in shape (Knott, 1972, Figs. 1 and 2b). The onset of "significant" drift effects (i.e. floating potential changes $\gtrsim 10\%$) is seen to occur at S_i values as low as 0.1, depending on conditions. It occurs at lower S_i values in the presence of the "quiet" distribution than in any of the other cases shown in Figs. 2.15 and 2.16. In Figs. 2.15 and 2.16, negative floating potentials for $S_i = 1$ are in most cases about twice as large as the corresponding potentials for nondrifting situations.

3. MULTIPLE FLOATING POTENTIALS, AND THE "THRESHOLD MATERIAL TEMPERATURE FOR HIGH-VOLTAGE CHARGING"

3.1 INTRODUCTION

The high-voltage charging behaviour of spacecraft surfaces, especially in outer-magnetospheric plasma conditions, displays a variety of unexpectedly complex features.

These features are most evident in the absence of photoemission (as on shaded surfaces of a spacecraft). One of them is the existence of multiple roots (zeros) in the current-voltage characteristic of various spacecraft materials exposed to certain kinds of ambient plasma environments. An example of such a current-voltage characteristic was shown in Fig. 2.5. In this illustration, only the right- and left-hand roots, which are located at +1.9 and -4100 volts, respectively, represent stable floating surface potentials, because the centre root is an unstable one, in the sense that any voltage excursion from the indicated value (-500V) would result in a net current of a sign which would cause the voltage excursion to increase, ultimately driving the voltage to the right- or left-hand roots.

The possibility of such triple-root situations was first proposed by Whipple (1965, pp. 4-7). Prokopenko and Laframboise (1977, 1980) calculated current-voltage characteristics of various surface materials in outer-magnetospheric (including geostationary-orbit) plasma environments, and found numerous examples in which triple-root characteristics were actually obtained. Sanders and Inouye (1979) did calculations to examine the ranges of conditions in which such characteristics would occur. Besse (1981) examined the mechanisms underlying them. Meyer-Vernet (1982) showed that they may also occur on dust grains in space, such as those in Saturn's rings. It is now generally recognized that in triple-root situations, the stable floating potential near space potential is the result primarily of a current balance between incident "primary" electrons and emitted (secondary and backscattered) electrons,

with incident ion current making only a minor contribution, while at the more negative stable potential, the current balance is primarily between incident ion and electron currents, even though in this case also, both of these may be substantially modified by secondary or backscattered electron emission.

Another feature of the high-voltage charging phenomenon is the occurrence of "sensitivity" effects in the numerical prediction of spacecraft potentials (Stannard et al, 1981), in which relatively small changes in assumed surface properties or ambient conditions can cause large changes in spacecraft floating potentials. Evidently, this phenomenon may frustrate attempts to make reliable predictions of spacecraft charging, and it is important to identify the parameter ranges in which such sensitivity effects occur.

This phenomenon is closely related to that of "threshold" effects, both predicted (Stannard et al, 1981), and observed (Gussenhoven and Mullen, 1982), in which no high-voltage charging occurs over a large range of environmental or surface conditions, but a small further change in conditions then results in a large change in surface potential from a small value (relative to space) to a value typically several kilovolts negative.

Another closely-related effect is that of sudden large changes in surface potential in response to relatively slow temporal changes in ambient plasma conditions (Sec. 2.3). This phenomenon was predicted by Prokopenko and Laframboise (1980) and Besse (1981), and subsequently observed both on the SCATHA (P78-2) satellite and in numerical simulations made using the NASA Charging Analyzer Program (NASCAP) (Schnuelle et al, 1981; Stannard et al, 1982).

In Secs. 3.2 and 3.3, we introduce the concept of threshold temperature as a property of a spacecraft surface material, and we show that all of the above-mentioned phenomena are unified and explained by this concept.

A separate phenomenon, which often controls the differential charging of other surfaces, including sunlit ones, relative to the most highly-charged surface, is the "barrier" effect; we discuss this in Sec. 4.5.

3.2 THE THRESHOLD-TEMPERATURE PROPERTY.

A typical secondary-electron yield curve is shown in Fig. 3.1(a). For most commonly-used spacecraft surface materials, there exists a region of this yield curve in which more than one secondary is produced on average per primary. This generally occurs for incident electron kinetic energies of a few hundred eV. In Fig. 3.1(b), energy-differential incident-electron flux (particle current density) curves are shown for Maxwellian electron velocity distributions at two representative values of electron temperature T_e . In the example shown, the peak of the lower-temperature curve is at almost the same energy as that of the secondary yield curve. In this situation, there is a large production of secondaries; in fact, the total secondary flux, which is given by an integral involving the product of these two functions [Eq. (2.10); Prokopenko and Laframboise (1977, 1980, Eq. 10)], will be greater than the incident primary flux if the maximum secondary yield $\delta_{\max}$ per primary is greater than about 1.16 (Besse, 1981, Fig. 2). In contrast, the peak of the higher-temperature curve does not coincide closely with that of the secondary-emission curve, and in this case, the total secondary flux will be less than the incident flux. Evidently, a critical value of T_e must exist, intermediate between the two values indicated, at which emitted flux would exactly balance incident flux (H.I. Cohen, 1982, private communication). (There will also be another such critical temperature, below the peak of the secondary yield curve, but this is not of importance here.)

Maxwellian ambient distributions also have the special property that if they are retarded by a repelling (negative) surface potential, the distribution of particle kinetic energies reaching the surface is independent of the value of this potential. Therefore, for a Maxwellian ambient distribution, the preceding conclusions have a special property: they are independent of spacecraft surface potential (Besse, 1981; H.I. Cohen, private communication, 1982) as long as this potential is negative (with respect to space). Therefore, if the ambient electrons were Maxwellian at the critical temperature, incoming and outgoing fluxes would balance each other for all negative values of surface potential, and the surface then "would not know at what potential to float", i.e. the surface potential would become indeterminate, except for the (relatively small) current contribution from ambient ions. It is therefore evident that very large (negative) increases in floating potential will result for very small increases in ambient electron temperature in the neighbourhood of this critical value, which is a property of the surface material only. We will therefore refer to this critical value as the threshold material temperature T^* for high-voltage charging. In terms of this property, the first four effects mentioned in Sec. 3.1 can be immediately explained, as follows.

(1) Triple-root current-voltage characteristics have a simple explanation if the ambient electron velocity distribution can be approximated by a double Maxwellian. Such an approximation, although empirically-based, is often a very good one (Garrett and DeForest, 1979 ; Garrett et al, 1981). In this case, a characteristic will have three roots if (i) the temperature T_1 of one Maxwellian is less than T^* , but the other one T_2 is greater than T^* , and (ii) the total emitted electron (secondary and backscattered) flux at space potential is greater than the incident flux.

This can be proven as follows. The roots of the current-voltage characteristic are given by the zeros of the function:

$$J_{\text{net}} = J_i - J_e + J_{\text{sec}} + J_{\text{scat}} \quad (3.1)$$

where J_i , J_e , J_{sec} and J_{scat} are particle current densities (fluxes) for incident (ambient) ions and electrons, secondary electrons and backscattered electrons, respectively. Except at relatively large negative surface potentials ϕ_s relative to space, J_i is relatively small, and will be neglected in what follows. For $\phi_s < 0$, we then have, in this approximation:

$$\begin{aligned}
 J_{\text{net}} &= (J_{\text{sec},1} + J_{\text{scat},1} - J_{e,1}) \exp(e\phi_s/kT_1) \\
 &\quad + (J_{\text{sec},2} + J_{\text{scat},2} - J_{e,2}) \exp(e\phi_s/kT_2) \\
 &\approx J_{\text{net},1} \exp(e\phi_s/kT_1) + J_{\text{net},2} \exp(e\phi_s/kT_2) \quad (3.2)
 \end{aligned}$$

where $e > 0$ is the elementary charge, k is Boltzmann's constant, and all double-subscripted J are space-potential values. A triple-root characteristic must have an unstable root, i.e. a value of ϕ_s such that (a) $J_{\text{net}} = 0$, and (b) $dJ_{\text{net}}/d\phi_s > 0$. This can happen only for $\phi_s < 0$ because J_{sec} and J_{scat} both decrease rapidly at positive potentials (an exception to this, applicable at very small electron temperatures, has been found by Meyer-Vernet (1982)). Condition (a) requires that $J_{\text{net},1}$ and $J_{\text{net},2}$ have opposite signs, i.e. T^* is between T_1 and T_2 . Condition (b) implies that $J_{\text{net}} > 0$ for all ϕ_s values between this root and zero; this in turn implies that $J_{\text{net},1} + J_{\text{net},2} > 0$. This completes the proof of (i) and (ii). Even though this proof is only approximate for real velocity distributions, it will still be generally valid in terms of "temperatures" related in the usual way ($\bar{E} = \frac{3}{2} kT$) to the mean energies obtained from a double-Maxwellian fit. Meyer-Vernet (1982) has shown that triple roots can also occur with Maxwellian electrons, when the electron temperature is less than the "temperature" of emission of secondary electrons. The unstable root then occurs at a positive rather than negative value of ϕ_s .

(2) For T (or $2\bar{E}/3k$) close to T^* , most current-voltage characteristics will have both a very small value and small slope over a large range of potentials, and the floating potential(s) will then be subject to large changes when only small changes in conditions occur. This explains "sensitivity" effects.

(3) For T slightly less than T^* , $J_{\text{sec}} + J_{\text{scat}} > J_e$ if $\phi_p < 0$, and the floating potential will generally be slightly positive. For T slightly greater than T^* , $J_{\text{sec}} + J_{\text{scat}} < J_e$ and the floating potential will generally be very negative. Clearly T^* is the temperature at which "threshold" effects may be expected.

(4) For a distribution which is (nearly) Maxwellian and has $T \approx T^*$, small (or gradual) changes in ambient conditions can cause the sign of $J_{\text{sec}} + J_{\text{scat}} - J_e$ to change, resulting in large, sudden changes in floating potential. For a distribution which may not be near-Maxwellian but which leads to a triple-root characteristic, changes in ambient conditions may cause two of the three roots to coalesce and disappear, also producing large, sudden potential changes (Sec. 2.3; Prokopenko and Laframboise, 1980; Besse, 1981; Meyer-Vernet, 1982).

3.3 CALCULATION OF THRESHOLD TEMPERATURES; DISCUSSION

We have calculated threshold-temperature values (Table 2) for a variety of spacecraft surface materials; a listing of our computer program for doing this appears in Appendix B. In order to do this, we have calculate $J_{\text{sec}} + J_{\text{scat}} - J_e$ as a function of T for Maxwellian incident distributions, and searched numerically for the value T^* at which this function changes from positive to negative as T increases.

For ambient electrons normally incident to a surface, we have used the secondary and backscattered flux expressions given by Prokopenko and Laframboise (1977, 1980), together with data given by Dekker (1958), Haenenberg and Brauer (1959, 1962), Gibbons (1966), Willis and Skinner (1973), Katz et al (1977, p. 38), Schnuelle et al (1979), Leung et al (1981), and Krainsky et al (1981).

The increased yields for electrons incident at other angles have an important influence on our results (last three columns of Table 2). For both secondary (Dekker, 1958; Salehi and Flinn, 1981; Krainsky et al, 1981) and backscattered (Darlington and Cosslett, 1972; Krainsky et al, 1981) electrons, it is found experimentally that the dependence of yield (average number of emitted electrons per incident electron) $\delta(E, \theta)$ on angle of incidence θ relative to the surface normal can be usefully approximated by a relation of the form

$$\ln \delta(E, \theta) = \ln \delta(E, 0) + P(1 - \cos \theta). \quad (3.3)$$

For secondary emission, the coefficient P appears to depend primarily on E/E_{max} , where E_{max} is the energy at which δ is largest when $\theta = 0^\circ$. For backscattered emission, P appears to depend most strongly on the atomic number Z of the surface material, and only weakly on incident energy E . Also, available information on E dependence is fragmentary, and in any case, secondary emission predominates over backscattered emission at smaller values of E . For these reasons, we have ignored the E dependence.

The dependence given by Eq. (3.3) has the special advantage that for any isotropic ambient velocity distribution, the integration over angle in the emitted flux expression can be done analytically. In this case, we have:

$$\begin{aligned}
 J_{\text{sec}} \text{ or } J_{\text{scat}} &= \int f \delta v_n d^3\vec{v} \\
 &= \iiint f(E) \delta(E, \theta) (v \cos \theta) (v^2 \sin \theta dv d\theta d\phi) \\
 &= 2\pi \int_0^\infty f(E) \delta(E, 0) v^3 dv \int_0^{1/2\pi} e^{\beta(E)(1-\cos \theta)} \cos \theta \sin \theta d\theta
 \end{aligned} \quad (3.4)$$

where (v, θ, ϕ) are spherical coordinates in velocity space with polar axis normal to the surface, $f \equiv d^6N/d^3\vec{r} d^3\vec{v}$ is the velocity distribution of ambient electrons, $E = \frac{1}{2}mv^2$, and v_n is the normal component of incident electron velocity.

The integral over θ yields $[\exp(\beta) - \beta - 1]/\beta^2$, which has the value $\frac{1}{2}$ when $\beta = 0$. After β is specified as a function of E , multiplication of $\delta(E, 0)$ by the factor $\Gamma = (2/\beta^2)[\exp(\beta) - \beta - 1]$ then corrects $\delta(E, 0)$ to include angle-dependence of the secondary or backscattered yield [see also Whipple, 1981, Eq. (3.11)]. To obtain the resulting dependence of $\delta \equiv \delta_{\text{sec}} + \delta_{\text{scat}}$ on E , we require that E_{max} and δ_{max} for normal-incidence secondary yield be specified, together with Z . Our complete yield algorithm then is:

$$\xi = \ln(E/E_{\text{max}}); \quad \eta = 0.2755(\xi - 1.658) - \sqrt{[0.2755(\xi - 1.658)]^2 + 0.0228};$$

$$\beta_{\text{sec}} = e^\eta; \quad \Gamma_{\text{sec}} = (2/\beta_{\text{sec}}^2) [\exp(\beta_{\text{sec}}) - \beta_{\text{sec}} - 1]; \quad (3.5)$$

$$\beta_{\text{scat}} = 7.37Z^{-0.56875}; \quad \Gamma_{\text{scat}} = (2/\beta_{\text{scat}}^2) [\exp(\beta_{\text{scat}}) - \beta_{\text{scat}} - 1]$$

where the above expressions for β_{sec} and β_{scat} have been obtained by fits to the data of Dekker (1958), Darlington and Cosslett (1972), Salehi and Flinn (1981), and Krainsky et al (1981). Finally:

$$S(E) = \left[7.4 \delta_{\max} \frac{E}{E_{\max}} \exp\left(-2\sqrt{\frac{E}{E_{\max}}}\right) \right] \Gamma_{\text{sec}} + [A - B e^{-CE}] \Gamma_{\text{scat}} \quad (3.6)$$

where the factors multiplying Γ_{sec} and Γ_{scat} are, respectively, the secondary-yield curve of Sternglass (1954a), and an empirical factor given by Eq. 2.9 (See also Prokopenko and Laframboise, 1980, Eq. (9)), in which the coefficients A, B, and C are functions of Z obtained from the data of Sternglass (1954b) and Palluel (1947). These coefficients are also displayed in Table 2. $J_{\text{sec}} + J_{\text{scat}}$ is then given by 2π times the integral over v in (3.4) with f replaced by the Maxwellian distribution corresponding to temperature T , or more generally, by Eqs. (2.10) - (2.14). $J_e = n_o (kT/2\pi m_e)^{1/2}$, i.e. the usual random flux for a Maxwellian distribution (where n_o is ambient electron density and m_e is electron mass), or more generally, is given by Eqs. (2.1) - (2.3).

The resulting threshold temperatures T^* (labeled "TC3") appear in the last column of Table 1. Corresponding values of T^* for simplified forms of $\delta(E)$ as indicated (labeled "TC1" and "TC2") appear in the two adjacent columns. It is clear from these results that angle-dependence of δ_{sec} and δ_{scat} has an important effect on values of T^* . The values labeled "TC1" can also be inferred from Fig. 2 of Besse (1981).

Clearly, those surface materials having the largest values of T^* will be the "most resistant" to high-voltage charging (leaving aside the effects of material conductivity) because the ambient environment will exceed their threshold temperature the least often. From this viewpoint, and using the data of Table 1, MgF_2 is the "most resistant" material, followed by activated beryllium-copper, gold, and NASCAP 'BOOMAT', a spatially-averaged representation of a composite surface consisting of kapton partly covered with platinum strips, used on the SCATHA satellite (Schnuelle et al, 1979). The zero entries for T^* in Table 1 are those for which $J_{\text{sec}} + J_{\text{scat}} < J_e$ at all values of T .

Our discussion so far has been almost completely concerned with "absolute" or "overall" surface charging, and has been based only on calculations of local currents to and from surfaces. Calculations of this type are usually sufficient to determine the floating potential of the most highly (usually negatively) charged portion of a spacecraft surface, which is usually in a shaded or partly-shaded region of the spacecraft. However, the most damaging effects of high-voltage charging are "differential" effects involving large potential differences between adjacent parts of a spacecraft. These effects are frequently dominated by non-local phenomena, an example of which we present in Sec. 4.6.

4. CYLVIA: A TWO-DIMENSIONAL CHARGING SIMULATION FOR CYLINDRICAL SPACECRAFT CROSS-SECTIONS WITH ANGLE-DEPENDENCE.

4.1 INTRODUCTION: THE QUASISTATIC ITERATION METHOD

We have constructed a numerical simulation program called CYLVIA (CYLinder Voltages in Ionosphere and Above) which combines the following features:

a) infinite circular cylindrical geometry with angle-dependence. We have chosen this geometry for the following reasons: A realistic model must be at least two-dimensional because the asymmetry between sunlit and shaded surfaces, or between surfaces with large and small secondary-electron emission currents, is a key feature of the differential charging problem. Cylindrical geometry is the simplest two-dimensional geometry, and it is also a useful approximation to many spacecraft shapes, including the DSCS and SCATHA mainframes, which are finite circular cylinders. Effects of finite cylinder length (three-dimensionality) on sheath potential profiles, which tend to cause a more rapid decrease of potential with radius, can be approximated by using a modified form of Poisson's equation (Sec. 4.3).

b) Quasistatic time-dependent iteration (Laframboise and Prokopenko, 1977). In this procedure, sheath potential changes during particle transit times are ignored. This leads to the following iteration scheme: a distribution of surface potentials is chosen. Poisson's equation is then solved to provide a radius- and angle-dependent static sheath potential [see (c) below]. Particle orbits are then followed numerically in this potential, yielding net surface charging rate as a function of surface position. Using this information, the surface potentials are updated. This process is repeated until a steady-state floating condition is obtained or in order to follow temporal changes in external conditions, such as spacecraft rotation or eclipse passage.

c) use of simplified space-charge density expressions (Sec. 4.2; Laframboise and Prokopenko, 1977), rather than numerical orbit-following,

in solving Poisson's equation for sheath potentials. Approximations of this type are good ones for geostationary-orbit situations, in which the Debye length of the ambient plasma is generally large enough that space-charge effects are almost negligible. They also yield an important saving of computer time.

Features (b) and (c) are now also used in the NASCAP (Katz et al, 1977, 1979) simulation program.

A listing of CYLVIA appears in Appendices C and D. The numerical solution of Poisson's equation in CYLVIA calculations uses the subroutines POIS, POISGN, POINIT, TRID, TRIDP, and NCHECK written by Swarztrauber and Sweet (1975).

4.2 USE OF APPROXIMATE SPACE-CHARGE DENSITY EXPRESSIONS

At geostationary-orbit altitude, the Debye length λ_D for ambient particles is usually ~ 10 m, so for satellites of ordinary size, effects of ambient space charge on sheath potentials will be relatively small. Any reasonably realistic approximation of this space charge can therefore be expected to produce only negligible errors in solving Poisson's equation for sheath potentials. Furthermore, large savings in computer time can be expected to result if one can avoid exact density calculations involving numerical orbit-following. In calculations using CYLVIA, only a relatively small amount of orbit-following is done, in order to calculate surface currents (Sec. 4.4).

A more significant space-charge effect near the spacecraft may be caused by emitted photoelectrons or secondary electrons (Soop, 1972; Schröder, 1973), because of their relatively low velocities compared to ambient values. However, effects of these are likely also to be small enough that any reasonably realistic approximations for their densities will yield good accuracy (Lafon, 1976). Such approximations must ultimately be verified by comparison with exact calculations. It is advantageous if such approximations depend on local potential only (rather than potentials at many locations), together with a relatively small number of other parameters, such as spacecraft potentials and potential barrier heights and locations. Laframboise and Prokopenko (1977) have developed such an approximation. Here we develop three

approximate expressions for ambient space-charge density [Eqs. (4.1)-(4.3)], based on the use of exact density expressions developed for collisionless, Maxwellian particles in the presence of obstacle-free potential wells of arbitrary shape by Laframboise and Parker (1973). The appropriate expression for our purposes is the result given by their Eq. (2) for three-dimensional wells. This is true even for an "infinite", that is, very long cylindrical spacecraft geometry, because of particle entry at the ends of such a geometry. For definiteness, we consider a negative well given by $\phi(x,y,z) \leq 0$, with $\phi \rightarrow 0$ as $x^2 + y^2 + z^2 \rightarrow \infty$, where ϕ is electric potential. If only ambient particles are considered, Poisson's equation is:

$$\nabla^2 \phi = \frac{e}{\epsilon_0} (N_e - N_i) \quad (4.1)$$

where e is magnitude of unit electron charge, ϵ_0 is permittivity of space, and N_e , N_i are electron and ion number densities, respectively. Since positive ions are the attracted species in this well, we use Eq. (2) of Laframboise and Parker (1973) for ion density, and the usual Boltzmann factor for electron density. If $\lambda_{De} = (\epsilon_0 k T_e / e^2 N_\infty)^{1/2}$, N_∞ is electron or ion density far from the spacecraft, L is a characteristic spacecraft length, $\tilde{\nabla} = L \nabla$, $\chi = e\phi / k T_e < 0$, k is Boltzmann's constant and T is temperature, Eq. (4.1) becomes:

$$\tilde{\nabla}^2 \chi = \left(\frac{L}{\lambda_{De}} \right)^2 \left\{ e^{\chi} - \frac{2}{\sqrt{\pi}} \left[(-\chi T_e / T_i)^{1/2} + g(-\chi T_e / T_i)^{1/2} \right] \right\} \quad (4.2)$$

where $g(s) = \frac{1}{2} \sqrt{\pi} \exp(s^2) \operatorname{erfc}(s) = \exp(s^2) \int_s^\infty \exp(-t^2) dt$. An efficient method for calculating $\operatorname{erfc}(s)$ has been given by Shepherd and Laframboise (1981).

The important feature of Eq. (4.2) for our purposes is that its right-hand side is a function of χ only. For small χ , Eq. (4.2) reduces to:

$$\tilde{\nabla}^2 \chi = (1 + T_e / T_i) (L / \lambda_{De})^2 \chi \quad (4.3)$$

where terms of order $\chi^{3/2}$ and higher have been ignored. The linear form of (4.3) permits the use of direct Poisson-solvers for finding χ . Another simplified form can be obtained by rederiving Eq. (4.2) with monoenergetic instead of Maxwellian ions assumed. The appropriate monoenergetic velocity

distribution (Chen, 1965; Laframboise, 1966, p. 14) is:

$$f = \frac{d^3 N}{d^3 \vec{v}} = \frac{m_i^2 N}{4\pi} \frac{\delta(E - E_1)}{(2m_i E_1)^{1/2}} \quad (4.4)$$

where $E_1 = 4kT_i/\pi$ and m_i is ion mass; this distribution duplicates the ambient number density and flux values of a Maxwellian at temperature T_i . Rederivation of (2) using this distribution yields the computationally simpler form:

$$\nabla^2 \chi = \left(\frac{L}{\lambda_{De}}\right)^2 \left[e^\chi - \left(1 - \frac{\pi}{4} \frac{T_e}{T_i} \chi\right)^{1/2} \right]. \quad (4.5)$$

If any regions exist where $\chi > 0$, the roles of ions and electrons are interchanged, and Eqs. (4.2) - (4.5) must be modified accordingly.

The essential approximation contained in Eqs. (4.2) - (4.5) is the neglect of orbit depletion due to intersection with the spacecraft. The densities of ambient ions and electrons will therefore both be overestimated near the spacecraft in these results. As long as the spacecraft is at least moderately smaller than λ_{De} , the effects of this overestimate will be small. The attracted-species density will be overestimated by the greater amount for reasons involving the curvatures of attracted and repelled particle orbits. The sheath profiles predicted by (4.2) or (4.5) will therefore be steeper than real profiles, if electron emission effects are ignored. Laframboise and Prokopenko (1977, Secs. 2.4.2 and 2.4.3) have also discussed space-charge density approximations based on symmetric potentials and on equivalent potential wells, for ambient and emitted electrons.

4.3 APPROXIMATE INCLUSION OF FINITE-CYLINDER - LENGTH (THREE-DIMENSIONAL) EFFECTS IN POISSON'S EQUATION.

Effects of finite spacecraft length on sheath potential profiles can be included in either of two approximate ways which lead to modifications of the two-dimensional Poisson equation to be solved. We include here a description of these methods. The first method is derived by pretending that the circular inner boundary of the computation grid, which

represents the spacecraft surface, is no longer a cross-section of an infinite cylinder, but rather is a cross-section through the equatorial plane of a prolate spheroid of polar-to-equatorial axis ratio $L \geq 1$.

We also assume that the sheath potential is (for some unspecified reason) independent of the latitude coordinate perpendicular to this plane.

This leads to a modified Poisson equation of the form

$$\tanh^2 \xi \frac{\partial^2 \chi}{\partial \xi^2} + \tanh \xi \frac{\partial \chi}{\partial \xi} + \frac{\partial^2 \chi}{\partial \theta^2} = \frac{\sinh^2 \xi}{\sinh^2 \xi_s} \left(\frac{R_s}{\lambda_D} \right)^2 (n_e - n_i) \quad (4.6)$$

where $\chi = e\phi/kT_e$, ξ is a radial coordinate in the equatorial plane and is related to nondimensional radius $r = R/R_s$, defined in the same plane, by the relation

$r = (L^2 - 1)^{1/2} \sinh \xi$, $\xi_s = \frac{1}{2} \ln [(L+1)/(L-1)]$, θ is angular coordinate in the same plane, R_s is spacecraft radius, λ_D is Debye length, and n_e and n_i are the nondimensional electron and ion densities $N_e/N_{e\infty}$ and $N_i/N_{i\infty}$, where N_0 is ambient density of either species. Use of Eq. (4.6) in place of the usual polar-coordinate Poisson equation would result in sheath potential profiles which became increasingly steeper as L decreased, thus allowing for approximate estimates of sheath potentials around finite cylinders. The limiting case $L=1$ would correspond to an assumed spherical geometry without latitude dependence; the limit $L \rightarrow \infty$ leads to recovery of infinite cylindrical geometry.

The transformation $s = \ln \coth \frac{1}{2} \xi$ leads to the alternative form

$$\frac{1}{\cosh^3 \xi} \frac{\partial^2 \chi}{\partial s^2} + \frac{\partial^2 \chi}{\partial \theta^2} = \frac{\sinh^2 \xi}{\sinh^2 \xi_s} \left(\frac{R_s}{\lambda_D} \right)^2 (n_e - n_i) \quad (4.7)$$

which contains no first-order terms. For small ξ , s varies logarithmically with r ; for large ξ , s varies as r^{-1} .

The second method is derived by first writing the nondimensional Poisson equation for cylindrical coordinates, which has the form

$$\frac{\partial^2 \chi}{\partial z^2} + \frac{1}{r} \frac{\partial \chi}{\partial r} + \frac{1}{r^2} \frac{\partial^2 \chi}{\partial \theta^2} + \frac{\partial^2 \chi}{\partial z^2} = \left(\frac{R_s}{\lambda_D} \right)^2 (n_e - n_i) \quad (4.8)$$

We then assume that $\chi(r, \theta, z)$ is periodic in z , such that values of χ repeat after nondimensional distance 2ℓ parallel to the z axis. In particular, we assume that $\chi(r, \theta, z) = \text{some given dependence } \chi_2(r, \theta)$,

and that $\chi(r, \theta, 0) = \chi_0(r, \theta)$ to be found. We further assume that $\partial\chi/\partial z = 0$ at $z = 0$, $z = \pm l$, $z = \pm 2l$, etc, and that only the lowest Fourier component of the z dependence of χ is present. Then

$$\chi(r, \theta, z) = \frac{1}{2}[\chi_0(r, \theta) + \chi_l(r, \theta)] + \frac{1}{2}[\chi_0(r, \theta) - \chi_l(r, \theta)] \cos\left(\frac{\pi z}{l}\right) \quad (4.9)$$

and, at $z = 0$, we have

$$\frac{\partial^2 \chi_0}{\partial z^2} = \frac{1}{2} \left(\frac{\pi}{l}\right)^2 [\chi_l(r, \theta) - \chi_0(r, \theta)] \quad (4.10)$$

The Poisson equation for $\chi_0(r, \theta)$ now becomes

$$\frac{\partial^2 \chi_0}{\partial r^2} + \frac{1}{r} \frac{\partial \chi_0}{\partial r} + \frac{1}{r^2} \frac{\partial^2 \chi_0}{\partial \theta^2} - \frac{1}{2} \left(\frac{\pi}{l}\right)^2 \chi_0 = \left(\frac{R_s}{\lambda_D}\right)^2 (n_e - n_i) - \frac{1}{2} \left(\frac{\pi}{l}\right)^2 \chi_l(r, \theta) \quad (4.11)$$

We see that in this Poisson equation, effects of z -dependence are represented by a homogeneous "Helmholtz" term and a fictitious space charge contribution. The z -dependence incorporated into this equation could represent approximately the effects on sheath potentials of finite spacecraft length and/or features such as conductive circumferential bands. Equations (4.7) and (4.11) are both solvable by standard methods; both are linear. Both contain only two (radius and angle) independent variables.

4.4 ORBIT INTEGRATION AND CURRENT CALCULATION

CYLVIA uses a form of the particle orbit equations in which particle total energy is explicitly conserved. This formulation was adopted because of a difficulty which arose when using more standard methods to integrate photoelectron orbits. Accumulation of numerical errors was occasionally found to change the total energy of an orbit by amounts large compared to the assumed thermal energy of emission (1.5V), especially near points where orbits were "reflected" by a potential barrier; this in turn produced large errors in calculations of photoelectron currents reimpacting spacecraft surfaces.

In order to derive the orbit equations, we consider the motion of a particle in a plane. We let (r, θ) and (v_r, v_θ) represent its position and

velocity components in polar coordinates (Fig. 4.1). We let s represent arc length along its orbit, and $\hat{u}$ and $\hat{n}$ represent unit tangent and unit normal vectors at a point on the orbit, the latter directed toward its local centre of curvature. We let ρ represent its local radius of curvature. We let q, m , and E represent particle charge, mass, and total energy, and $\phi(r, \theta)$ represent electric potential. The equation of motion $m \, d\vec{v}/dt = -q\nabla\phi$ reduces to:

$$v \frac{dv}{ds} \hat{u} + \frac{v^2}{\rho} \hat{n} = \frac{q}{m} \left(-\hat{n} \frac{\partial \phi}{\partial n} - \hat{u} \frac{\partial \phi}{\partial s} \right) \quad (4.12)$$

We equate respective components of Eq. (4.12) and use the relations $ds = \rho d(\alpha + \theta)$, $dr = \cos(\alpha) ds$, and $r \, d\theta = \sin(\alpha) ds$. We then obtain the orbit equations in the following form:

$$\begin{aligned} \frac{d\alpha}{ds} &= - \frac{q}{mv^2} \left(\frac{\cos \alpha}{r} \frac{\partial \phi}{\partial \theta} - \sin \alpha \frac{\partial \phi}{\partial r} \right) - \frac{\sin \alpha}{r} \\ \frac{dr}{ds} &= \cos \alpha \\ \frac{d\theta}{ds} &= \frac{\sin \alpha}{r} \\ v^2 &= \frac{2}{m} \left[E - q\phi(r, \theta) \right] \end{aligned} \quad (4.13)$$

This system is reduced from fourth to third order because the last equation appears in integrated form. At points where particle reflection from potential barriers produces cusps or near-cusps in an orbit ($d\alpha/ds$ becomes singular or large), a segment of the orbit is replaced by a parabolic arc.

We illustrate the current calculation method used by CYLVIA by first considering photoelectrons which arrive at a point on the surface whose normal makes an angle θ with the sunward direction, each of them having originated at some other surface location θ_0 (Fig. 4.2a) and forced to return to the surface by a potential barrier which surrounds the spacecraft. Their current density at the surface location given by θ is:

$$J(\theta) = \int_{v=0}^{v=\infty} \int_{\omega=0}^{\omega=\pi} \hat{f}(v, \omega) (v \sin \omega) (v \, dv \, d\omega) \quad (4.14)$$

where $v = (v_r^2 + v_\theta^2)^{1/2}$ and $\omega = \tan^{-1}(v_r/v_\theta)$ are polar coordinates in incident velocity space at the surface location θ , $\hat{f} \equiv d^2N/dv_r dv_\theta$ is the two-dimensional velocity distribution of photoelectrons, and N is their number density. By Liouville's theorem, $\hat{f}$ is constant along a particle orbit. Assuming that photoelectrons are emitted with a Maxwellian distribution corresponding to a temperature T , their emission flux $J_{ph}(\theta_0)$ is related to $\hat{f}$ as follows:

$$\hat{f} = \frac{1}{\sqrt{2\pi}} J_{ph}(\theta_0) \left(\frac{m}{kT} \right)^{3/2} e^{-mv_0^2/2kT} \quad (4.15)$$

If the sunlit side of the spacecraft has uniform material properties, then

$J_{ph}(\theta_0) = J_{ph}(0) \cos \theta_0$. We introduce dimensionless variables as follows:

$$\chi = q\phi/kT; \quad u = v(m/2kT)^{1/2} \quad (4.16)$$

Since $\frac{1}{2}mv^2 + q\phi = \frac{1}{2}mv_0^2 + q\phi_0$, (4.15) and (4.14) become:

$$\hat{f} = \frac{1}{\sqrt{2\pi}} J_{ph}(\theta_0) \left(\frac{m}{kT} \right)^{3/2} e^{\chi_0 - \chi} e^{-u^2} \quad (4.17)$$

$$J(\theta) = \frac{2}{\sqrt{\pi}} \int_{u=0}^{u=\infty} du \, u^2 \, e^{-u^2} \int_{\omega=0}^{\omega=\pi} d\omega \sin \omega \left[J_{ph}(\theta_0) e^{\chi_0 - \chi} \right] \quad (4.18)$$

The factor in square parentheses in (4.18) is evaluated for each u and ω by integrating the corresponding photoelectron orbit backward to its origin to find θ_0 and χ_0 . To do the integrations in (4.18) we set up a polar-coordinate grid in velocity space at the surface location θ , as shown in fig. 4.2b, where we have defined $u_n = -u_r$, $u_t = -u_\theta$. We approximate $F(u, \omega) \equiv (2/\sqrt{\pi}) J_{ph}(\theta_0) \exp(\chi_0 - \chi)$ in each cell $u_i \leq u \leq u_{i+1}$, $\omega_j \leq \omega \leq \omega_{j+1}$ by $(A + Bu)(C + D\omega)$ where $A, \dots, D$ can be determined if the values of F at its four corners are found, again by integrating orbits backward. Equation (4.18) then becomes:

$$J(\theta) = \sum_{i,j} \int_{u_i}^{u_{i+1}} du u^2 e^{-u^2} (A_{ij} + B_{ij}u) \int_{\omega_j}^{\omega_{j+1}} d\omega \sin \omega (C_{ij} + D_{ij}\omega), \quad (4.19)$$

a form in which all integrals can be evaluated analytically. This method for evaluating $J(\theta)$ is essentially equivalent to the "inside-out" method of Parker and Whipple (1967). The factor $\exp(\chi_0 - \chi)$ in $F(u, \omega)$ may vary strongly within individual cells. The potential barrier which surrounds a spacecraft is always of finite height, permitting some photoelectrons to escape and ambient electrons to reach it. This means that the integration in (4.19) must be performed over two regions of velocity space, labelled I and II in Fig. 4.2b, containing photoelectrons (and secondary and backscattered electrons), and ambient electrons, respectively. In general, $\hat{f}$ will contain a discontinuity at the boundary between I and II (Whipple, 1976) which can produce large errors in the evaluation of $J(\theta)$. The integration method used in CYLVIA treats these discontinuities explicitly, using bisection searches to find points such as those circled in Fig. 4.2b. If the ambient electron velocity distribution is isotropic, then F in region II will be independent of ω .

4.5 RESULTS AND DISCUSSION

Figure 4.3 shows a CYLVIA calculation of equipotential contours surrounding a cylindrical spacecraft cross-section whose surface consists of two independently floating conductive sectors, the smaller of which is shaded and subtends an angle of 90° . In this calculation the ambient ion and electron velocity distributions are double Maxwellians with the following properties:

$N_{i1} = 1 \text{ cm}^{-3}$	$N_{e1} = 1 \text{ cm}^{-3}$
$T_{i1} = 20 \text{ eV}$	$T_{e1} = 500 \text{ eV}$
$N_{i2} = 1 \text{ cm}^{-3}$	$N_{e2} = 1 \text{ cm}^{-3}$
$T_{i2} = 10^4 \text{ eV}$	$T_{e2} = 5000 \text{ eV}$

The photoelectron charge flux eJ_{ph} is $45 \times 10^{-6} \text{ A/m}^2$ at normal sunlight incidence. $T_{ph} = 1.5 \text{ eV}$. Secondary and backscattered electron fluxes are assumed zero. Ambient ion and electron and photoelectron currents are calculated using numerical orbit-following as described in Sec. 4.4. The computation grid in (r, θ) contains 65×48 intervals. In this and subsequent calculations, the computation grid in (u, w) contains 8×16 intervals for each Maxwellian component of each particle species, apart from bisection searches (Sec. 4.4) which give finer resolution. Linear space charge is assumed [Sec. 4.2; Laframboise and Prokopenko, 1977, Eq. (3)]. The above-mentioned plasma parameters imply an ambient Debye length of 32.5 meters; spacecraft radius r_s is 1 meter. The outer boundary of the computation grid is at $e^5 r_s \approx 148 r_s$. The most noteworthy feature of Fig. 4.3 is a negative saddle-point potential barrier which surrounds the larger sector, and whose height varies from about 2 volts at the sunward point to several hundred volts near the edges of this sector. The potential of the 270° sector (-2.265 kV) is controlled by blocking of electron escape caused by this barrier; this mechanism is discussed in more detail in Sec. 4.6. In Sec. 6.5, surface photocurrents obtained from this calculation are compared with values given by an analytic approximation. In this and subsequent calculations, calculated surface potentials are all within 10 volts of the values at which the residual currents change sign.

Figure 4.4 shows a CYLVIA calculation of equipotential contours around a spacecraft cross-section divided into four 90° sectors, two covered with aluminum and two with quartz. The aluminum sectors are electrically connected to each other. In this calculation the ambient velocity distributions are single Maxwellians with $N_i = N_e = 3\text{cm}^{-3}$ and $T_i = T_e = 1\text{ keV}$. Photoelectron fluxes at normal sunlight incidence are 42 and $32\text{ }\mu\text{A/m}^2$ for aluminum and quartz, respectively. $T_{ph} = 1.5\text{ eV}$ for both. Secondary and backscattered fluxes are assumed zero. The computation grid in (r, θ) contains 65×16 intervals. The outer boundary of this grid is at $e^7 \times 1097$ spacecraft radii. The above-mentioned plasma parameters imply an ambient Debye length of 96 meters; spacecraft radius r_s is 1 meter. As in Fig. 4.3, a saddle-point barrier is present on the sunward side of the spacecraft (see Sec. 4.6), and controls the potential of the sunlit quartz sector and the two aluminum sectors.

In a separate calculation, which is not shown, we included secondary and backscattered electron emission; the calculated surface potentials then were all between 0 and +10V. This result can be readily interpreted in terms of the threshold material temperatures for high-voltage charging defined in Sec. 3 and listed in Table 2. Although the value of T_e for this case is greater than the threshold temperature of aluminum (Table 2), the aluminum sectors are partly sunlit, and photoemit enough to balance their ambient electron collection current. The threshold temperature of quartz is greater than T_e , so secondary and backscattered electron emission from these sectors is therefore enough to balance their ambient electron collection current. Thus in this case, no negative charging occurs on any sector. If T_e were made substantially larger than the threshold temperature of quartz (Table 2), then high-voltage negative charging of the shaded quartz sector would again occur.

In Fig. 4.5, the same spacecraft cross-section as in Fig. 4.4 has been rotated by 90° relative to the sunward direction. In this case the most negative potentials are those on the shaded regions of the quartz sectors, which float separately from the sunlit regions because the quartz is nonconductive. In this situation it is possible that

breakdown of orbit-limitation of the collection of ambient ions (Sec. 2.1) could occur, especially near the edges of these shaded regions, and this would restrict ion collection and cause their floating potentials to become even more negative than we have calculated, but the rather coarse θ -interval of our computational grid has prevented us from resolving this question in this calculation.

Also in Fig. 4.5, we have this time a saddle-point barrier on the shaded side of the spacecraft; if the calculation had included secondary and backscattered electrons, this barrier would have controlled their escape. In this case a negative current flows from the shaded to the sunlit aluminum sector, so the sunlit sector floats at a much more negative potential than it would otherwise.

Figure 4.6 shows the distribution of surface potentials corresponding to the calculations of Figs. 4.4 and 4.5, together with the calculated surface potential distribution of a completely nonconductive ("quartz" but with secondary and backscattered electron emission not included) cylinder which is placed in the same environment.

Figure 4.7 shows again the same surface potential distribution for a nonconductive cylinder as in Fig. 4.6, together with another distribution for conditions which are unchanged except that the outer boundary r_B of the calculation is moved inward to 12 spacecraft radii r_S . A third calculation is shown, which has been done not using CYLVIA but using a program called TWOD, which combines the physical assumptions of the NASCAP program with circular cylindrical geometry (M. Mandell, Systems, Science and Software Inc., private communication). Except as noted, the physical situations treated in the CYLVIA and TWOD calculations are the same; in both cases $r_B = 12 r_S$, zero secondary and backscattered emission is assumed, and a 16-point angular discretization is used. In the TWOD calculation, zero space charge is assumed, but since $\lambda_D = 96 r_S$ in the CYLVIA calculation, the comparison shown is probably unaffected by this

difference. In the TWOD calculation, photoelectron temperature and normal-incidence flux are 2 eV and $20 \mu\text{A}/\text{m}^2$, whereas for CYLVIA, the corresponding parameters are 1.5 eV and $45 \mu\text{A}/\text{m}^2$.

We see that rough agreement exists between the CYLVIA and the TWOD calculations. Either our higher photoemission flux, or the rather coarse angular discretization used in both calculations, may account for the differences; we have not yet investigated this question with further calculations. Even though the barrier which surrounds the sunlit side of the cylinder prevents almost all photoelectron escape in the (two) regions $60^\circ \leq \theta < 90^\circ$ where the largest disagreement occurs, our larger assumed flux permits greater surface migration of photoelectrons (Sec. 6), and the resulting surface current will drain excess negative charge from these regions (to an extent which we have so far not determined). The large difference between the two CYLVIA calculations for $r_B = 12r_S$ and $r_B = e^7 r_S$ is symptomatic of the great sensitivity which two-dimensional Laplace-potential (or nearly Laplace-potential, as in our case) calculations have to outer-boundary position generally. On the other hand, tests with CYLVIA have indicated that $r_B \gtrsim e^5 r_S$ is sufficient to overcome this sensitivity, especially when a small amount of linear (or other) space charge is included, as we have done.

4.6 THE BARRIER EFFECT

As we have seen (Secs. 2 and 3), charging calculations based on local-current-balance considerations are usually sufficient to determine the floating potential of the most highly (usually negatively) charged portion of a spacecraft surface, which is usually in a shaded or partly-shaded region of the spacecraft. However, the most damaging effects of high-voltage charging are "differential" effects involving large potential differences between adjacent parts of a spacecraft. These effects are frequently dominated by non-local phenomena, several examples of which occurred in Sec. 4.5, and which we now examine in more detail.

The most important among these phenomena is the "barrier" effect, which often controls the differential charging of other surfaces, including sunlit ones, relative to the most highly-charged surface. In the "barrier" effect, a strong dipole or higher moment of the spacecraft's potential distribution produces "saddle-point" barriers over less-highly-charged portions of the spacecraft, limiting photoemitted or other electron escape from these portions and causing them to charge more negatively than otherwise. Space-charge effects are normally not important in the formation of such barriers. Their existence, and the resulting implications for differential charging, were first predicted by Fahleson (1973). Whipple (1976) presented evidence for the existence of such a barrier on the ATS-6 satellite. Other properties and consequences of these barriers were discussed by Prokopenko and Laframboise (1977,1980) and Laframboise and Prokopenko (1977). Katz et al (1979) performed a numerical simulation which showed the formation of such a barrier near a polyhedral "quasispherical" model satellite, together with the resulting effects for differential charging. Besse and Rubin (1980) developed an analytical treatment of the barrier effect for a spherical satellite. Purvis (1982) presented a variety of NASCAP numerical simulations to illustrate the prevalence of the barrier effect in high-voltage charging situations. Katz and Mandell (1982) examined mechanisms underlying the barrier effect, called by them the "field-reversal" effect, and in one particular application, the "snapover" effect. In this Section, we present results of a numerical simulation for circular cylindrical geometry, which emphasize the importance of the barrier effect for differential charging.

Using CYLVIA (Secs. 4.1 - 4.5), we have calculated the equilibrium charging state of a cylindrical spacecraft shape with a nonconductive surface in a model geostationary-orbit plasma with sunlight incident normally to the cylinder axis on one side. Figure 4.8 shows the results of a CYLVIA calculation in which we have deliberately made an important oversimplification: we have calculated the surface potential distribution on the basis of local current balance only. Because sunlight

strikes only one side of the spacecraft, photoelectrons are emitted only from this side. In this example, the escaping photoelectron flux from most of the sunlit side is sufficient to balance the ambient electron flux, so the sunlit side of the spacecraft floats at a potential of 5.1V, while the shaded side floats at -2.96 kV. As a result, the spacecraft potential has a strong dipole moment, resulting in the existence of a potential barrier which surrounds its sunlit side. The height of this barrier is -0.61 kV, while the assumed photoelectron emission temperature is only 1.5 eV, so almost all photoelectrons reflect from the barrier and return to the spacecraft, an effect which we have not taken into account in this calculation.

In Fig. 4.9 we have included this effect, and have allowed CYLVIA to converge to the resulting more-realistic steady state. As a result of photoelectron reflection from the barrier, the sunlit side of the spacecraft has charged to a more negative potential. As a result, the barrier height in the sunward direction has been reduced to -0.2V. A substantial fraction of the photo-electrons now escape over the barrier, permitting the local currents to come into balance. A further indication of this is that the saddle point has moved inward from 5.9 spacecraft radii almost to the spacecraft surface: such an inward movement was first predicted by Fahleson (1973), and is evident also in the results of Katz et al (1979, Figs. 17-21) and Besse and Rubin (1980).

The resulting changes in the potential profile along the spacecraft-sun line are shown in Fig. 4.10. The inward motion of the saddle point is again evident. Most importantly, the amount of differential charging between the sunlit and shaded sides has been reduced dramatically, from 2.96 kV to 1.19 kV. Potential-barrier formation evidently exerts a controlling effect on the differential charging. This is increasingly recognized as being the normal condition in differential-charging situations (Purvis, 1982; Katz and Mandell, 1982). Because the capacitances between various parts of a spacecraft are generally much larger than the free-space capacitance of the entire spacecraft, the

charging times for differential charging are usually much larger than those for absolute charging (Purvis, 1982).

It is clear from our example and also the examples presented in Sec. 4.5 (and also another example to be presented in Sec. 5.2), that the formation of potential barriers is very geometry-dependent. This is the case because in geostationary-orbit conditions, space-charge shielding around spacecraft of "ordinary" size (up to a few tens of meters) is a small effect (since the ambient Debye length is usually at least this large), and electric fields produced by charging on one part of a spacecraft surface readily surround other parts of it, even if these are on the other side of the spacecraft. Detailed simulations which include realistic representation of spacecraft geometry therefore appear likely to remain important for studies of spacecraft charging whenever the possibility of barrier effects exists.

In Fig. 4.11 we show another CYLVIA calculation which is discussed in detail in Sec. 5.

5. XYCIC: A SIMULATION FOR GENERAL PLANAR-SYMMETRIC (TWO-DIMENSIONAL) SPACECRAFT GEOMETRIES

5.1 INTRODUCTION

We have developed and partly tested a program called XYCIC [(X,Y) Charging Investigation Code], which is designed to permit simulation of a wider class of two-dimensional geometries than does CYLVIA. XYCIC is designed to treat any spacecraft cross-section which takes the form of one or more polygons, each of which joins a set of unit lattice points in a Cartesian plane with lines having slopes of 0, $\pm\frac{1}{2}$, ± 1 , ± 2 , or ∞ . Thus a circular cylinder can be approximated by either an octagon or a hexadecagon (16-sided polygon). At present, the geometric features, or "object-generation" portion of XYCIC, and its Poisson-solver, have been completed and tested, and program segments incorporating the same plasma simulation features as in CYLVIA (Secs. 4.1-4.4) have been written and partly tested. A listing of the present version of XYCIC appears in Appendix E.

As noted in connection with Fig. 4.7, plasma simulations in two dimensions generally involve strong sensitivity to boundary effects, unless space-charge shielding intervenes, an effect which frequently does not occur at the large Debye lengths typical of geostationary-orbit conditions. In such cases, as we have seen, it may become necessary to place the outer boundaries of computational domains very far from a (simulated) spacecraft. In order to accomplish this in XYCIC without the penalty of excessive numbers of grid points, we have constructed its computational domain as a set of nested square grids, each of which is centered in the next larger one, and such that in crossing the boundary from each to the next larger one, the grid interval is doubled. A similar succession of nested sub-domains is used in three dimensions in NASCAP (Katz et al, 1977). On the boundary of the outermost domain, the potential is assumed to be zero.

5.2 PRELIMINARY RESULTS

Figure 5.1 shows a XYCIC calculation of equipotential contours around an octagonal approximation to the circular cylindrical geometry of Fig. 4.11. As in the case of Fig. 4.11, the surface potentials in Fig. 5.1 have the imposed values shown, rather than self-consistent values. A total of 7 nested grids have been used in this calculation, with the outermost grid boundary located at 27.4 half-widths of the simulated object.

This calculation, and the CYLVIA calculation shown in Fig. 4.11, have been done for comparison with a NASCAP calculation (Olsen, 1980, p. 190; Olsen and Whipple, 1980, Fig. 16) of potentials around an octagonal-cylinder "model object" which approximates the ATS-5 satellite. The feature of greatest interest in both sets of calculations is the potentials of the four saddle points which occur outside the 50 V sections of the spacecraft surface, which represent conductive areas from which electron emission occurred on the real spacecraft. Comparison of our results, Figs. 4.11 and 5.1, with each other indicates a satisfactory level of agreement between them with regard to the potentials and locations of the saddle points. This is the case even though the CYLVIA calculation contains a small amount of linear space charge, while the XYCIC calculation contains none.

Comparison of either result with that of Olsen and Whipple indicates that our saddle points are located about twice as far from the spacecraft surface as theirs, and have larger negative potentials (-56 to -59 V) than theirs (-53 V). These differences undoubtedly result from the fact that our simulation is two-dimensional and theirs is three-dimensional, even though our geometry in Fig. 5.1 is identical with that of their cross-section. Incorporation of three-dimensionality into our calculation, using the approximate method described in Sec. 4.3, would probably bring our results into much closer agreement with theirs, but we have not yet done this. In modifying our calculation in this fashion, it would probably be advantageous to perform our calculation as the superposition

of two modified calculations of the type described by Eqs. (4.8) to (4.11). One of these would have surface potentials given by the (uniform) average (taken over surface position) of those in our Figures, and the characteristic length λ used in it would be that of the ATS-5 model object. The other would have surface potentials given by the departures from this average, and its (much smaller) value of λ would be that of the conductive patches on the ATS-5 object. The disturbance potential of the patches would then decrease more quickly with radius, in better agreement with the Olsen and Whipple calculation.

Figure 5.2 shows a XYCIC prediction of equipotentials around a composite "object" which represents a cross-section through a hypothetical spacecraft-body-and-antenna combination. Again the surface potential values are given ones; in this case they are hypothetical. Other data pertinent to this calculation are given in the figure caption. If self-consistent calculations are made in the future with a geometry similar to the one shown, the "cutout" in the spacecraft body, and the region between the spacecraft body and the antenna, would both become examples of the "shaded cavities" discussed in connection with Fig. 2.8. It would then be possible to verify the prediction, made in Sec. 2.3, that electrically-isolated surfaces inside such cavities may charge to larger negative potentials than those elsewhere on the spacecraft. It would also be possible to investigate the relative importance of the two mechanisms, discussed in Sec. 2.3, which may produce such charging.

6. AN ANALYTIC CALCULATION OF SURFACE PHOTOCURRENTS

6.1 INTRODUCTION

Photoelectron migration can be an important cause of surface currents on spacecraft in charging situations. Numerical methods of calculating photoelectron migration involve following a large number of electron orbits which will generally be short (from origin to impact point) and have large curvature. Such a procedure can be a major source of expense in operating a simulation program. A good analytic approximation for surface photocurrent can therefore be of great value. If photoelectron migration takes place over a curved surface, the sunlight incidence angle will vary over this surface and therefore so will the photoemission flux. On the other hand, if the normal component of electric force on the electrons is attractive toward the surface and is large enough, the total distance of their travel along the surface will be short enough that effects of surface curvature on their orbits can be neglected, so a model situation involving a planar surface with a photoemission gradient along it becomes appropriate. In Section 6.2, we perform an analytic calculation of surface photocurrent for such a situation. In Section 6.3, we do a partial numerical verification of our result by comparing it with a numerical result obtained using CYLVIA.

6.2 THEORY

In this Section, we derive an analytic expression for the surface current density of photoelectron migration along a plane surface $y=0$, in the presence of: (a) a uniform normal electric field $E_y > 0$, which causes photoelectrons emitted from the surface to reimpact it (Fig. 6.1) (b) a uniform tangential electric field E_x (c) a uniform photoemission current density gradient $J'_{ph} = dJ_{ph}/dx$, so that the photoemission current per unit surface area is $J_{ph}(x) = J_{ph,0} + J'_{ph} x$. This photoemission gradient, or "production gradient", would ordinarily be caused by a spatial variation in the illumination of the surface. We also assume

that photoelectrons are emitted with a Maxwellian velocity distribution corresponding to a temperature $T = T_{ph}$. In the presence of (a) and (b), all photoelectron orbits are parabolas whose axes are parallel to the resultant electric field vector (Fig. 6.1). The impact location x for a photoelectron which originates at x_0 with emission velocity components v_{x0} and v_{y0} is:

$$x = x_0 + \frac{2m}{eE_y} (v_{x0} v_{y0} - \frac{E_x}{E_y} v_{y0}^2) \quad (6.1)$$

where e is the magnitude of unit electronic charge. The surface current Γ in the x direction, per unit distance z perpendicular to the (x, y) plane, can now be found by integrating over position and velocity of emission to find the number of photoelectrons per unit z and unit time which cross the plane $x = 0$ in the direction of increasing x , then subtracting the corresponding result for decreasing x . We note that $v_{y0} \hat{f}(x_0, v_{x0}, v_{y0})$ is the number of photoelectrons produced per unit surface area per unit v_{x0} and v_{y0} , where $\hat{f} \equiv d^2N/dv_x dv_y$ is the two-dimensional velocity distribution of photoelectrons and N is their number density.

We obtain:

$$\Gamma = \int_{-\infty}^0 dx_0 \int_{-\infty}^{\infty} dv_{x0} \int_0^{\infty} dv_{y0} v_{y0} \hat{f}(x_0, v_{x0}, v_{y0}) H_+(x_0, v_{x0}, v_{y0}) - \int_0^{\infty} dx_0 \int_{-\infty}^{\infty} dv_{x0} \int_0^{\infty} dv_{y0} v_{y0} \hat{f}(x_0, v_{x0}, v_{y0}) H_-(x_0, v_{x0}, v_{y0}) \quad (6.2)$$

where $\hat{f} = (1/2\pi) J_{ph}(x) (m/kT)^{3/2} \exp(-mv_0^2/2kT)$, and H_+ and H_- are equal to 1 if the impact location x given by (6.1) is positive or negative, respectively, and equal to 0 otherwise. We define:

$$v_0^2 = v_{x0}^2 + v_{y0}^2; \quad \psi = \tan^{-1}(v_{y0}/v_{x0}); \quad \xi = \tan^{-1}(E_y/E_x). \quad (6.3)$$

Since $v_{y0} > 0$, (6.1) implies that $x \geq x_0$ if $v_{x0} \geq (E_x/E_y)v_{y0}$, or $\psi \geq \xi$.

Equation (6.2) now becomes:

$$\Gamma = \frac{1}{\sqrt{2\pi}} \left(\frac{m}{kT} \right)^{3/2} \int_0^{\infty} dv_0 v_0^2 \exp\left(-\frac{mv_0^2}{2kT}\right) \int_0^{\xi} d\psi \sin\psi \int_0^0 dx_0 (J_{ph,0} + J'_{ph} x_0) - \frac{2mv_0^2}{eE_y} (\cos\psi \sin\psi - \cot\xi \sin^2\psi) - \frac{2mv_0^2}{eE_y} (\cos\psi \sin\psi - \cot\xi \sin^2\psi) - \frac{1}{\sqrt{2\pi}} \left(\frac{m}{kT} \right)^{3/2} \int_0^{\infty} dv_0 v_0^2 \exp\left(-\frac{mv_0^2}{2kT}\right) \int_{\xi}^{\pi} d\psi \sin\psi \int_0^{\pi} dx_0 (J_{ph,0} + J'_{ph} x_0) \quad (6.4)$$

We define:

$$\begin{aligned}\Gamma_o &= J_{ph,o} kT/eE_y; \quad \gamma = \Gamma/\Gamma_o; \\ \tilde{x} &= (eE_y/kT)x; \quad j' = J'_{ph} \Gamma_o/J_{ph,o}^2; \\ u &= v_o \sqrt{m/2kT}.\end{aligned}\tag{6.5}$$

Then (6.4) becomes:

$$\begin{aligned}\gamma &= \frac{2}{\sqrt{\pi}} \int_0^\infty du u^2 e^{-u^2} \int_0^\pi d\psi \left[4u^2 (\cos \psi \sin^2 \psi - \cot \xi \sin^3 \psi) \right. \\ &\quad \left. - 8u^4 j' (\cos^2 \psi \sin^3 \psi - 2\cos \psi \sin^4 \psi \cot \xi + \cot^2 \xi \sin^5 \psi) \right] \\ &= -4\cot \xi - j'(4 + 16\cot^2 \xi).\end{aligned}\tag{6.6}$$

Using (6.3) and (6.5), we finally obtain:

$$\Gamma = -\frac{4J_{ph,o} kT}{eE_y^2} \frac{E_x}{E_y} - J'_{ph} \left(\frac{kT_{ph}}{eE_y} \right)^2 \left[4 + 16 \left(\frac{E_x}{E_y} \right)^2 \right].\tag{6.7}$$

This result contains, respectively, a potential-gradient term, a production-gradient term, and a cross-term. The effect of the cross-term can be substantial: we see that it enhances the production-gradient term five-fold if $(E_x/E_y)^2 = 1$, in comparison with its value when $E_x = 0$. This is true regardless of the sign of E_x ; in other words, surprisingly, an "opposed" electric field causes the same enhancement as an "aligned" one.

The potential-gradient term is twice that given by Eq. (14) of Pelizzari and Criswell (1978); this can be seen as follows. If one assumes that photoelectrons are emitted isotropically, corresponding to a value of zero for the parameter b in their Eqs. (13) and (14), then in our notation, their Eq. (14) is:

$$-e\Gamma = \frac{4J_{ph,o} \left(\frac{3}{2} kT_{ph} \right) E_x}{3E_y^2}\tag{6.8}$$

where our quantities $-e\Gamma$, $J_{ph,o}$, and $\frac{3}{2}kT_{ph}$ are the same as their J_a , F , and $\langle E \rangle$, respectively. It is readily seen that (6.7) with $J'_{ph} = 0$ gives a result twice as large as (6.8), as just mentioned. To see why this difference occurs, we rederive Pelizzari and Criswell's result more rigorously, as follows. From our Eq. (6.1), the contribution of E_x to particle displacement in the x direction is

$$\frac{-2mE_x v_{yo}^2}{eE_y^2} \quad (6.9)$$

which is the same as their Eqs. (9) and (11) combined. The contribution due to v_{xo} in (6.1) averages to zero. Now the surface current density Γ per unit z equals the integral over v_{xo} and v_{yo} of: photoelectron production rate per unit v_{xo} and v_{yo} per unit surface area in the (x,z) plane, times distance travelled by particles of a given v_{yo} before impact [given by (6.9)]. This production rate in turn equals number per unit volume per unit v_{xo} and v_{yo} , times the value of v_{yo} .

Therefore:

$$\begin{aligned} \Gamma &= \int_0^\infty dv_{yo} \int_{-\infty}^\infty dv_{xo} \hat{f} v_{yo} \left(-\frac{2mE_x v_{yo}^2}{eE_y^2} \right) \\ &= \frac{J_{ph,o}}{\sqrt{2\pi}} \left(\frac{m}{kT} \right)^{\frac{3}{2}} \left(-\frac{2mE_x}{eE_y^2} \right) \int_{-\infty}^\infty dv_{xo} \exp \left(-\frac{mv_{xo}^2}{2kT} \right) \int_0^\infty dv_{yo} v_{yo}^3 \exp \left(-\frac{mv_{yo}^2}{2kT} \right) \\ &= -\frac{4J_{ph,o} kT_{ph}}{eE_y^2} \quad (6.10) \end{aligned}$$

in agreement with our result [Eq. (6.7)] rather than that of Pelizzari and Criswell. The reason for the difference evidently involves the fact that we have integrated Eq. (6.9) over v_{yo} but they did not. Thus we perform an integral containing v_{yo}^3 [in the first line of (6.10)], but their procedure involves essentially an integral containing v_{yo}^2 (to evaluate their quantity $\langle E \rangle$), times a separate integral containing v_{yo} (to obtain $J_{ph,o}$ from $\hat{f}$). Their procedure therefore involves the use of incorrect moments of the velocity distribution function of photoemitted electrons.

6.3 COMPARISON WITH A NUMERICAL RESULT FROM CYLVIA

Figure 4.3 shows a CYLVIA calculation of equipotential contours surrounding a cylindrical spacecraft cross-section whose surface consists of two independently floating conductive sectors, the smaller of which is shaded and subtends an angle of 90° . Data pertinent to this calculation are given in Sec. 4.5. The most noteworthy feature of Fig. 4.3 is a negative saddle-point potential barrier which surrounds the larger sector, and whose height varies from about 2 volts at the sunward point to several hundred volts near the edges of this sector.

The resulting normalized current densities j_i, j_e , and j_{ph} of ambient ions, ambient electrons, and photoelectrons are shown as functions of surface position in Fig. 6.2. We have made a separate calculation of j_{ph} using Eq. (6.7) with the tangential electric field E_x set equal to zero since the spacecraft surfaces are conductive. To use (6.7), we note that the net photoelectron flux out of the surface is equal to the divergence of Γ with respect to surface coordinates. In our geometry, this means that

$$J_{ph,net\ in} \equiv J_{ph,in} - J_{ph,out} = -\frac{1}{r_s} \frac{d\Gamma}{d\theta} = \frac{4}{r_s^2} \frac{d}{d\theta} \left[\left(\frac{kT_{ph}}{eE_r} \right)^2 \frac{dJ_{ph,out}}{d\theta} \right] \quad (6.11)$$

where

$$edJ_{ph,out}/d\theta = -45 \times 10^{-8} \sin \theta \text{ A/m}^2 \left(-\frac{1}{2}\pi < \theta < \frac{1}{2}\pi \right),$$

and the radial electric field E_r is obtained from the numerical solution for $\phi(r, \theta)$ used to construct Fig. 4.3. Net photoelectron currents obtained in this way are shown as dashed curves in Fig. 6.2. We see that near $\theta = 0^\circ$, the net outward photocurrent is badly underestimated by Eq. (6.11) since the potential barrier for electrons at this location is not much higher than the photoelectron mean thermal energy, so a substantial fraction of photoelectrons escape, and this is not allowed for in Eqs. (6.7) and (6.11). However, in the interval $30^\circ \lesssim \theta \lesssim 90^\circ$, where photoelectron escape is negligible, agreement between Eq. (6.11) and the numerical result is much better. The numerical result is about 10% to 20% above that given by (6.11); the most important reason for this

difference is probably the fact that the tangential electric field, although zero at the spacecraft surface, is nonzero outside it, and the form of the cross-term in (6.7) indicates that the production-gradient current [which is the one calculated in Eq. (6.11)] is strongly sensitive to such fields. We have shown the photoelectron current as decreasing to zero almost discontinuously beyond $\theta = 90^\circ$, because the average angular distance of photoelectron migration in the electric fields at this point ($E_\theta = 0$, $E_r = 1824$ V/m) is about 0.1° .

Another noteworthy feature of Fig. 6.2 is the decrease in the flux of ambient electrons at larger θ , caused by the increasing height of the potential barrier as one moves away from the sunward point $\theta = 0^\circ$.

7. FLUX AND DENSITY CALCULATION FOR COLLISIONLESS PARTICLE ORBITS

Calculation of current density deposited on a surface by particle orbits neighbouring a given orbit is of importance in several contexts related to spacecraft charging. Examples of these are: calculation of current density deposited on one part of a spacecraft by photoelectrons, secondary electrons, or beams of charged particles emitted from another point on it, or calculation of ion current density deposited on spacecraft surfaces in the presence of either a (model) infinite or a large but finite ion speed ratio. In this Section, a simple, general procedure is described for obtaining such information essentially as a byproduct of a numerical orbit calculation. The procedure is based on a perturbation of the orbit equations, and involves finding the evolution along an orbit of the axes of a differential tube of neighbouring orbits. The positions of these axes are given in terms of a set of integrals, contributions to which are collected as the orbit is followed numerically, and whose integrands involve the space derivatives $\partial F_i / \partial x_j$ of the force components of points along it. At a surface impingement point, current density is then obtained by projecting the cross-section of this tube onto the surface tangent plane. The same formulation can also be used to obtain information about particle number density along an orbit.

In order to appreciate the usefulness of such a procedure it is instructive to compare it with the "standard" procedure which one would normally follow in calculating values of current density deposited on surfaces, and space charge density, of collisionless ions with negligible thermal motion flowing past a collecting object. The "standard" procedure is to numerically follow sets of neighbouring, initially-parallel particle orbits inward from an assumed unperturbed region far from the object, and to calculate flux and density everywhere between any two orbits by finding out how far apart they have become at their impingement points or elsewhere. This method has inherent difficulties: if the orbits chosen are too far apart initially, an orbit may eventually go off in a very different direction than the orbit next to it, making calculations of flux or density between them impossible or unrealistic. On the other hand, if they are initially too close together, inaccuracies in calculating either orbit may obscure the small difference which one is trying to calculate.

Our calculation proceeds as follows. The equations of particle motion are:

$$\frac{d^2 \vec{x}}{dt^2} = \frac{F(\vec{x}, t)}{m} \quad (7.1)$$

which is equivalent to:

$$\frac{d^2 x_i}{dt^2} = \frac{F_i(x_1, x_2, x_3, t)}{m} \quad (7.2)$$

Integration of this yields:

$$x_i(t) = x_i(0) + v_i(0)t + \int_0^t dt' \int_0^{t'} dt'' \frac{F_i[x_k(t''), t'']}{m} \quad (7.3)$$

For perturbed orbits, (7.2) is replaced by:

$$\frac{d^2}{dt^2} (x_i + \delta x_i) = \frac{F_i + \delta F_i}{m} \quad (7.4)$$

Subtraction of (7.2) from (7.4) yields:

$$\frac{d^2}{dt^2} \delta x_i = \frac{\delta F_i}{m} \quad (7.5)$$

We now assume that perturbations at any instant are small. Then:

$$\delta F_i = \sum_j \frac{\partial F_i}{\partial x_j} \delta x_j \quad (7.6)$$

i.e. we ignore $(\delta x_j)^2$, $(\delta x_j)^3$, etc.

Equations (7.5) and (7.6) now imply, after integrating twice:

$$\delta x_i(t) = \frac{1}{m} \int_0^t dt' \int_0^{t'} dt'' \sum_j \frac{\partial F_i}{\partial x_j} [x_k(t''), t''] \delta x_j(t'') + \delta x_i(0) + t \delta v_i(0) \quad (7.7)$$

where the nine quantities $\partial F_i / \partial x_j$ must be provided along the unperturbed orbit given by $x_k(t'')$ and t'' .

By noting that the region of integration in (7.7) is a triangle in (t', t'') coordinates, and then interchanging the order of integration, we can change (7.7) into the equivalent form (A.D. Stauffer, private communication):

$$\delta x_i(t) = \frac{1}{m} \int_0^t dt'' (t-t'') \sum_j \frac{\partial F_i}{\partial x_j} [x_k(t''), t''] \delta x_j(t'') + \delta x_i(0) + t \delta v_i(0) \quad (7.8)$$

which contains only a single integration.

We now consider a monokinetic particle beam having initial velocity $(v_0, 0, 0)$. This implies a zero initial perturbation velocity: $\delta \vec{v}(0) = (0, 0, 0)$. We choose two mutually orthogonal initial perturbations in position:

$$\delta_2 \vec{x}(0) = (0, 1, 0) \quad (7.9)$$

$$\delta_3 \vec{x}(0) = (0, 0, 1)$$

Since (7.8) is both linear and homogeneous in $\delta \vec{x}$, final values of $\delta_2 \vec{x}$ and $\delta_3 \vec{x}$ are proportional to initial values, as one expects for perturbation quantities.

Furthermore, if $\delta \vec{x}(0) = a \delta_2 \vec{x}(0) + b \delta_3 \vec{x}(0)$, then $\delta \vec{x}(t) = a \delta_2 \vec{x}(t) + b \delta_3 \vec{x}(t)$, where a and b are unchanged.

We now consider an initially circular differential tube of orbits defined by (7.9). As the unperturbed orbit is followed numerically, we simultaneously calculate $\delta_2 \vec{x}$ and $\delta_3 \vec{x}$ using (7.8). At the impingement point of the orbit, we project these onto the surface tangent plane (Fig. 7.1). The area of the ellipse thus generated is inversely proportional to the current density deposited on the surface.

For a monokinetic beam, this gives current density with no approximations.

The linearity of the perturbation equation (7.8) now implies that all orbits passing through A_0 (Fig. 7.1) also pass through A . Therefore the total current carried by the tube is a constant, equal to $A_0 j_0 = \frac{\pi}{4} j_0$, where j_0 is the current density through A_0 .

The area A is given by:

$$A = \frac{\pi}{4} \left| \delta_2^{\vec{x}} \times \delta_3^{\vec{x}} \right| = \frac{\pi}{4} \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ \delta_2^{x_1} & \delta_2^{x_2} & \delta_2^{x_3} \\ \delta_3^{x_1} & \delta_3^{x_2} & \delta_3^{x_3} \end{vmatrix} \quad (7.10)$$

where $\hat{i}$, $\hat{j}$, and $\hat{k}$ are unit vectors along the coordinate axes.

The current density at the surface therefore varies inversely as the projected tube area given by:

$$\frac{\pi}{4} \hat{n} \cdot (\delta_2^{\vec{x}} \times \delta_3^{\vec{x}}) = \frac{\pi}{4} \begin{vmatrix} n_1 & n_2 & n_3 \\ \delta_2^{x_1} & \delta_2^{x_2} & \delta_2^{x_3} \\ \delta_3^{x_1} & \delta_3^{x_2} & \delta_3^{x_3} \end{vmatrix} \quad (7.11)$$

evaluated at the orbit impingement point on the surface, where $\hat{n}$ is a unit vector perpendicular to the surface tangent plane (Fig. 7.1).

The current density at the surface therefore is:

$$j_{\text{surface}} = j_0 \left/ \begin{vmatrix} n_1 & n_2 & n_3 \\ \delta_2^{x_1} & \delta_2^{x_2} & \delta_2^{x_3} \\ \delta_3^{x_1} & \delta_3^{x_2} & \delta_3^{x_3} \end{vmatrix} \right|_{\text{surface}} \quad (7.12)$$

It is possible for the plane of the ellipse to be perpendicular to the surface tangent plane. This occurs when the perturbed orbits happen to cross each other at the surface. The current density at the surface will then be infinite. This can occur only for a monokinetic distribution of initial velocities, which is only an approximation to real distributions.

We can also obtain an expression for number density n along the orbit, since $n\vec{v}$ times the projection of A on a plane perpendicular to $\vec{v}$ remains constant along the orbit.

i.e. the product $\frac{\pi}{4} n \left| \vec{v} \cdot (\delta_2 \vec{x} \times \delta_3 \vec{x}) \right|$ is constant.

We therefore obtain:

$$n = n_o v_o / \left\| \begin{array}{ccc} v_1 & v_2 & v_3 \\ \delta_2 x_1 & \delta_2 x_2 & \delta_2 x_3 \\ \delta_3 x_1 & \delta_3 x_2 & \delta_3 x_3 \end{array} \right\| \quad (7.13)$$

For a monokinetic distribution, n can also become infinite if the perturbed orbits cross each other. For the same distribution, n (and j_{surface} if a surface is present) can also become infinite if one of the vectors $\delta_2 \vec{x}$ or $\delta_3 \vec{x}$, or some linear combination of them, becomes zero. An example of this occurs on the (wake) axis of symmetry behind a sphere in a flowing collisionless plasma containing infinite-speed-ratio ions.

In two dimensions the perturbation produces a differential strip rather than tube. The corresponding results are:

$$j_{\text{surface}} = j_o / \left\| \begin{array}{cc} n_1 & n_2 \\ \delta x_1 & \delta x_2 \end{array} \right\|_{\text{surface}} \quad (7.14)$$

$$n = n_o v_o / \left\| \begin{array}{cc} v_1 & v_2 \\ \delta x_1 & \delta x_2 \end{array} \right\| \quad (7.15)$$

We can also consider velocity-space rather than position-space initial perturbations. We assume that:

$$\delta_2 \vec{x} = \delta_3 \vec{x} = 0, \text{ but } \delta_2 \vec{v} = (0,1,0), \text{ and } \delta_3 \vec{v} = (0,0,1). \quad (7.16)$$

This permits us to treat situations where the ion speed ratio is large but not infinite. We can use (7.16) to do a calculation of ion defocusing on the wake axis behind a sphere, valid to order S_i^{-1} , where S_i is the ion speed ratio. We consider the situation shown in Fig. 7.2, in which an unperturbed orbit, initially parallel to the ion drift direction, has already been computed, in the presence of some known or given electric potential distribution e.g. a Coulomb potential. This orbit crosses the z axis at a downstream point z_o . Because

all orbits having the same impact parameter r_0 cross at z_0 , the ion density at this point is "infinite" unless the ions also have some random motion (S_i is finite). In reality the resulting space charge along this axis will influence ion orbits near it, but we ignore this effect here. We assume that values of $\partial F_r / \partial r$, $\partial F_r / \partial z$, $\partial F_z / \partial r$, and $\partial F_z / \partial z$ are known along the unperturbed orbit. Our procedure is as follows. We choose two initial velocity perturbation vectors $\delta_a \vec{v}(0)$ and $\delta_b \vec{v}(0)$ in the plane of the unperturbed orbit (Fig. 7.2). We also choose $\delta_2 \vec{x}(0) = \delta_3 \vec{x}(0) = 0$ at z_0 . We now do our perturbation calculations backward, or "inside-out" along the ion orbit, even though we initially calculated the orbit forward, in the ion direction of motion. A single integration of (7.5) with (7.6) yields:

$$\delta v_i(t) = \frac{1}{m} \int_0^t dt' \sum_j \frac{\partial F_i}{\partial x_j} [x_k(t'), t'] \delta x_j(t') + \delta v_i(0). \quad (7.17)$$

For each of our two initial velocity perturbation vectors, we first integrate (7.8) from z_0 to an upstream point at which the orbit is essentially no longer affected by the electric field of the sphere. We then use the resulting values of $\delta x_j(t')$ [in this case $\delta r(t')$ and $\delta z(t')$] in (7.17) to calculate $\delta v_i(t)$ [in this case $\delta v_r(t)$ and $\delta v_z(t)$] at the same upstream point. The linearity of the perturbation calculation

already discussed, implies now that multiplying $\delta_a \vec{v}(0)$ and $\delta_b \vec{v}(0)$ by any constants a and b means that $\delta_a \vec{v}(t)$ and $\delta_b \vec{v}(t)$ are also multiplied by a and b . Suppose now that the velocity distribution at the upstream point is a drifting Maxwellian. The linearity just mentioned now implies that velocity components in the (r, z) plane at the upstream point map linearly into those on the axis at z_0 , so an integration over velocity space to find the density at z_0 is easy to perform. This now will be found to yield a finite rather than infinite result, essentially because most ions will now have a small amount of angular momentum about the axis of symmetry and will no longer be found at z_0 , and our perturbation calculation implicitly takes this into account.

As a final example, we consider the case of a nearly-monokinetic beam (the usual case for ion or electron guns on a spacecraft). We first need to calculate the five perturbation quantities $\delta_2 \vec{x}, \dots, \delta_6 \vec{x}$ resulting from choosing initial perturbations given by (7.9) and by $\delta_1 \vec{v}(0) = (1, 0, 0)$, $\delta_2 \vec{v}(0) = (0, 1, 0)$, $\delta_3 \vec{v}(0) = (0, 0, 1)$. The values of $\delta_2 \vec{x}$ and $\delta_3 \vec{x}$ then give, as before, current density or space-charge density at any point of interest, but these are now differential

quantities with respect to the velocity distribution $f \equiv d^3N/dv_1dv_2dv_3$ of the beam at its emission point; i.e. the values of these quantities found in this way are proportional to $f(v_1, v_2, v_3)dv_1dv_2dv_3$. The remaining perturbation quantities $\delta_4^{\vec{x}}$, $\delta_5^{\vec{x}}$, and $\delta_6^{\vec{x}}$ then give the required information about the spread of the beam in position space. This may itself be due or partly due to beam space-charge; if this is the case, then the force derivatives $\partial F_1/\partial x_j$ must themselves be found self-consistently, complicating the problem; in this case, calculations of the kind presented here would presumably become part of an iterative scheme.

If the beam is not nearly monokinetic (as will often be the case if it has not been deliberately accelerated) or it creates its own potential barrier around the spacecraft, so that part of it escapes and part does not, then evidently differential perturbations in velocity do not provide a realistic description of the result, and one would then need to replace calculations of $\delta_4^{\vec{x}}$, $\delta_5^{\vec{x}}$, and $\delta_6^{\vec{x}}$ by separate, non-perturbation, orbit calculations for a representative discrete sample of the particle velocities most strongly represented in the beam.

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Table 1

Floating potentials of shaded surfaces of geostationary-altitude spacecraft, using the incident velocity spectra assumed by Knott [1972], with backscattered and secondary electron emission due to electron impacts included, with three-, two-, and one-dimensional velocity-space cutoffs corresponding to orbit-limited ion collection in spherical, infinite cylindrical and planar symmetries, respectively.

Material	Secondary Electron Emission Data		Back-scatter Data $\eta(5000\text{eV})$	Spectrum 1 "Quiet"			Spectrum 2b "Disturbed"		
	δ_{max}	E_{max} (eV)		Floating Potential (volts) 3-dimen.	Floating Potential (volts) 2-dimen.	Floating Potential (volts) 1-dimen.	Floating Potential (volts) 3-dimen.	Floating Potential (volts) 2-dimen.	Floating Potential (volts) 1-dimen.
Gold	1.45	800	.42	-39.9	-40.0	-40.8	-3470	-6430	-15,450
Aluminum	.97	300	.16	-1410	-2140	-5390	-6770	-11,500	-21,770
Aluminum with Oxide Coating	2.60	300	.12	+4.6 -630* -750	+3.0 -490* -1560	+1.9 -420* -4900	-6610	-11,360	-21,610
Quartz	2.50	420	.12	+3.9	+2.5	+1.5 -640* -4120	-6310	-10,960	-21,130
Aquadag	.75	350	.08	-1560	-2380	-5890	-7090	-12,010	-22,350
Beryllium Copper	2.20	300	.31	+4.7	+2.9	+1.9 -560* -3430	-5740	-9920	-19,890
Beryllium Copper Activated	5.00	400	.31	+8.0	+5.8	+4.2	-4.3 -900* -3950	+2.9 -830* -7580	+1.6 -770* -17,670
Teflon	3.00	300	.10	+5.2	+3.6 -660* -1370	+2.3 -490* -4870	-6640	-11,430	-21,700
Kapton	2.10	150	.07	+3.9 -170* -1580	+2.5 -170* -2440	+1.4 -170* -6040	-7180	-12,130	-22,520
No secondary or backscattered electrons	—	—	—	-1860	-2830	-6680	-7550	-12,690	-23,130

* Unstable

TABLE 2

THRESHOLD TEMPERATURES T* FOR SPACECRAFT SURFACE MATERIALS
 IC1: INCLUDING SECONDARY ELECTRONS.
 IC2: INCLUDING SECONDARY AND BACKSCATTERED ELECTRONS.
 IC3: SAME AS IC2 EXCEPT THAT ANGULAR DEPENDENCE OF YIELD IS INCLUDED.

MATERIAL	SECONDARY		BACKSCATTERING				T* (keV)		
	E _{max} (keV)	δ _{max}	Z	A	B	C	IC1	IC2	IC3
GOLD	.80	1.45	79.0	.4802	.3566	.6103	1.278	2.931	4.939
ALUMINUM	.30	.97	13.0	.1569	.0303	.3431	0.000	0.000	.601
ALUMINUM OXIDE	.30	2.60	10.0	.1238	.0172	.3435	1.116	1.777	1.931
SiO2(QUARTZ)	.42	2.50	10.0	.1238	.0172	.3435	1.496	1.713	2.621
FUSED SILICA	.33	3.46	10.0	.1238	.0172	.3435	1.645	1.847	2.707
ARADAG(COLLOIDAL GRAPHITE)	.35	.75	6.0	.0800	0.0000	0.0000	0.000	0.000	0.000
BERYLLIUM-COPPER	.30	2.20	29.0	.3136	.0692	.6207	.918	1.349	2.157
BERYLLIUM-COPPER(ACTIVATED)	.40	5.00	29.0	.3136	.0692	.6207	2.754	3.697	5.423
TEFLON	.30	3.00	8.0	.0900	0.0000	0.0000	1.299	1.477	2.102
KAPTON (Willis and Skinner, 1973)	.15	2.10	5.3	.0700	0.0000	0.0000	.433	.474	.769
KAPTON (Leung et al, 1981)	.25	1.80	5.3	.0700	0.0000	0.0000	.583	.647	1.096
INDIUM OXIDE	.80	1.40	24.4	.2750	.0600	.5400	1.184	2.010	3.596
MAGNESIUM	.25	.92	12.0	.1460	.0250	.3440	0.000	0.000	.441
MAGNESIUM OXIDE	.40	4.00	10.0	.1738	.0172	.3435	2.280	2.548	3.686
SILVER	.80	1.00	47.0	.3900	.2890	.6320	0.000	1.233	2.754
ITO ON KAPTON	.35	2.55	15.3	.1830	.0370	.3820	1.275	1.550	2.370
ITO ON 'FEP' TEFLON	.36	2.39	16.2	.1920	.0400	.3990	1.217	1.507	2.329
ITO ON BOROSILICATE GLASS	.35	2.35	16.9	.2000	.0420	.4100	1.160	1.456	2.254
ION-SPUTTERED ITO ON KAPTON	.39	1.52	15.3	.1830	.0370	.3820	.684	.921	1.587
MGF2	.85	6.38	10.0	.1238	.0172	.3435	7.141	7.889	11.054
NASCAP 'MPAI'	.15	2.10	5.0	.0600	0.0000	0.0000	.433	.468	.747
NASCAP 'SOLA'	.41	2.05	10.0	.1238	.0172	.3435	1.147	1.338	2.123
NASCAP 'CPAI'	.15	2.10	5.0	.0600	0.0000	0.0000	.433	.468	.747
NASCAP 'WHITEN'	.15	2.10	5.0	.0600	0.0000	0.0000	.433	.468	.747
NASCAP 'BLACKC YELLOWC'	.15	2.10	5.0	.0600	0.0000	0.0000	.433	.468	.747
NASCAP 'GOLIPD'	.72	1.03	70.1	.4560	.3380	.6120	0.000	1.392	2.857
NASCAP 'YGULDS'	.48	1.49	42.0	.3730	.2760	.6170	.810	1.392	2.444
NASCAP 'EDUHAT'	.59	1.86	63.4	.4380	.3250	.6130	1.443	2.596	4.203
NASCAP 'MLI2'	.30	1.00	6.0	.0800	0.0000	0.0000	0.000	0.000	.602

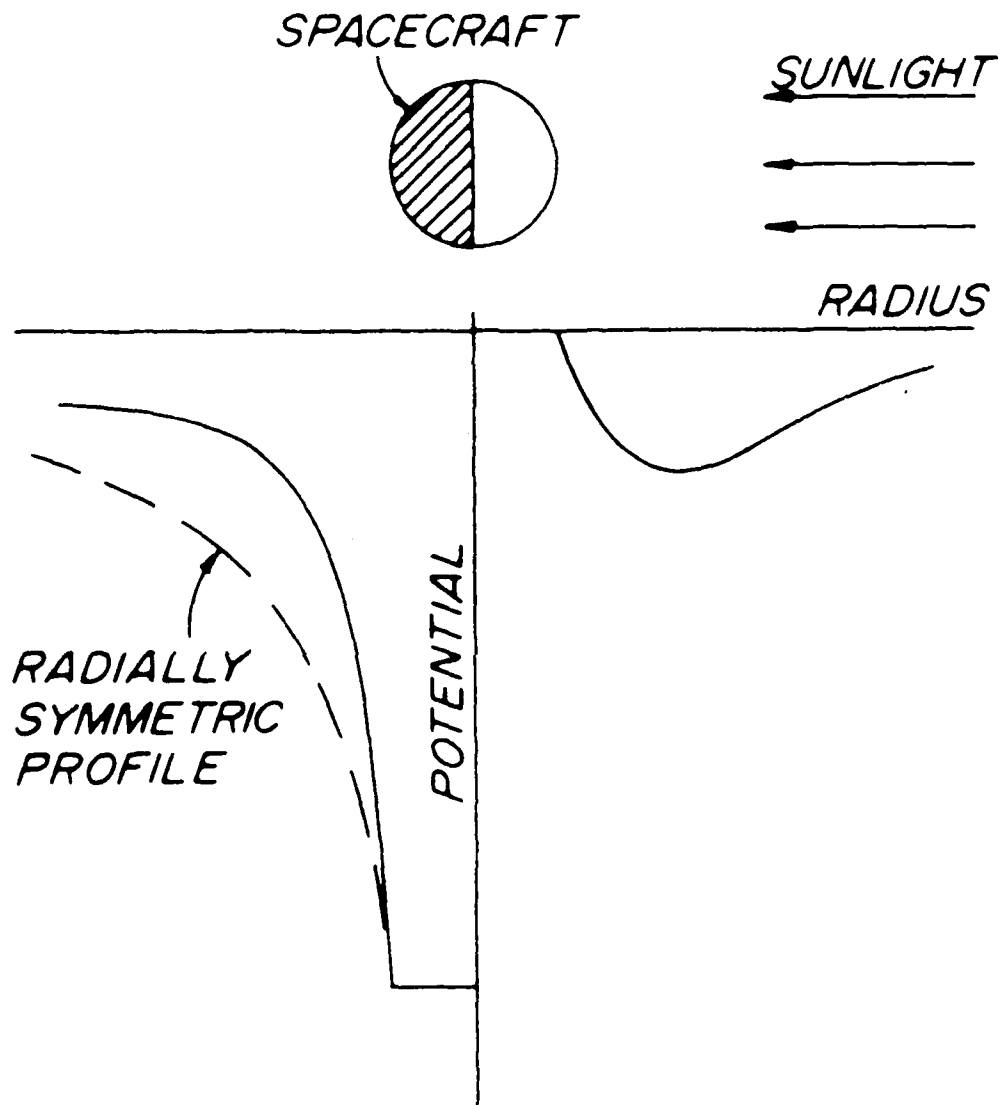


Fig. 2.1. Steepening of shaded-side potential profile, and sunlit-side potential barrier formation, caused by shaded-sunlit asymmetry on a spacecraft with an insulated surface, after Fahleson [1973].

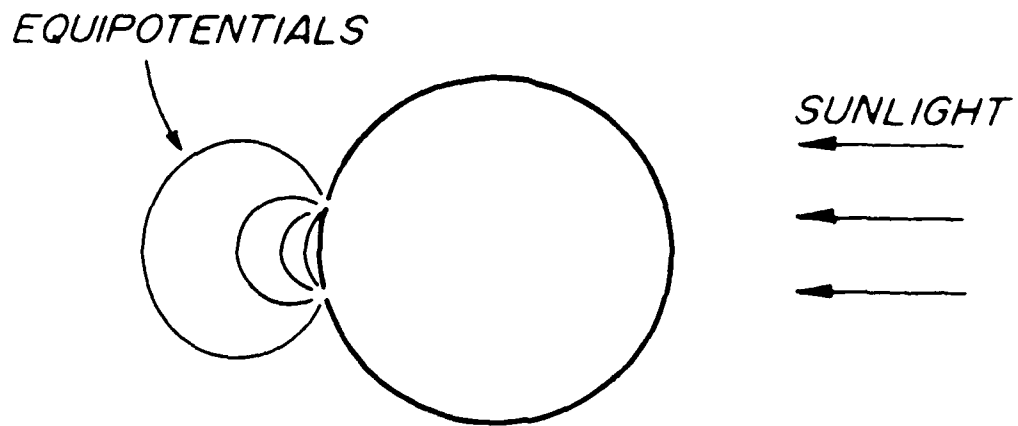


Fig.2.2. Conductive spacecraft with shaded isolated surface patch.

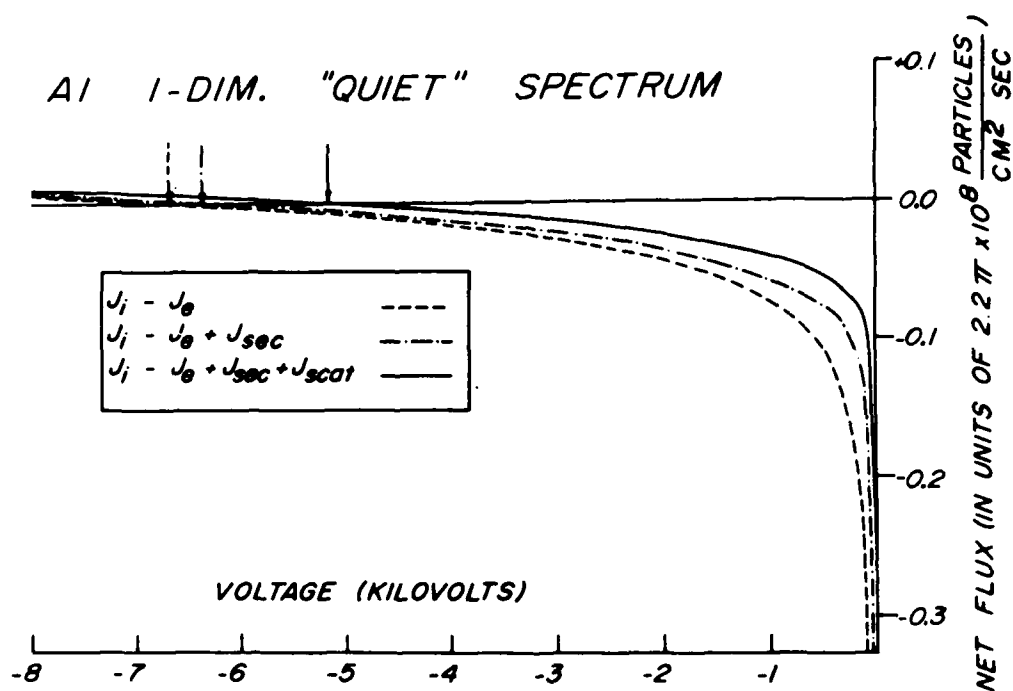


Fig. 2.3. Current-voltage characteristic for aluminum in "quiet" conditions, with a one-dimensional velocity-space cutoff. In Figures 2.3 - 2.7 the zeros of the characteristics are indicated by arrows.

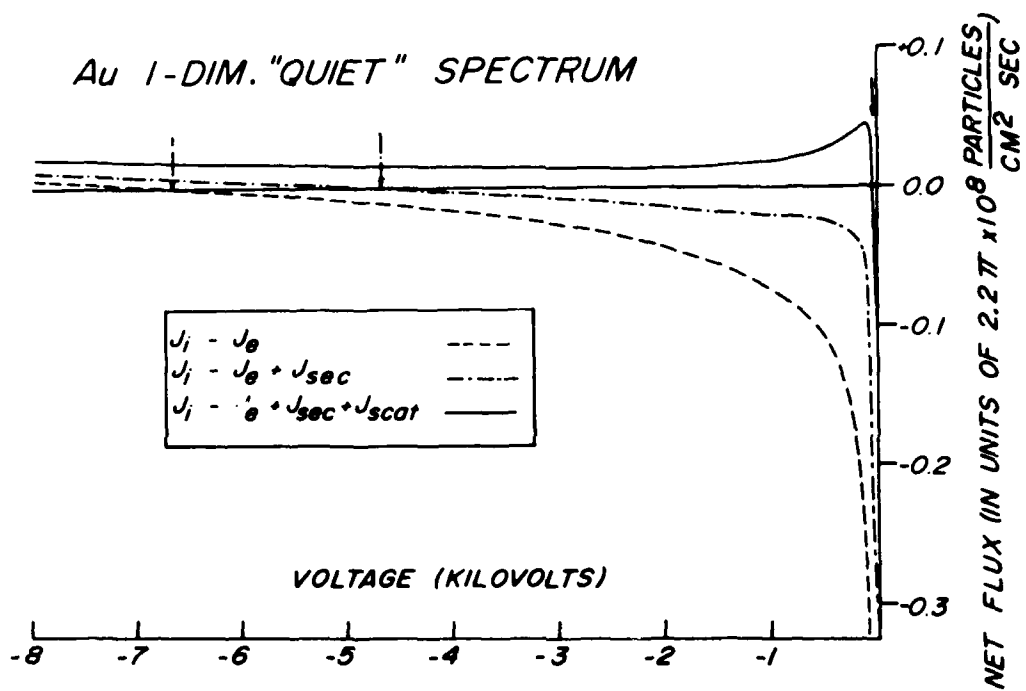


Fig. 2.4. Current-voltage characteristic for gold in "quiet" conditions, with a one-dimensional velocity-space cutoff.

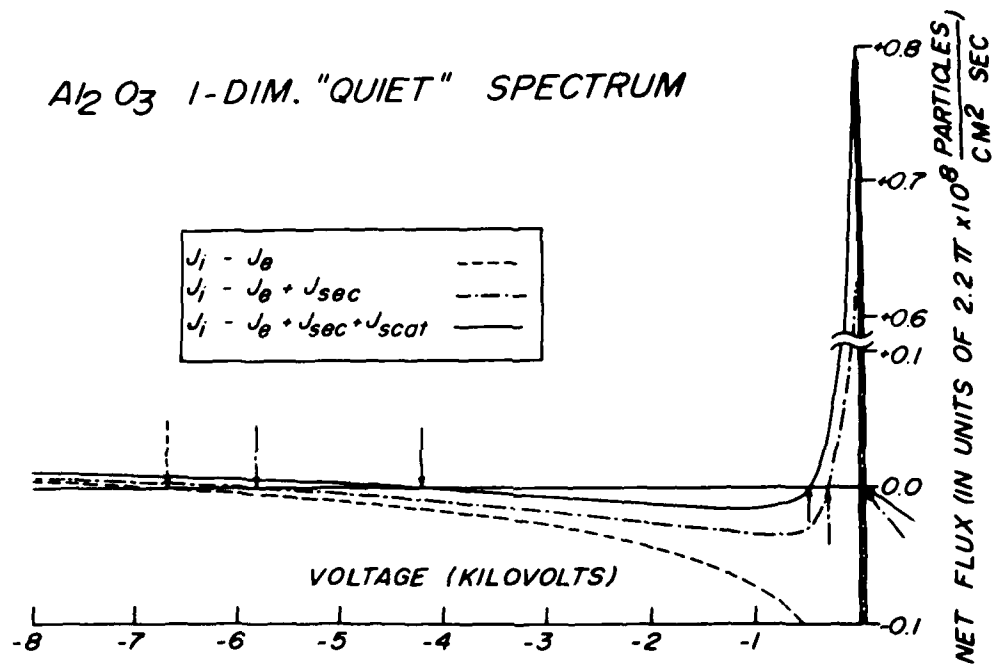


Fig. 2.5. Current-voltage characteristic for aluminum oxide in "quiet" conditions, with a one-dimensional velocity-space cutoff.

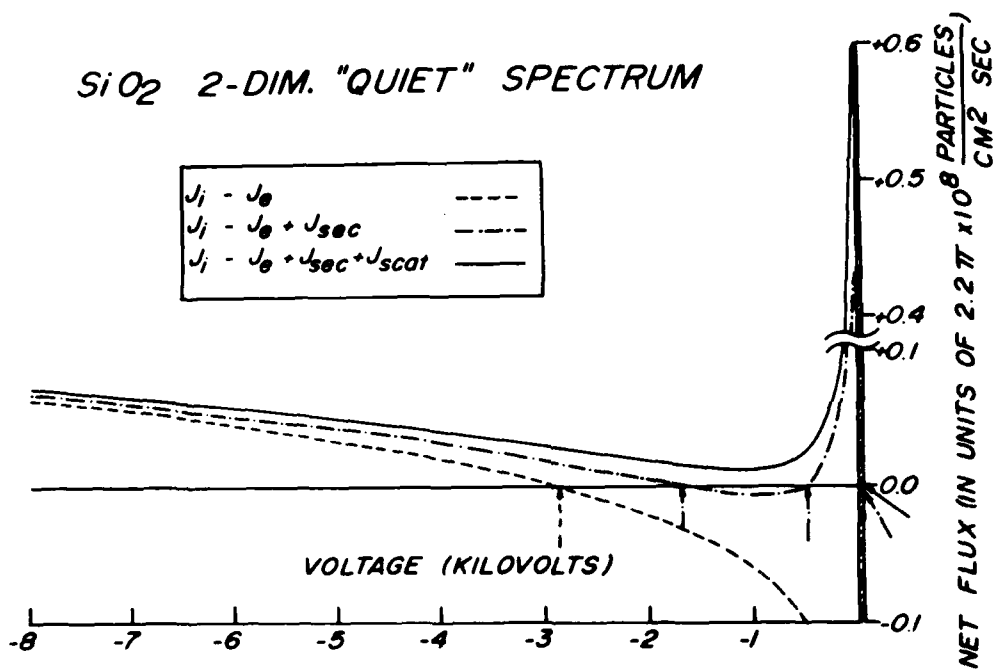


Fig. 2.6. Current-voltage characteristic for quartz in "quiet" conditions, with a two-dimensional velocity-space cutoff.

*Activated Beryllium-Copper
1-DIM. "QUIET" SPECTRUM*

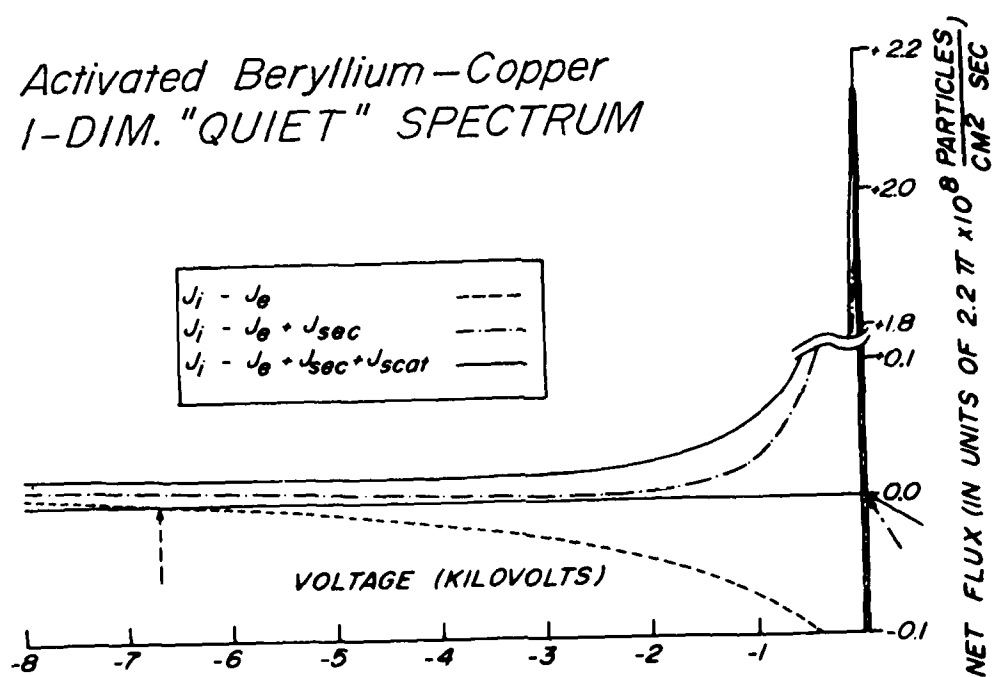


Fig. 2.7. Current-voltage characteristic for activated beryllium-copper in "quiet" conditions, with a one-dimensional velocity-space cutoff.

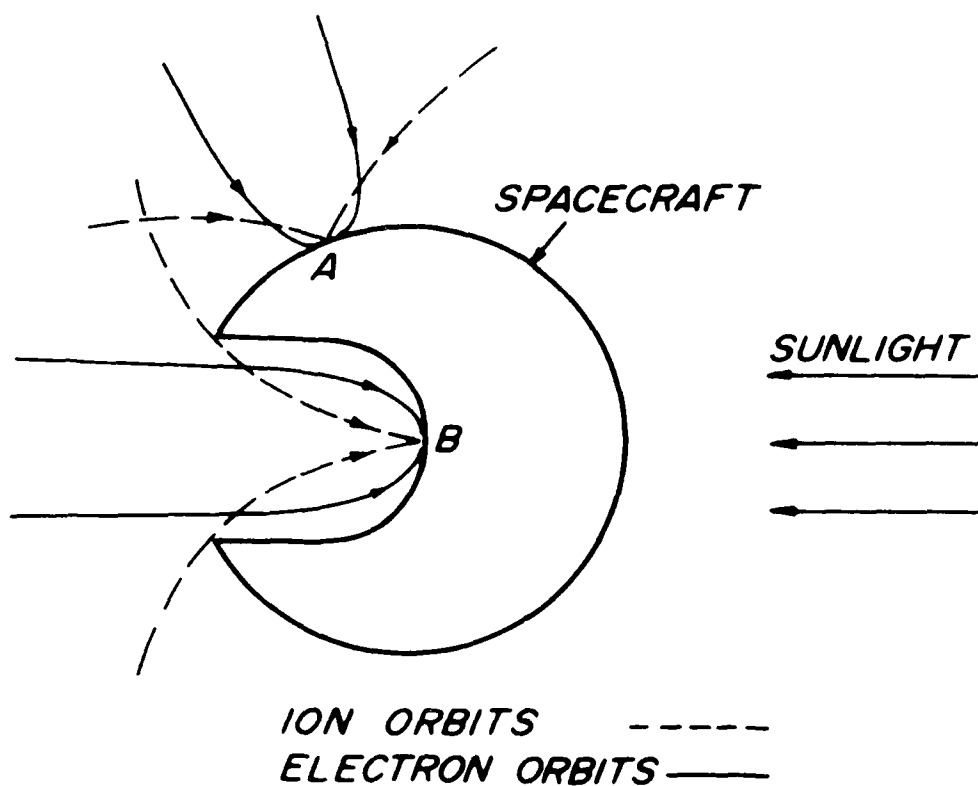


Fig. 2.8. Spacecraft with shaded isolated cavity, showing incident ion and electron orbits with energies close to the lowest for which collection of each species is possible. The orbits shown are cutoff orbits, defined as the most nearly tangential orbits for which incident particles of a given energy are able to reach a given point on the spacecraft surface, having tangential velocity component in a given direction.

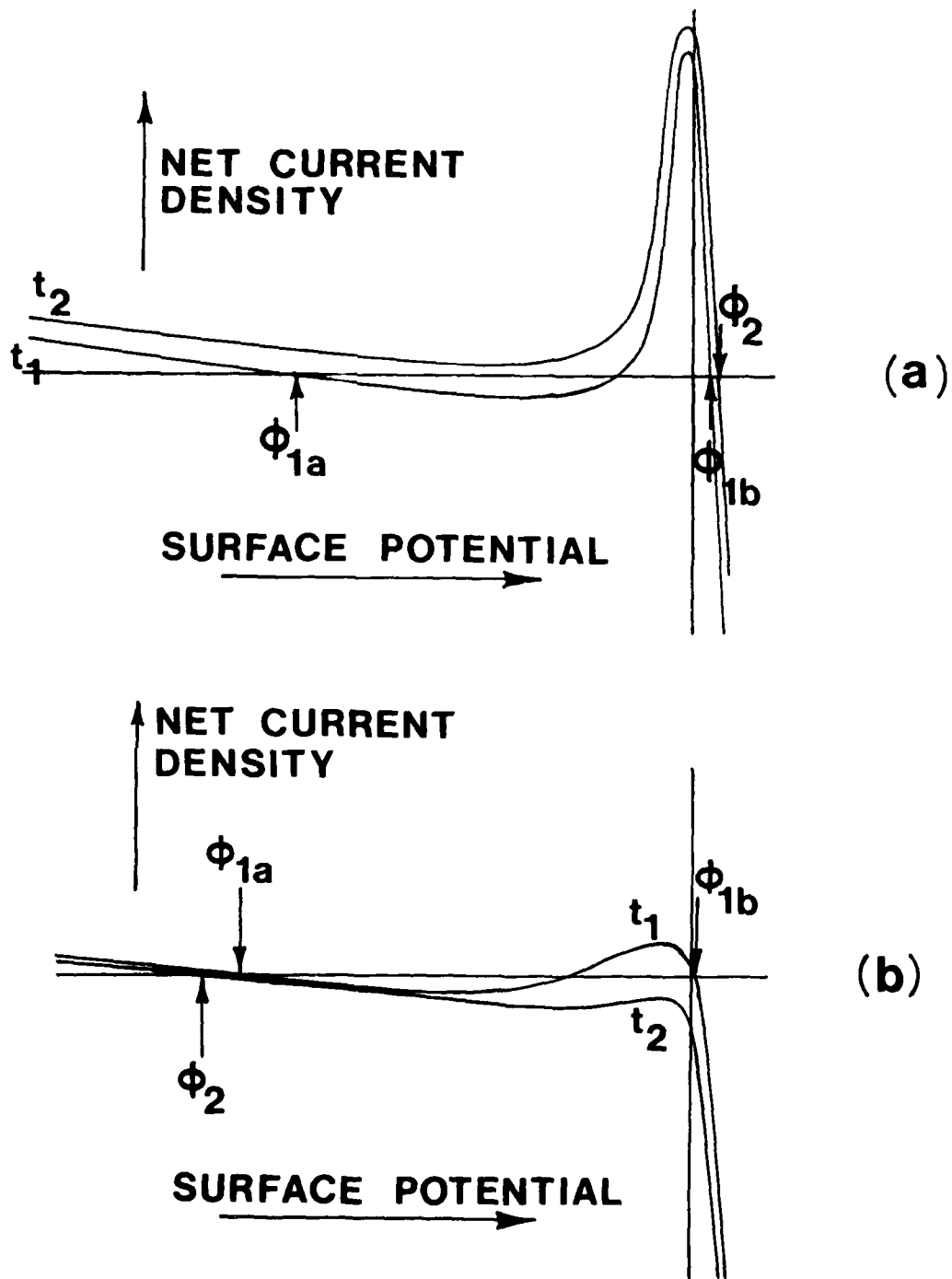


Fig. 2.9. Disappearance of multiple roots in the current-voltage characteristic of a spacecraft surface, as a result of temporal changes in ambient electron velocity distributions. These illustrations are schematic only but are representative of predicted behavior for various surface materials. Some combinations of materials and environments for which such behavior is predicted appear as clusters of three numbers in Table 1.

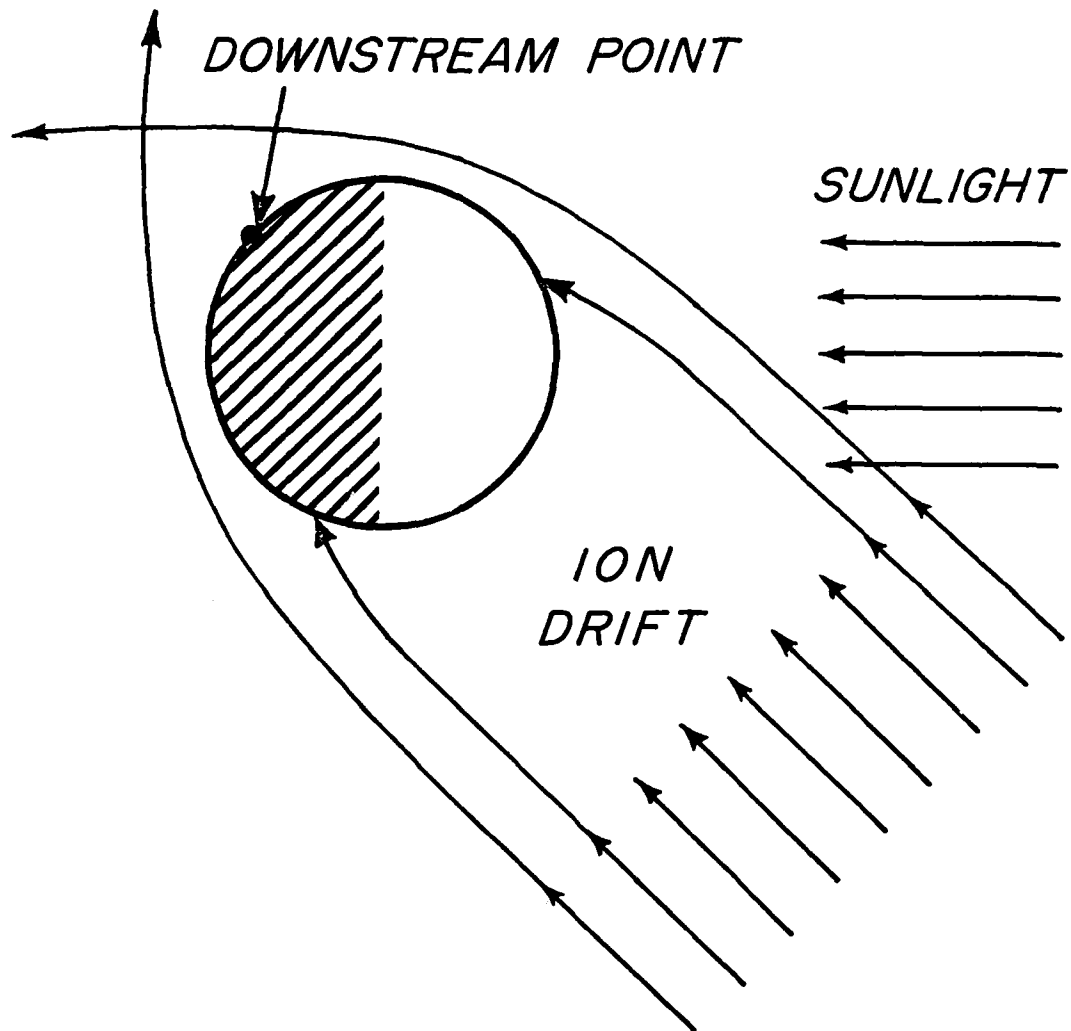


Fig. 2.10. Spherical spacecraft with downstream point (relative to ion drift direction) shaded.

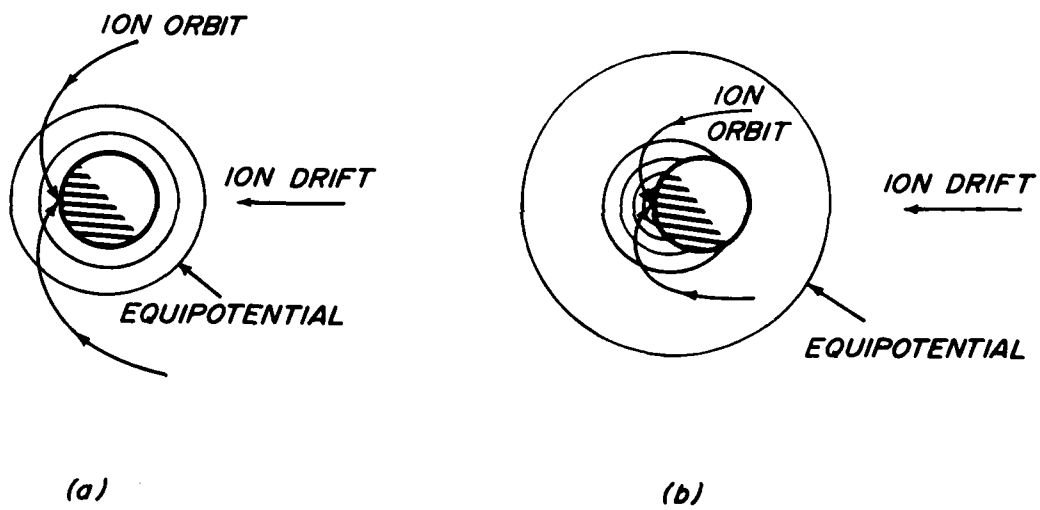


Fig. 2.11(a) Hypothetical symmetric equipotentials around a spherical spacecraft (b) nonsymmetric equipotentials around the same spacecraft.

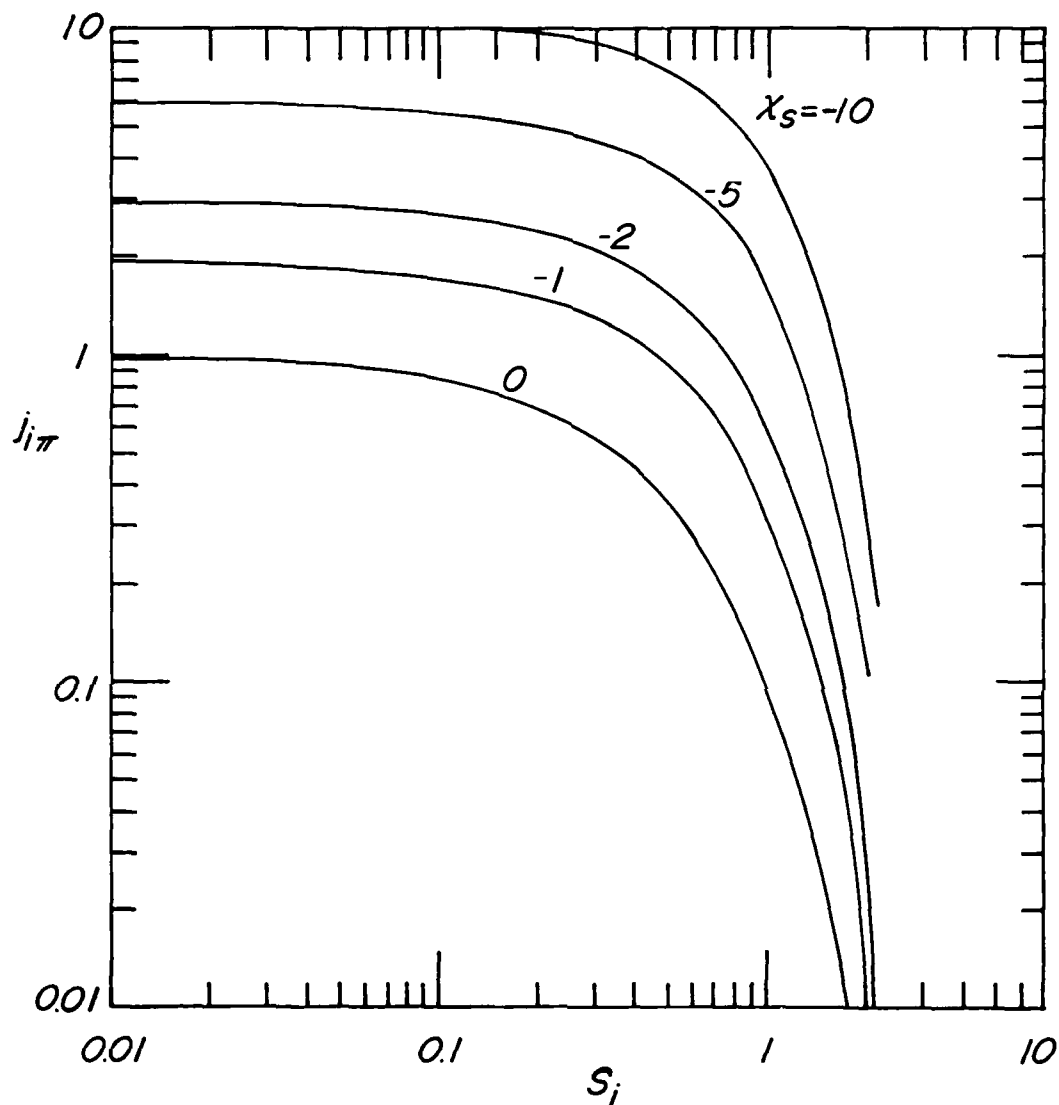


Fig. 2.12. Nondimensional downstream-point ion current density $j_{i\pi} = J_{i\pi} / [N_{\infty} e (kT_i / 2\pi m_i)^{1/2}]$ as a function of ion speed ratio $S_i = U / (2kT_i / m_i)^{1/2}$ for various nondimensional surface potentials $\chi_s = e\phi_s / kT_i$, assuming spherical geometry, zero magnetic field, uniform surface potential, collisionless large-Debye-length conditions, and drifting Maxwellian ions. For $S_i \rightarrow 0$, $j_{i\pi} \rightarrow 1 + |\chi_s|$ when $\chi_s < 0$.

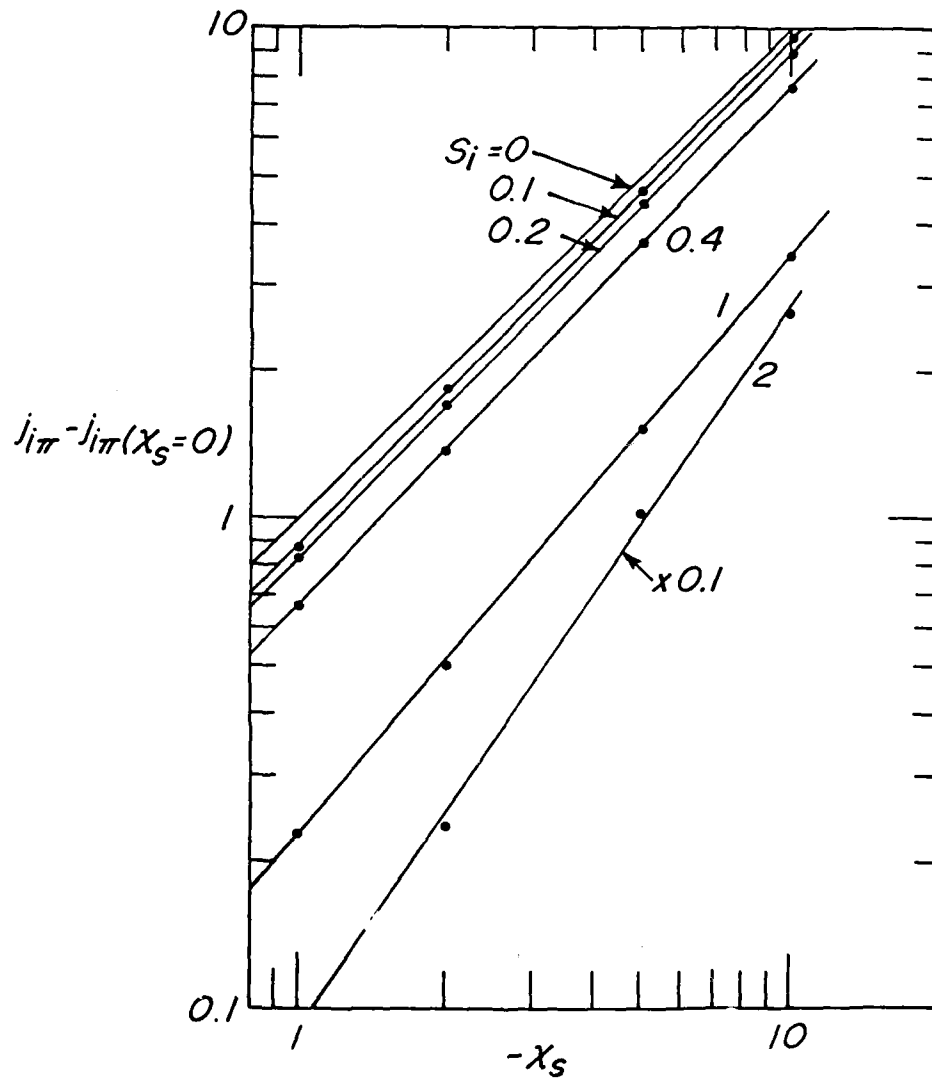


Fig. 2.13. Nondimensional downstream-point ion current density $j_{i\pi}$ as a function of surface potential X_s for various ion speed ratios S_i , for the same conditions as in Fig. 2.12. The straight lines shown are power-law approximations.

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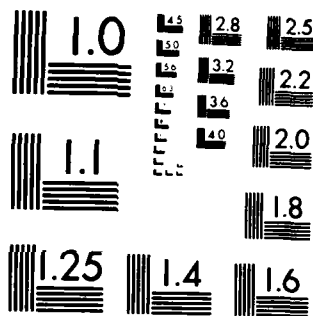
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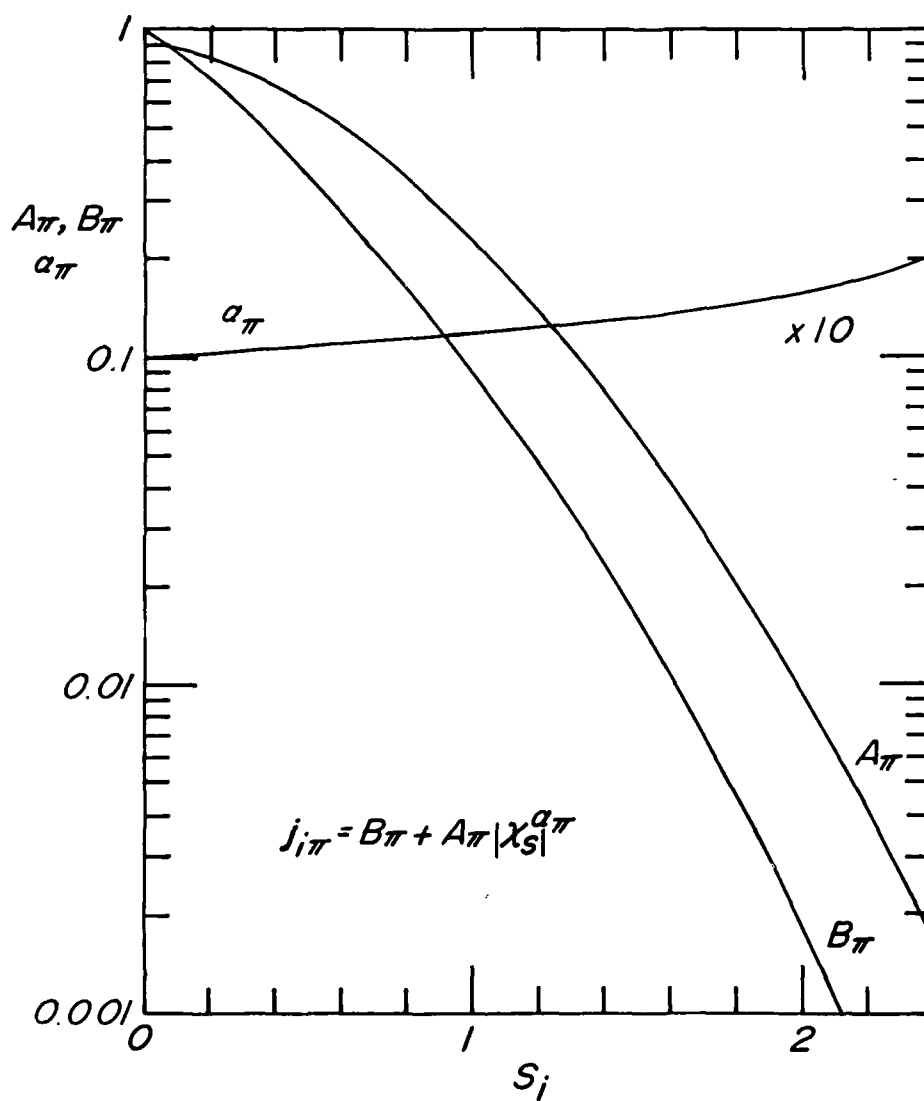


Fig. 2.14. Dependence of the power-law coefficients A_π , B_π and α_π on ion speed ratio S_i .

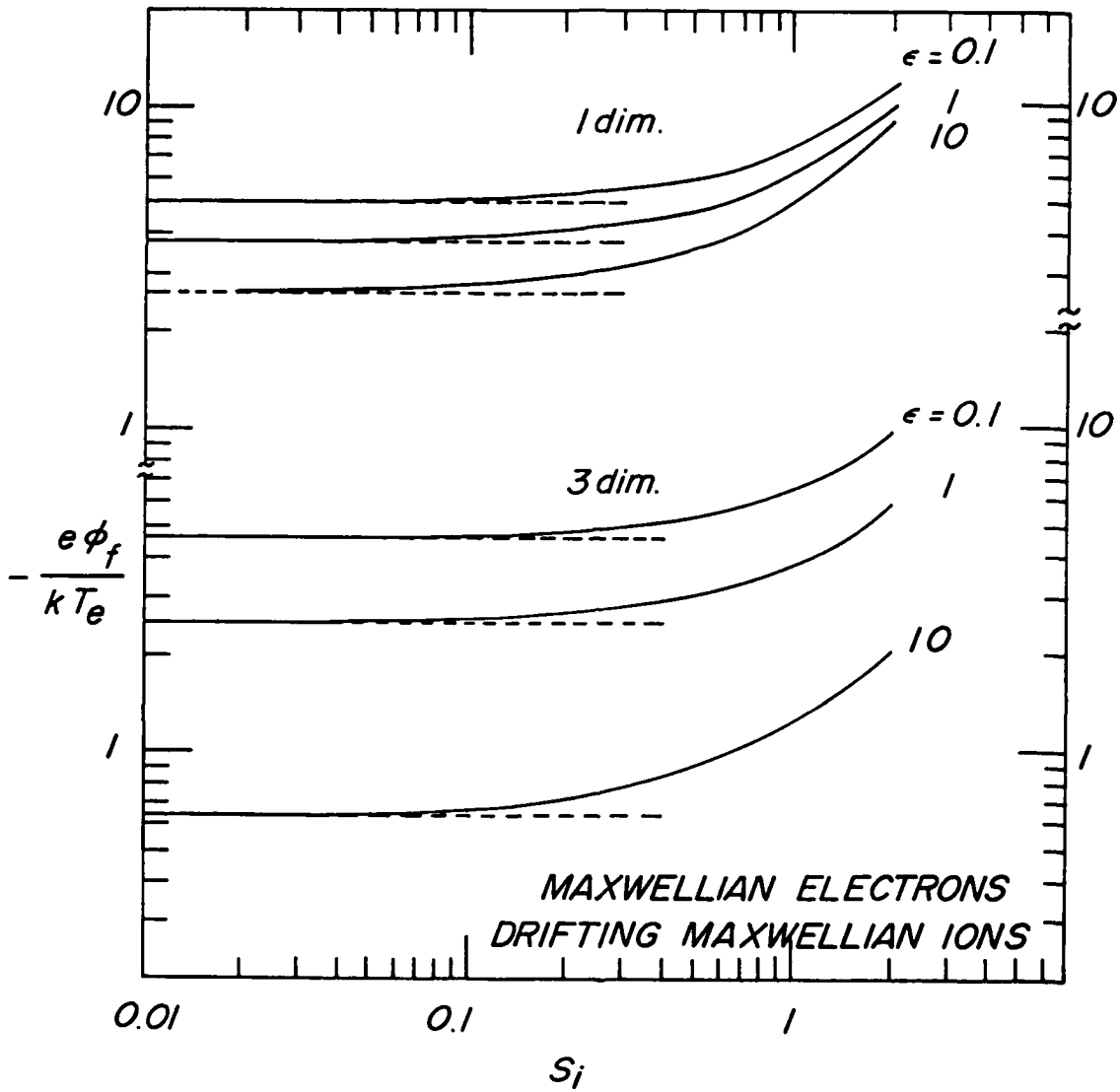


Fig. 2.15. Upper and lower bounds on floating potential ϕ_f at shaded downstream point of spacecraft, as a function of ion speed ratio S_i for various ion-to-electron temperature ratios ϵ , for Maxwellian electrons and drifting Maxwellian ions, for one-dimensional and three-dimensional ion velocity space cutoffs.

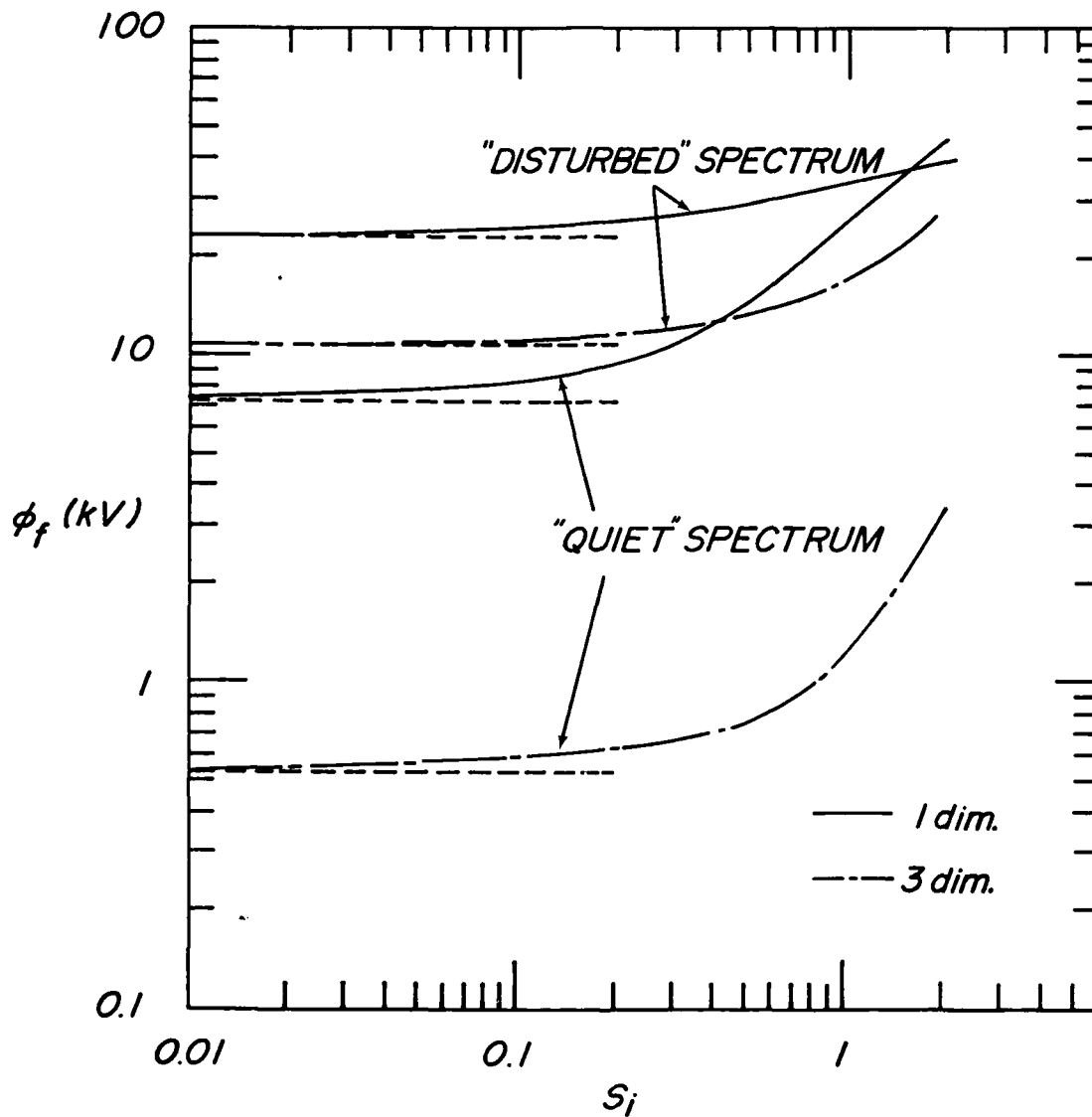


Fig. 2.16. Upper and lower bounds on floating potential ϕ_f at shaded downstream point of spacecraft, as a function of ion speed ratio S_i for "disturbed" and "quiet" electron velocity spectra representing geostationary orbit conditions, for one-dimensional and three-dimensional ion velocity space cutoffs.

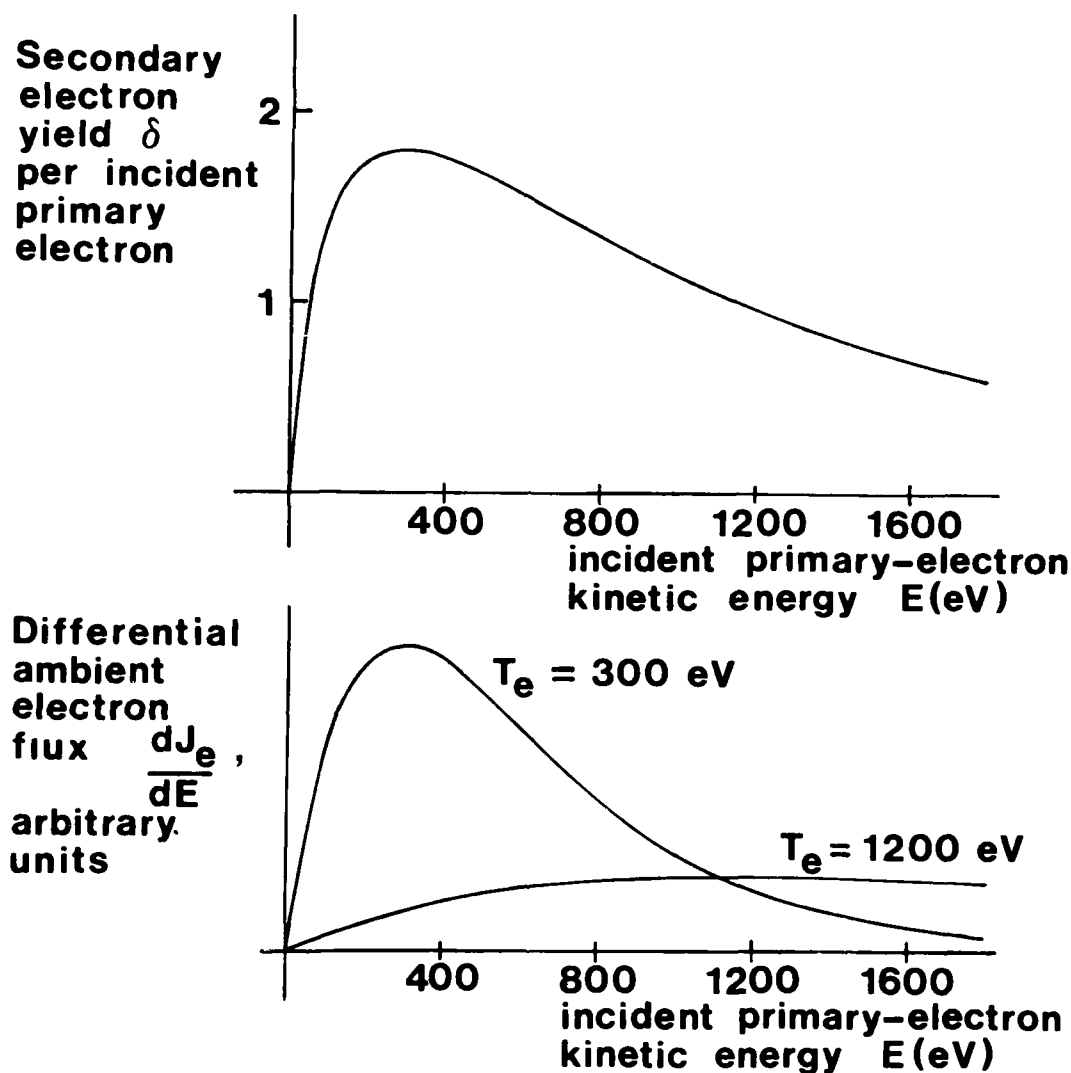


Fig. 3.1.(a) typical form of secondary-electron yield δ (secondary electrons per incident primary electron), as a function of incident primary kinetic energy E , at normal incidence (b) energy-differential electron flux dJ_e/dE for Maxwellian ambient electron velocity distributions at two different temperatures. Total secondary-electron flux is obtained by integrating the product of these two functions [multiplied by another factor given in Eq. (2.10)] over energy E .

PARTICLE ORBIT

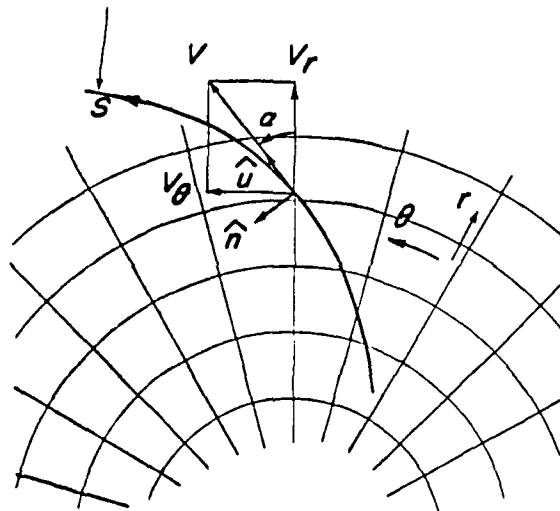


Fig. 4.1. Coordinate system and definitions for particle orbit integration.

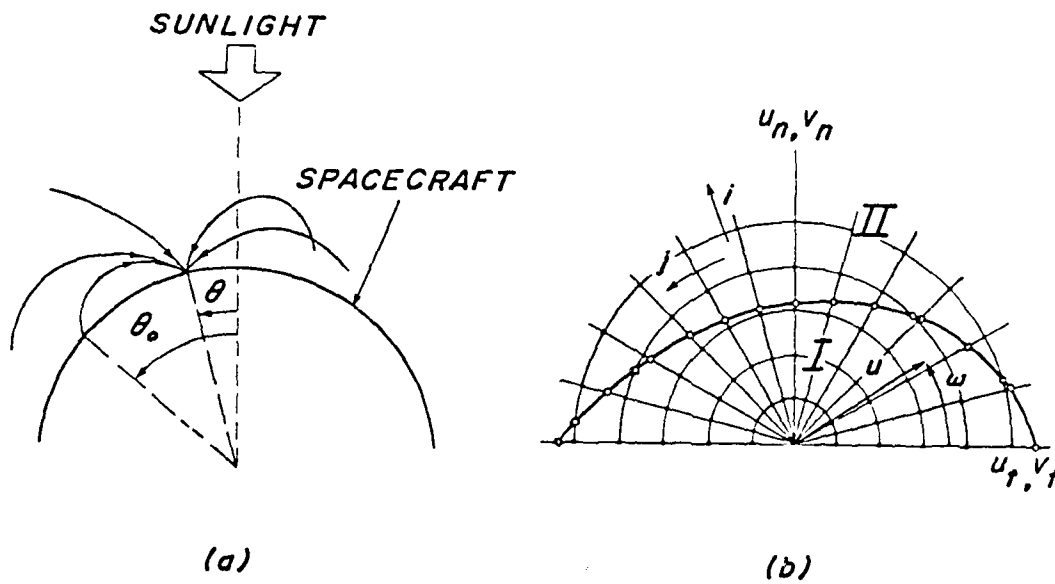


Fig. 4.2. Position-space (a) and velocity-space (b) coordinates for calculation of incident current density at a surface point. Figure 4.2a shows several particle orbits incident at a surface point θ , one of them having originated at the surface point θ_0 .

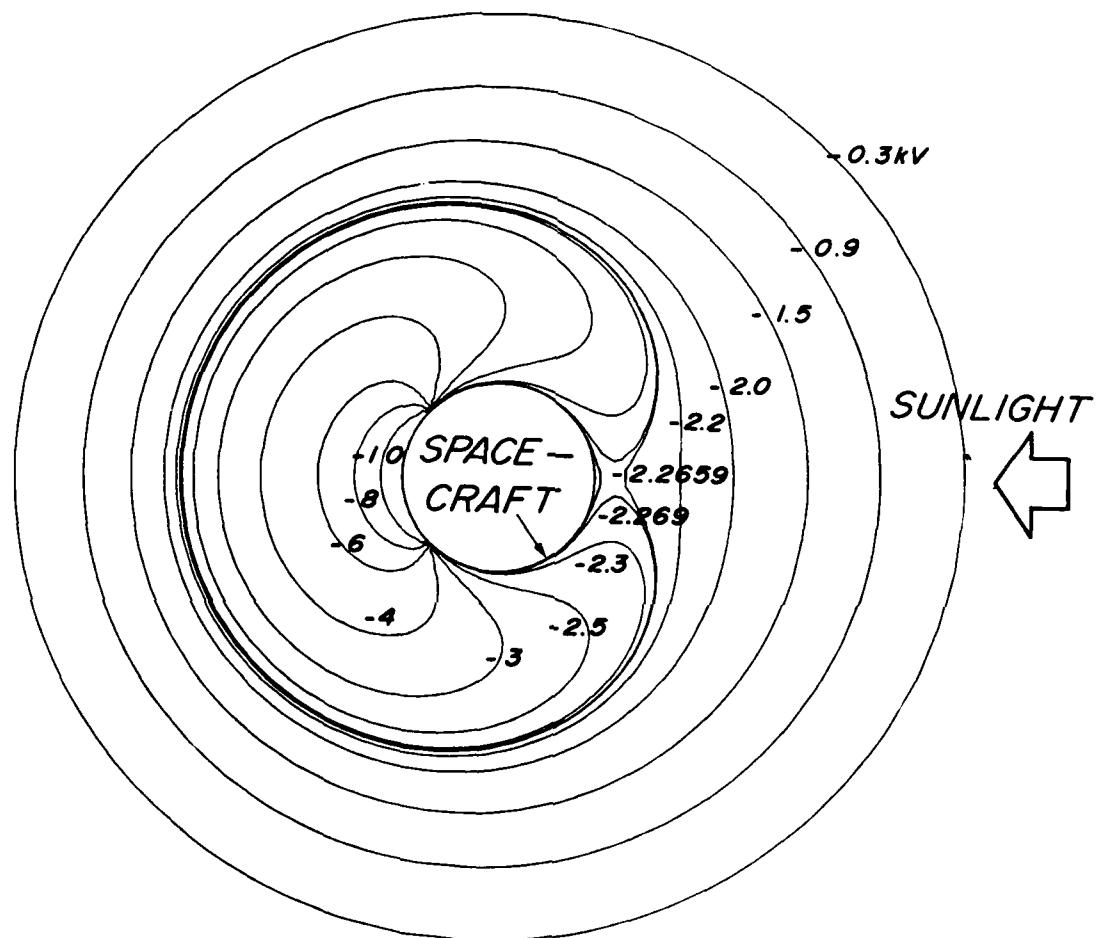


Fig. 4.3. Equipotential contours around a cylindrical spacecraft cross-section with two conductive sectors having angles of 270° and 90° . Sector potentials are -2.265 kV and -11.88 kV, respectively. Other data pertinent to this calculation are given in Sec. 4.5. The radial coordinate in Figs. 4.3 ~ 4.5, 4.8 and 4.9 is $1 + \ln(r/r_s)$ where r_s is spacecraft radius.

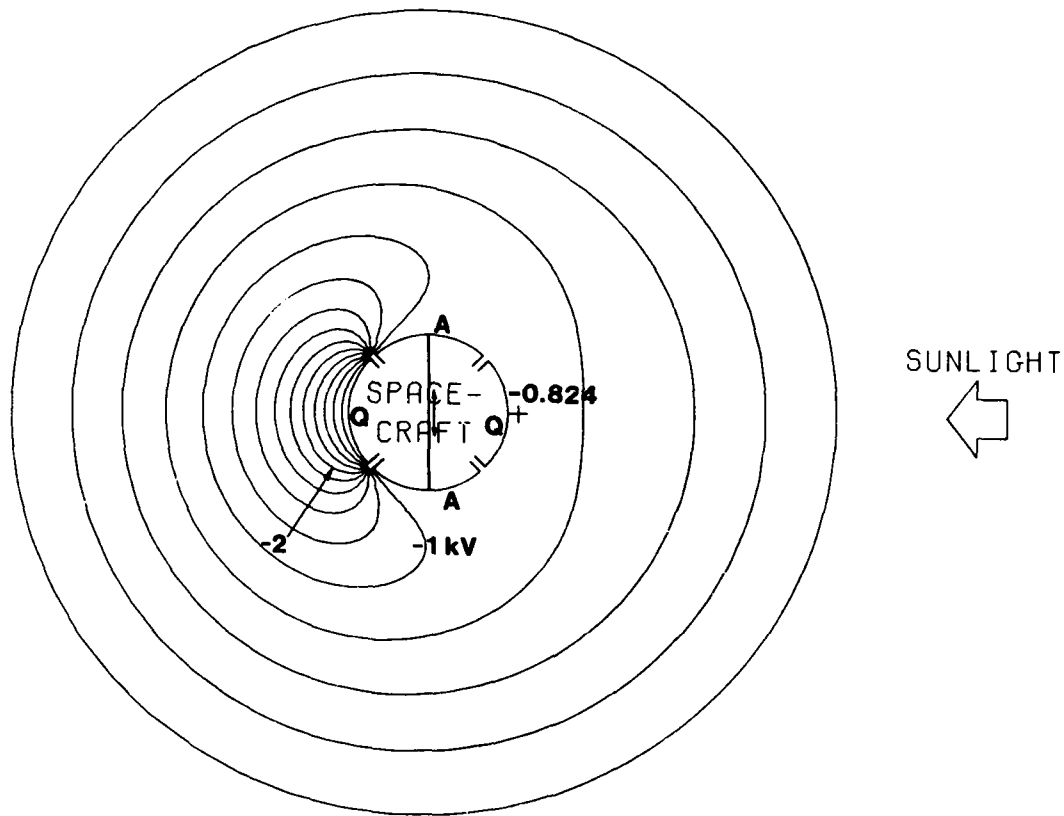


Fig. 4.4. CYLVIA calculation of equipotential contours around a cylindrical spacecraft cross-section with four sectors each having an angle of 90° . The two sectors labeled "A" are conductive, have the photoemission properties of aluminum, and are connected together electrically, as shown schematically in the figure. The two sectors labeled "Q" are nonconductive and have the photoemission properties of quartz. In this and subsequent figures, the symbol + indicates the location of a saddle point. Other data pertinent to this calculation are given in Sec. 4.5. The radial coordinate in this figure is as in Fig. 4.3. The floating surface potential distribution resulting from this calculation is shown in Fig. 4.6.

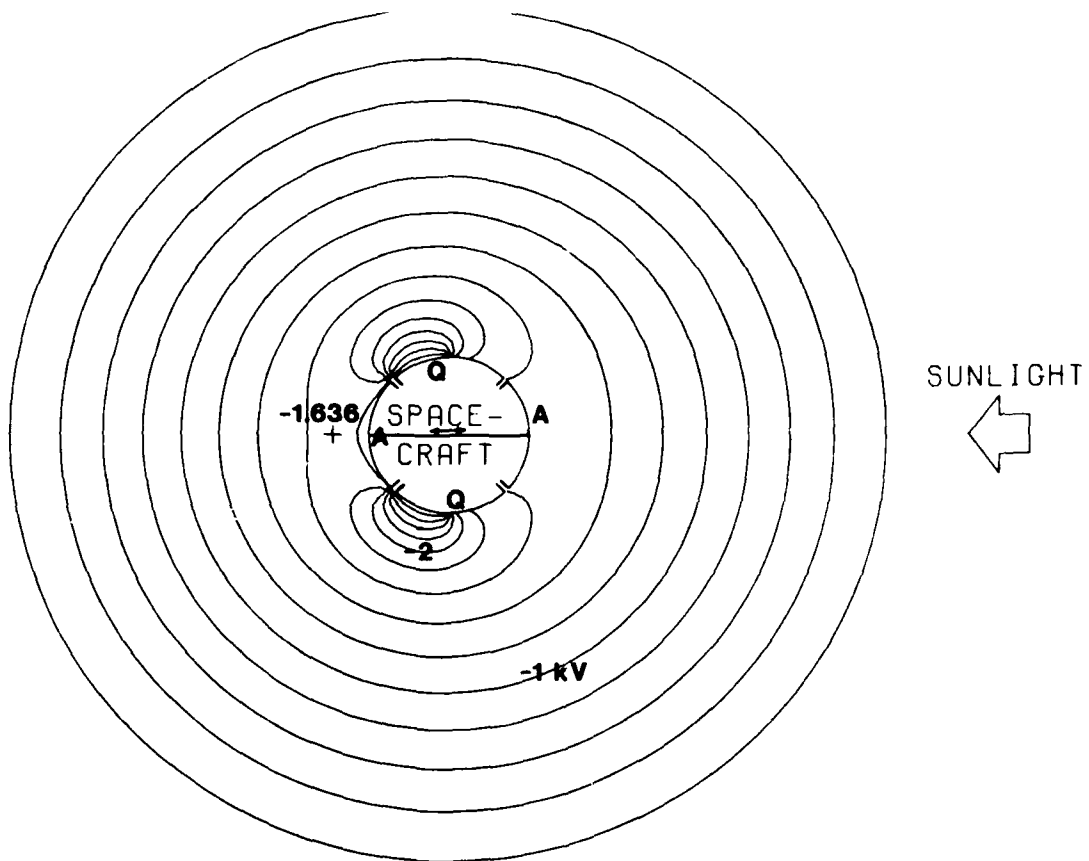


Fig. 4.5. Same as Fig. 4.4 except that the spacecraft has been rotated by 90° .

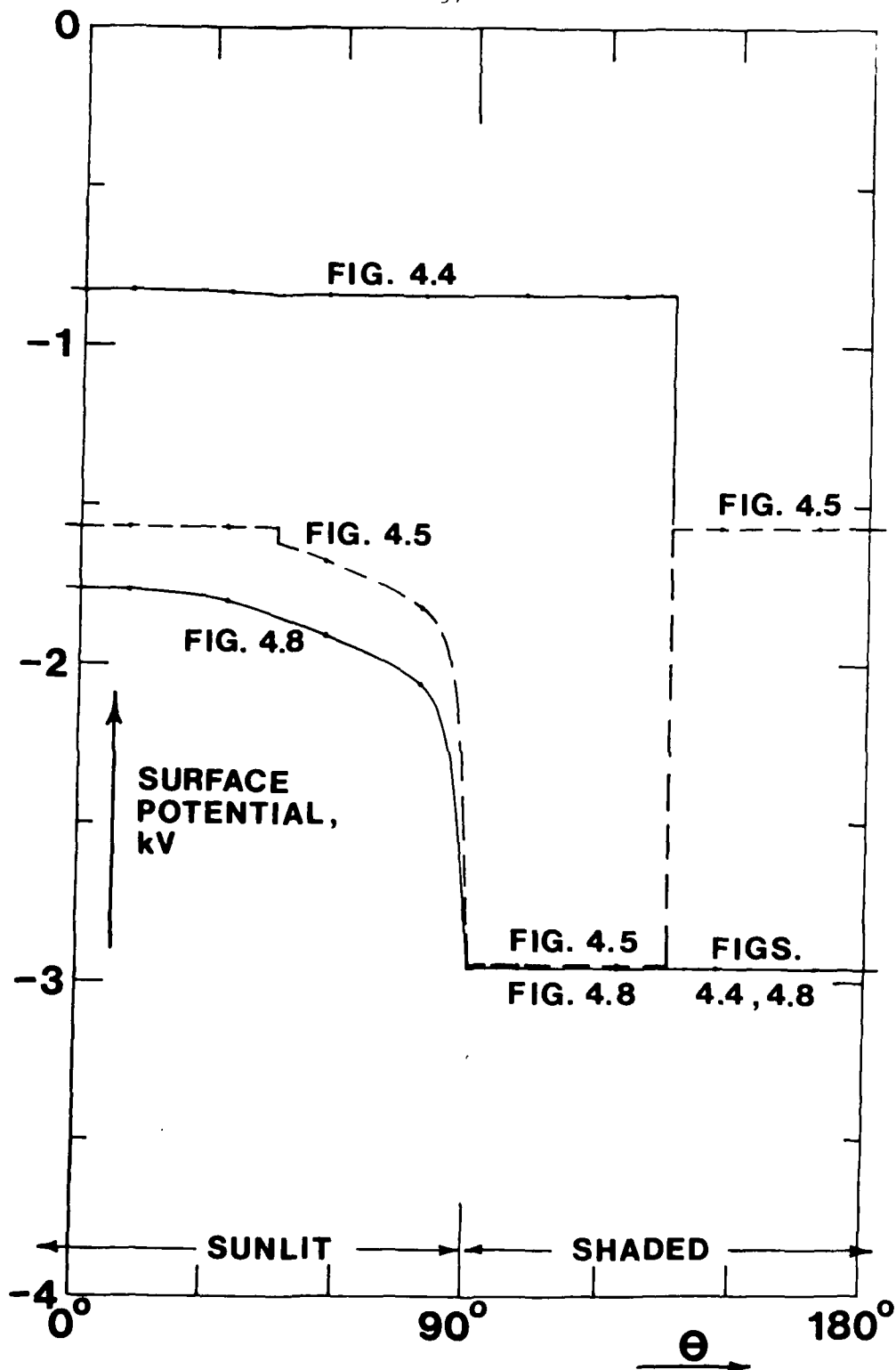


Fig. 4.6. Distributions of floating surface potential vs angle for the calculations shown in Figs. 4.4, 4.5, and 4.8.

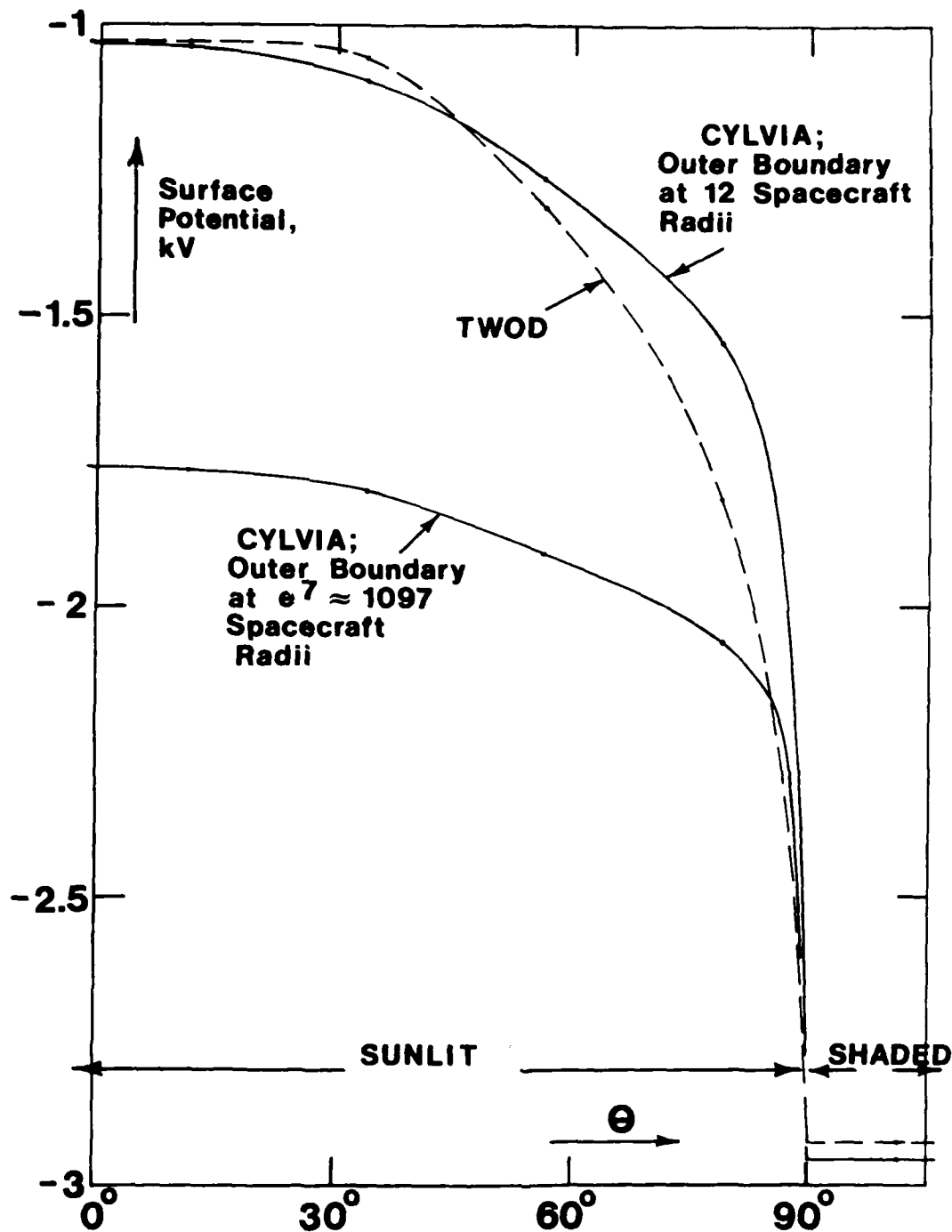


Fig. 4.7. Distributions of floating surface potentials vs angle for the calculation shown in Fig. 4.9, and also for another one which is the same except that the outer boundary of the calculation (which is held at space potential in all cases) is at $12r_s$ rather than e^7r_s . Also shown is another result for which the outer boundary is at $12r_s$, calculated using a program called TWOD, which combines NASCAP physical assumptions with circular cylindrical geometry (M. Mandell, Systems, Science and Software, Inc., private communication). Other data pertinent to these calculations are given in Sec. 4.5.

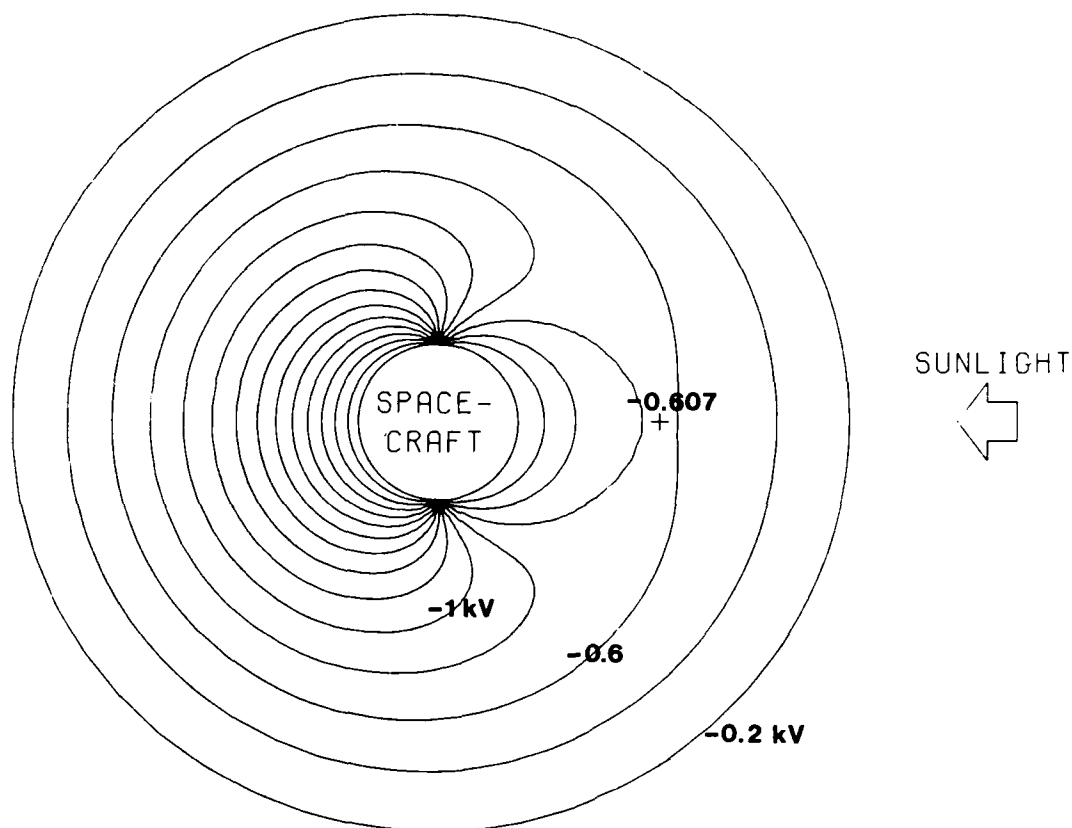


Fig. 4.8. CYLVIA calculation of equipotential contours around a cylindrical spacecraft cross-section having a nonconductive surface, corresponding to a surface potential distribution calculated assuming local current balance only (i.e., the presence of a potential barrier is ignored in calculating photoelectron escape). The symbol + indicates the location of a saddle point. The photoelectron charge flux $eJ_{ph} = 4.2 \times 10^{-5} \text{ A/m}^2$ at normal incidence.

$T_{ph} = 1.5 \text{ eV}$. Ambient ion and electron distributions are single Maxwellians, each with $n_p = 3 \text{ cm}^{-3}$ and $T = 1 \text{ keV}$. Secondary and backscattered electron fluxes are assumed zero. The polar-coordinate computation grids in position (r, θ) and in velocity space contain 65×16 and 8×16 intervals, respectively. Outer grid boundary radius r_B is e^7 times spacecraft radius r_s . Linearized ambient space charge (Eq. 4.3; Laframboise and Prokopenko, 1977), corresponding to a Debye length of $96 r_s$, is assumed. Radial coordinate in Figure is $1 + \ln(r/r_s)$.

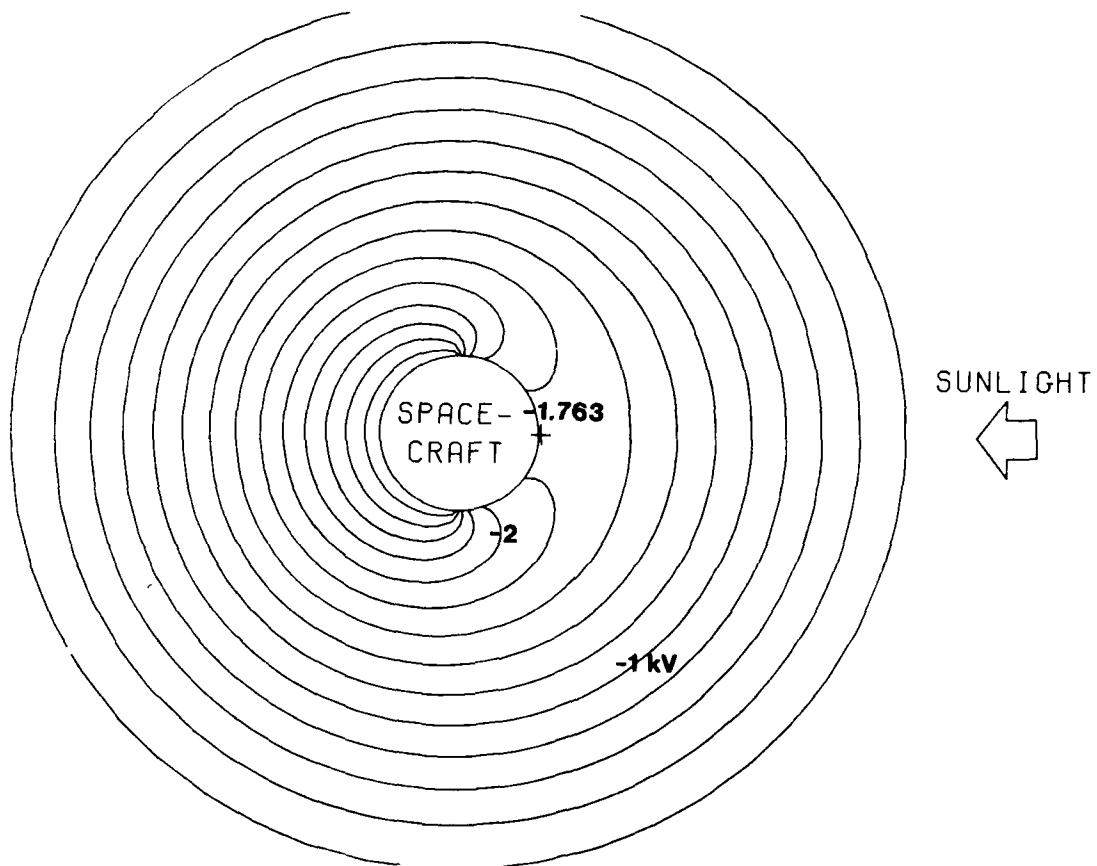


Fig. 4.9. Same as Figure 4.8 except that the calculation is now self-consistent including potential-barrier effects on photoelectron and other particle orbits.

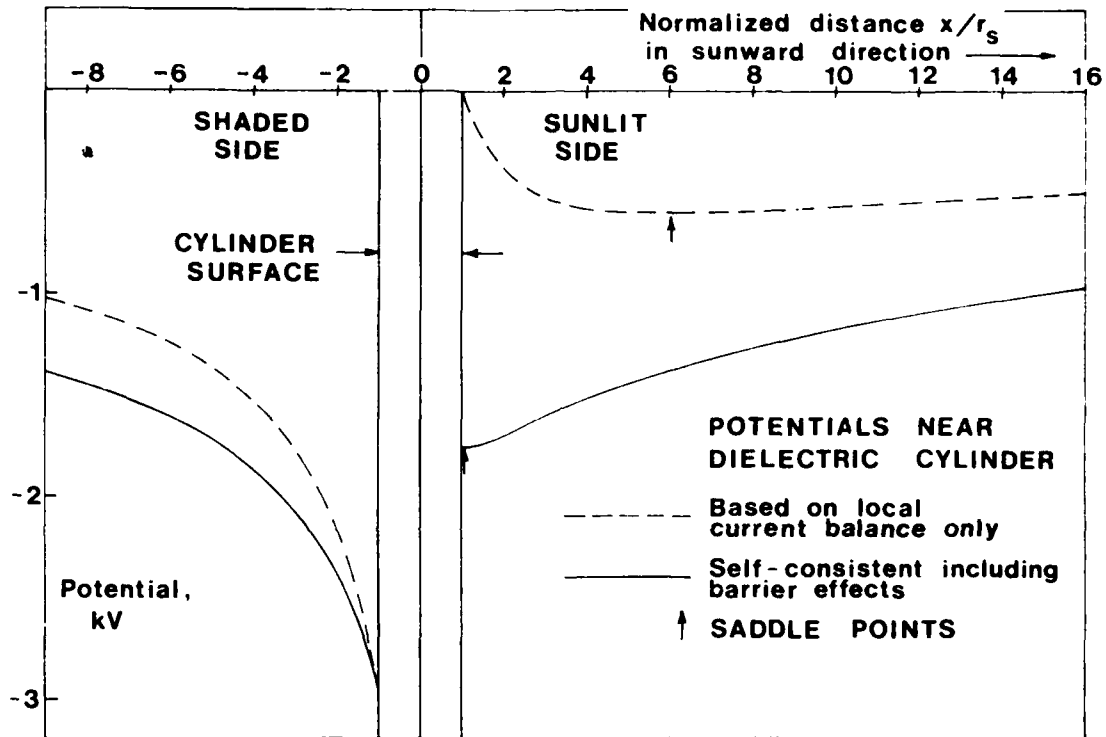


Fig. 4.10. Potentials vs distance along spacecraft-sun line for the situations shown in Figs. 4.8 and 4.9, showing the large decrease in differential charging which results when potential-barrier effects on particle (especially photoelectron) orbits are included. Without these effects, surface potentials at the sunward and anti-sunward points are 5.1V and -2.96 kV; with these effects, these potentials are -1.76 kV and -2.96 kV.

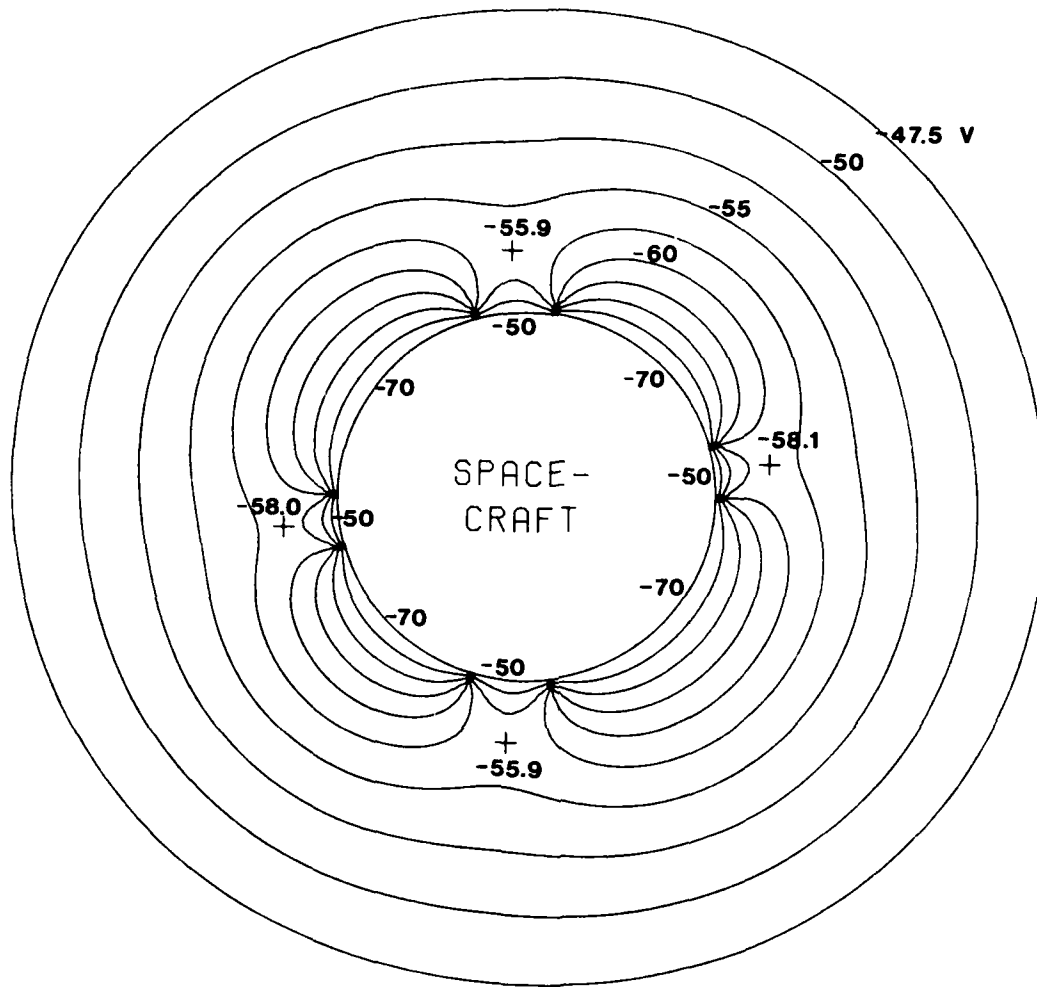


Fig. 4.11. CYLVIA calculation of equipotentials around a circular spacecraft cross-section with given rather than self-consistent surface potentials, as shown. In this Figure, the radial coordinate is proportional to radius. The computational grid in (r, θ) contains 65×180 intervals. The outer grid boundary is at $e^5 \approx 148$ spacecraft radii. Linear space charge corresponding to $\lambda_D = 32.5$ spacecraft radii is assumed. Other data pertinent to this calculation are given in Sec. 5.2. This calculation was done for the purpose of comparison with a XYCIC calculation shown in Fig. 5.1, and also with a similar but three-dimensional calculation done using NASCAP (Olsen, 1980, p. 190; Olsen and Whipple, 1980, Fig. 16). The results of this comparison are discussed in Sec. 5.2.

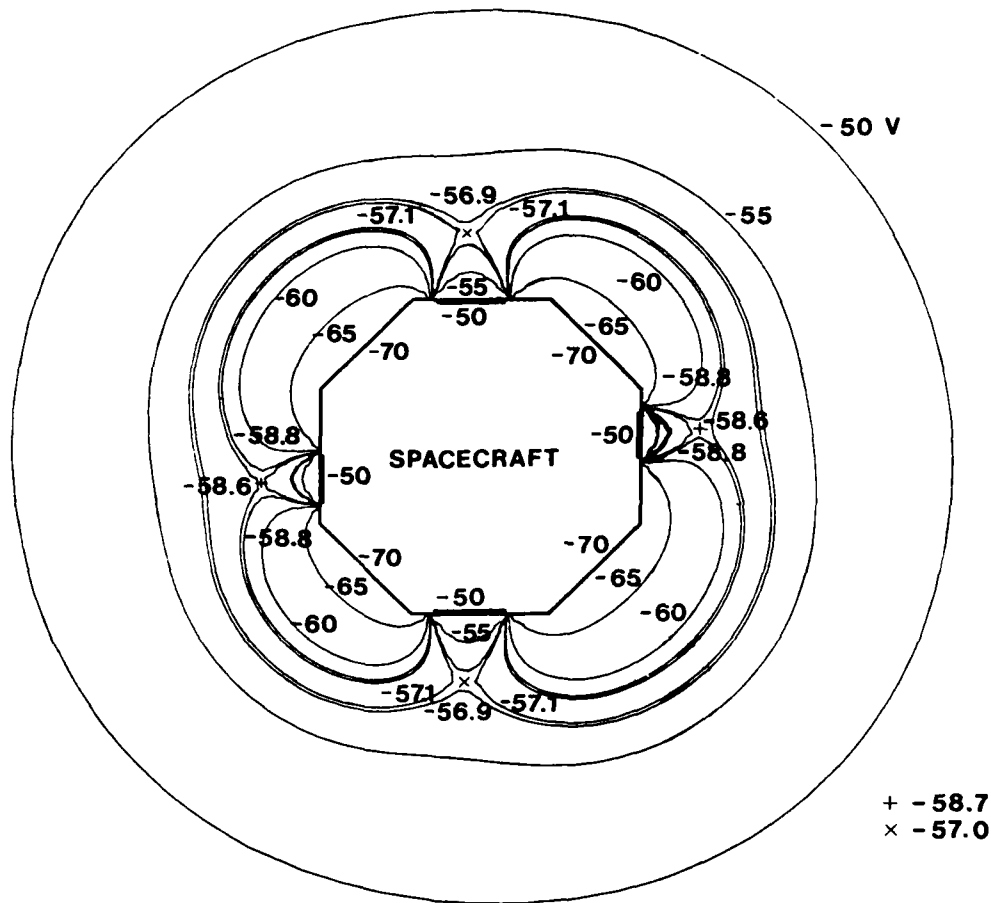


Fig. 5.1. XYCIC calculation of equipotentials, corresponding to the CYLVIA calculation shown in Fig. 4.11. One difference between these two calculations is that in the XYCIC calculation, zero space charge is assumed. The innermost grid used in the XYCIC calculation contains 40×40 intervals; the octagon has a dimension of 28×28 intervals and is centred in this grid. Six other grids surround the innermost grid; the outermost grid boundary is a centred square of side 19.2 times as large as the innermost grid boundary, i.e. located at 27.4 object half-widths.

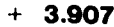


Fig. 5.2. XYCIC calculation of equipotentials around a cross-section through a hypothetical antenna + spacecraft body combination. As in Figs. 4.11 and 5.1, surface potentials are imposed (in this case, also hypothetical) values. Zero space charge is assumed. The innermost grid used contains 32×32 intervals with the combined total width of the "object" being 24 intervals. Six other grids surround the innermost grid; the outermost grid boundary is a centred square of side 20 times the innermost grid boundary, i.e. located at 26.7 half-widths of the combined object.

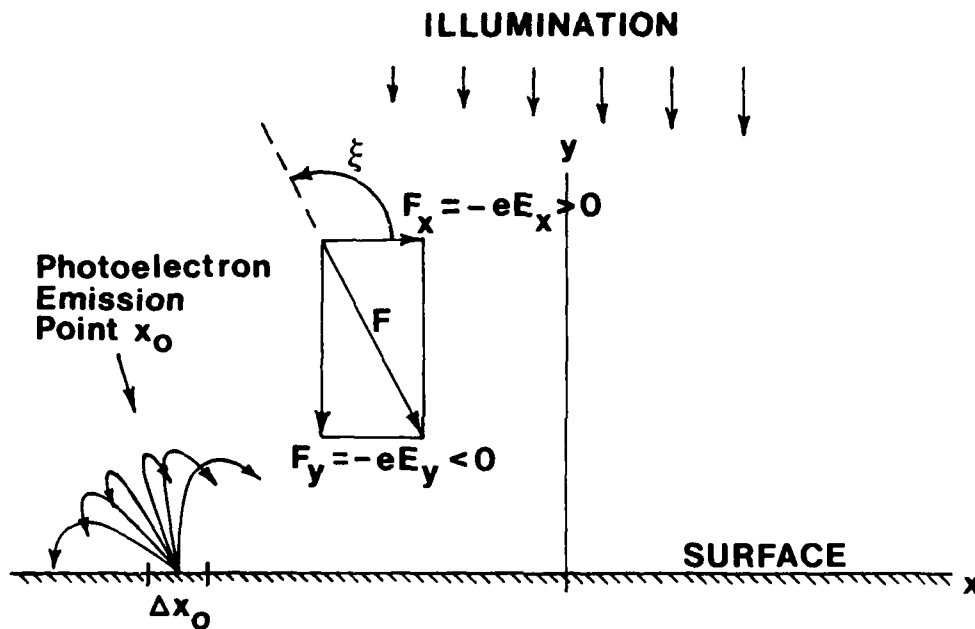


Fig. 6.1. Geometry for photocurrent sheet calculation. The illumination is assumed to vary linearly with x , producing a photoemission current density $J_{ph}(x_0) = J_{ph,0} + J_{ph}'x_0$. The electric field components E_x and E_y are assumed uniform, so that the surface potential varies linearly with x . The electron orbits are then tilted parabolas. Their impact points x can be found analytically (Eq. 6.1) for given values of emission position x_0 and emission velocity components v_{x0} and v_{y0} .

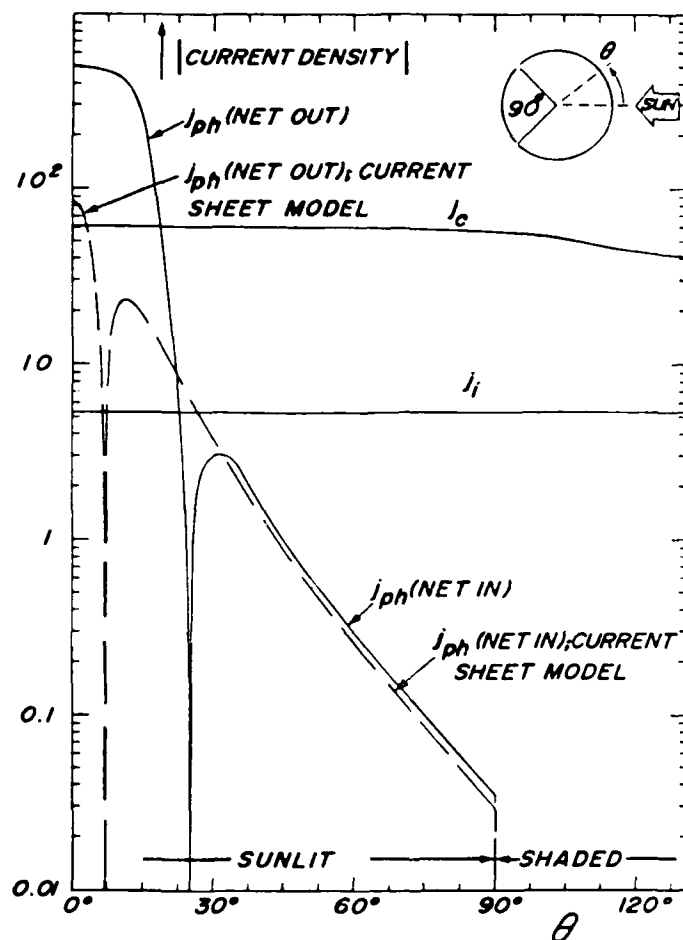


Fig. 6.2. Current densities vs surface position for the situation shown in Fig. 4.3 and described in Sec. 6.3. In this Figure, normalized current density j is defined as J/J_{ref} , where J_{ref} is the random flux of Maxwellian ions having a temperature and density of 1 keV and 1 cm^{-3} . Approximate photoelectron currents j_{ph} obtained using the approximate surface current ("current sheet") model given by Eqs. (6.7) and (6.8) are shown as dashed curves.

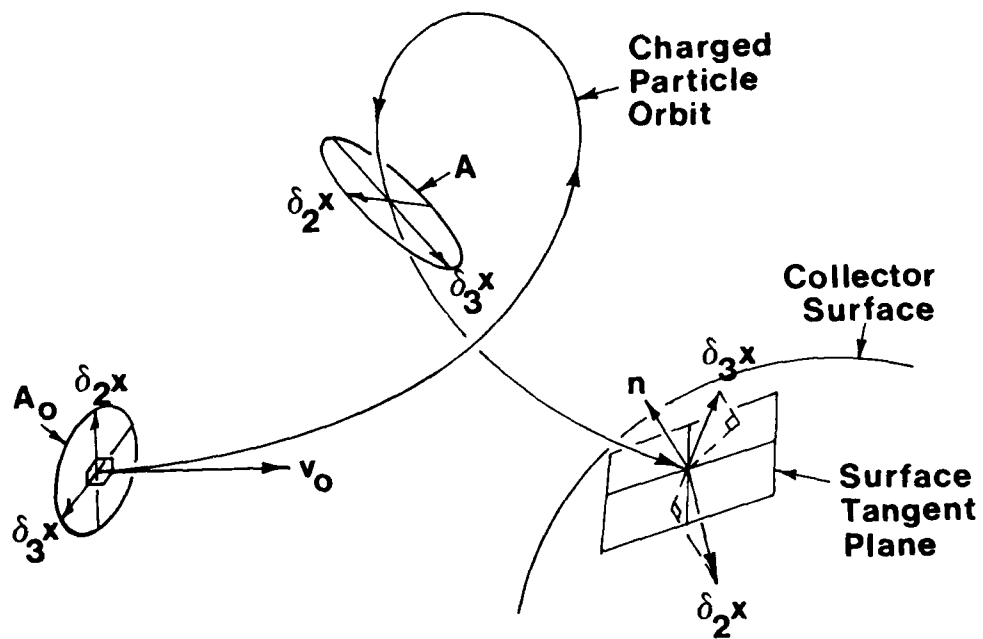


Fig. 7.1. Particle orbit geometry.

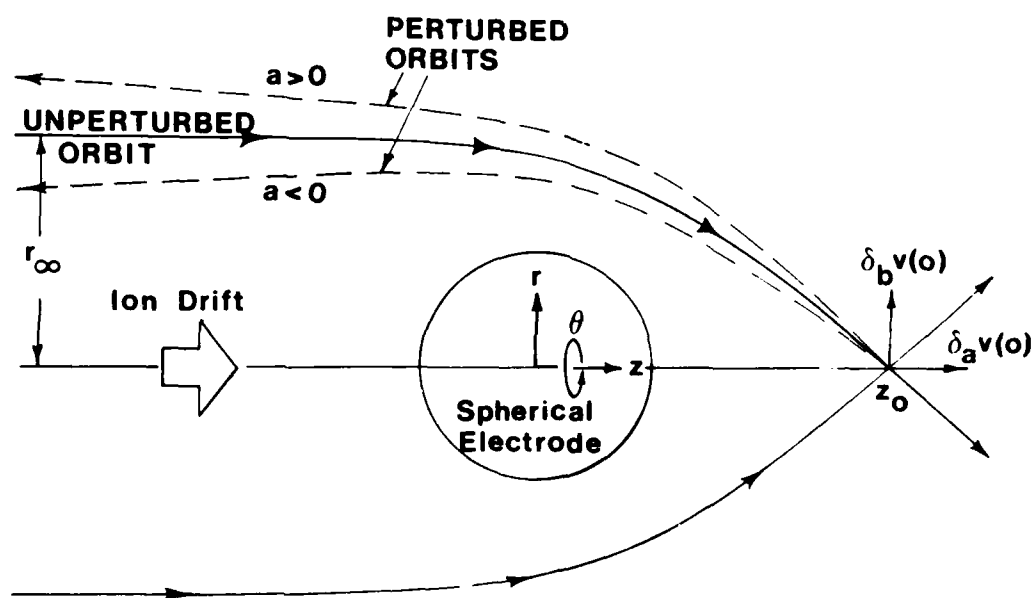


Fig. 7.2. Geometry for perturbation calculation of sphere axial defocusing.

[illegible]

[illegible]

SENTRY
1414 4
-7962349
-9204349
-8272013
-6872929
-5152404
-3191124
-1080549
-1080549
-3191124
-5152404
-6872929
-8272013
-9204349
-9962349
-3511946E-01
-6015809E-01
1215184
1572032
1855304
2051988
2152439
2152439
2051988
1855304
1572032
1215184
6015809E-01
-141946E-01

Appendix B: Listing of threshold temperatures program

```

C ***** IN UNITS OF 10000 PLAS K=0000

```

```

104 PROGRAM TEMP

```

```

      THIS SUB COMPUTES THE CRITICAL TEMPERATURES FOR SPATIAL
      MATERIALS INCLUDING ANGULAR DEPENDENCE OF TFIELD.

```

```

      DOUBLE PRECISION DZ
      COMMON/CTRL/ENX(12),DNX(12),BSA(12),BSB(12),BSC(12),Z(12)
      COMMON EM,DM,KEM,A,B,C,FZ,IFLG,ICNN,DINTG(10)
      DIMENSION TC(12),DUMMY(12),IDUM(44),DDTS(12)
      EQUIVALENCE (DUMMY,IDUM)
      DATA EPS/1.0E-5/,DDTS/0.05/1.0/
      DATA NUNS/17/,NUME/29/,IFLGE/3/,NP1/17/,NP2/2/
      DATA LU/13/,ITRAC/20/,ISECT/0/

      DO 500 N=NUNS,NUME
        WRITE(1,800) N
1000  F0RMAT(15, ' ', N, ' ', 12)
        ENX(N)=
        DNX(N)=
        DO 500 NPART=NP1,NP2
          PAC=NPART/2.3
          DTS=DDTS(NPART)
          WRITE(1,804) NPART
1004  F0RMAT(10, ' ', NPART, ' ', 12)
          DO 500 IFLG=1,IFLGE
            IF (IFLG.GE.2) GO TO 90
            A=0.0
            B=0.0
            C=0.0
            IF (NPART.EQ.1) TS=EM
            IF (NPART.EQ.2) TS=EM/2.0
            GO TO 10
10  A=BSA(N)
            B=BSB(N)
            C=BSC(N)
            IF (IFLG.EQ.2) GO TO 4
            DZ=DOUBLE(Z(N))
            BETAB=SNGL(7.37000DZ**(-0.5087500))
            FZ=(EXP(BETAB)-BETAB-1.0)/BETAB**2.0
            WRITE(1,201) Z(N),BETAB
201  F0RMAT(10, ' Z= ', F5.1, 'X ', BETAB, 'E15.7)
            GO TO 9
            FZ=1.0
            TS=TC(N,NPART)
            IF (NPART.EQ.1.AND.TS.LE.1.0E-4) TS=EM
            IF (NPART.EQ.2.AND.TS.LE.1.0E-4) TS=EM/2.0
            DT=DTS
            NPATH=1
            FL=RCUR(TS)
            TSS=TS+DT*FAC
            IF (TSS.LE.1.0E-4) GO TO 500
            FN=RCUR(TSS)
            WRITE(1,600) TS,FL,FN,DT
600  F0RMAT(4F15.7)
            IF (NPART.EQ.1.AND.TS.LE.1.0E-4) GO TO 500
            IF (NPART.EQ.2.AND.TS.GT.20.0) GO TO 500
            IF (FL.FN) 50=50.40
            TS=TS+DT*FAC
            FL=FN
            GO TO (30,50),NPATH
            DT=DT/2.0
            NPATH=2
            IF (DT.EPS) 40=40.30
            NPAT=NPART+(IFLG-1)*2
            TC(N,NPAT)=TS
            WRITE(1,200) IFLG,TS
200  F0RMAT(5X, ' IFLG= ', I1.5X, ' TC= ', F8.4)
500  CONTINUE
            CALL EXEC(2,LU,ENX+64,ITRAC,ISECT)
            CALL EXEC(2,LU,DNX+64,ITRAC,ISECT+1)
            CALL EXEC(2,LU,BSA+64,ITRAC,ISECT+2)
            CALL EXEC(2,LU,BSB+64,ITRAC,ISECT+3)
            CALL EXEC(2,LU,BSC+64,ITRAC,ISECT+4)
            CALL EXEC(2,LU,Z+64,ITRAC,ISECT+5)
            DO 300 J=1+6
              ISECT=ISECT+J+5
              NO 310 I=1+32
              DUMMY(I)=TC(I,J)
310  CONTINUE
            CALL EXEC(2,LU,DUMMY+64,ITRAC,ISECT)
300  CONTINUE
            IDUM(1)=NUNS
            IDUM(2)=NUME
            CALL EXEC(2,LU,IDUM+64,ITRAC,ISECT+12)
            STOP
            END

```

```

      BLOCK DATA
      COMMON/CTRL/ENX(12),DNX(12),BSA(12),BSB(12),BSC(12),Z(12)
      DATA ENX/0.8,0.3,0.3,0.42,0.33,0.35,0.3,0.4,0.3,0.15/
      A0.25,0.8,0.25,0.4,0.8,0.35,0.36,0.33,0.39,0.85,0.15/
      B0.41,0.15,0.15,0.15,0.72,0.48,0.59,0.3/
      DATA DNX/1.45,0.97,2.6,2.3,3.46,0.75,2.2,5.0,3.0,2.1,
      A1.8,1.4,0.92,4.0,1.0,2.55,2.39,2.35,1.52,6.38,2.1/
      B2.05,2.1,2.1,2.1,1.03,1.49,1.86,1.0/
      DATA Z/79.0,13.0,10.0,10.0,10.0,10.0,4.0,29.0,29.0,8.0,5.3,
      A5.3,24.4,12.0,10.0,47.0,15.3,16.2,16.9,15.3,10.0,5.0/
      B10.0,5.0,5.0,5.0,70.1,42.0,63.4,6.0/
      DATA BSA/0.4802,0.1568,0.1238,0.1238,0.1238,0.06,0.3134,
      A0.3134,0.09,0.07,0.07,0.275,0.146,0.1238,0.39,0.183,0.192,
      B0.2,0.183,0.1238,0.06,0.1238,0.06,0.06,0.06,0.456,0.373,
      C0.438,0.08/
      DATA BSB/0.3566,0.0303,0.0172,0.0172,0.0172,0.0,0.0692,
      A0.0692,0.0,0.0,0.0,0.04,0.025,0.0172,0.289,0.037,0.04,
      B0.042,0.037,0.0172,0.0,0.0172,0.0,0.0,0.0,0.138,0.276,
      C0.325,0.0/
      DATA BSC/0.6103,0.3431,0.3435,0.3435,0.3435,0.0,0.6207,
      A0.6207,0.0,0.0,0.0,0.56,0.0,0.3435,0.632,0.382,0.599,
      B0.41,0.382,0.3435,0.0,0.3435,0.0,0.0,0.0,0.612,0.617,
      C0.613,0.0/
      END

```

```

      SUBROUTINE INTG(EINTG)
      COMMON EM,DM,KEM,A,B,C,FZ,IFLG,ICNN,DINTG(10)
      DATA ERROR/1.0E-4/,EFCUT/1.0E-7/
      ITER=0
      DO 100 I=1,200
        CUTOFF=1
        EFCUT=EINTG/CUTOFF
        IF (EFCUT.LE.EFCUT) GO TO 110
100  CONTINUE
        WRITE(1,900)
900  F0RMAT(' INSUFFICIENT # OF DOMAINS')
110  DE=CUTOFF/10.0
        SUM1=0.0
        SUM2=0.0
        F=0

```

```

      1  SUM2=SUM2+INTG(E)
      E=E*10
      IF (E.GT.1.0) CUTOFF=1.5E-4
      4  SUM1=0.0
      E=DE/2.0
10  SUM4=SUM4+INTG(E)
      E=E*10
      IF (E.GT.1.0) CUTOFF=1.0E-5/20
      20  EINTG=DE/6.0*(SUM1+2.0SUM2+4.0SUM4)
      ITER=ITER+1
      IF (ITER.GT.1) GO TO 60
      DINTG(1)=EINTG
      GO TO 40
60  DINTG(4)=DINTG(5)
      DINTG(5)=EINTG
      40  IF (ABS(EINTG-SUM4)/EINTG-ERROR) 50=50+10
      30  SUM2=SUM2+SUM4
      SUM4=EINTG
      IF (DE.GT.1.0)
        GO TO 4
      50  DINTG(1)=CUTOFF
      DINTG(2)=EFCUT
      DINTG(3)=DE
      IF (ITER.EQ.1) RETURN
      EINTG=(16.0*DINTG(5)-DINTG(4))/15.0
      RETURN
      END

      FUNCTION RCUR(T)
      COMMON EM,DM,KEM,A,B,C,FZ,IFLG,ICNN,DINTG(10)
      KEM=EM/7
      CALL INTG(EINTG)
      RCUR=KEM**2*EXP(2.0)*DM*EINTG*(A-B/(1.0+C*BT)**2)*FZ-1.0
      RETURN
      END

      FUNCTION FINTG(E)
      COMMON EM,DM,KEM,A,B,C,FZ,IFLG,ICNN,DINTG(10)
      P1=-2.0*SQRT(E)-RENE
      IF (IFLG.GE.3) GO TO 10
      IF (P1.GT.-20.0) GO TO 5
      FINTG=0.0
      RETURN
      5  FINTG=E**2*EXP(P1)
      RETURN
      10  F=0.2755*(ALOG(E)-1.658)
      F=-0.0228/(1+SQRT(1+0.228*F))
      BETAS=EXP(F)
      F2=P1*BETAS
      IF (F1.GT.-20.0) GO TO 15
      FINTG=(E/BETAS)**2*EXP(F2)*82.0
      RETURN
      15  FINTG=(E/BETAS)**2*(EXP(F2)-EXP(P1))*BETAS*1.0)*82.0
      RETURN
      END
      ENDS

```

Appendix C: Listing of CYLVIA

PKHAM + VUAC (150)

1. PURPOSE OF PROGRAM LYLVA

TO OBTAIN THE FULL

THE SPACECRAFT IS DIVIDED INTO SECTIONS, EACH OF WHICH MAY CONTAIN SEVERAL GRID POINTS. SURFACE MATERIAL PROPERTIES ARE SET UP IN SIZE DATED USING THE CONTENT OF THE FILE IN THE INPUT FILE DATING WHICH GATS HOW THE SPACECRAFT SURFACE IS DIVIDED. IS ALSO READ IN DATED.

```

1  DATIN,DATABZ,POTIN ARE INPUT FILES
2  POTIN IS USED IF FLAG I(10)=2
3  POTIN MAY CONTAIN SURFACE POTENTIAL INFORMATION
4  WHICH SHORT-CIRCUITS THE GUESS FIELD INITIALIZATION.
5  TAPER-OUTPUT CONTAINS BRIEF INFORMATION ABOUT POTENTIAL
6  TAPER IS REQUESTED AT EACH MAJOR ITERATION
7  TAPER-OUTPUT IS THE MAIN OUTPUT FILE

```

1. DESCRIPTION OF THE VARIABLES

```

C  ACCURACY TOLERANCE FOR OBJECTIVE FUNCTION
C  ANG  ANGULAR LOCATION OF GRID POINT (0-360 IN 5.7 PHOTO)
C  ANGLD IS ANGLE BETWEEN THE FIRST GRID POINT AND THE SURFACE POINT
C  C  (NON-ION) CURRENT DUE TO SURFACE POINT
C  CSEAT  EMITTED BACKSCATTER CURRENT AT GRID POINT
C  CSEAT1,CSEAT2,CSEAT3  COEFFICIENTS OF BACKSCATTER EMISSION
C  CSECE  ELECTRON CURRENT AT GRID POINT
C  CSECE1,CSECE2  CURRENT DUE TO ELECTRON OR ION GUN
C  CTION  ION CURRENT
C  CPHOTOX  PHOTOELECTRON COEFF FOR A GIVEN MATERIAL (MATERIALS MODEL)
C  CPHOTO  PHOTOELECTRON CURRENT
C  CSE2  EMITTED SECONDARY ELECTRON CURRENT AT GRID POINTS
C  CSE21  TOTAL SECONDARY ELECTRON CURRENT AT GRID POINTS
C  CSECTR  TOTAL CURRENT FOR A GIVEN SECTOR
C  CSECF,DELTA  COEFFICIENTS OF SECONDARY EMISSION
C  DELT  STEP IN ORBIT INTEGRATION
C  DPOT  POTENTIAL INCREMENT
C  DEN1  ELECTRON NUMBER DENSITY PER CUBIC METER

```

```

C DENEZ ELECTRON NUMBER DENSITY CORRESPONDING TO A HIGH ENERGY
C DENE1,DENE2 ION NUMBER DENSITIES
C DELTAX GRID SPACING IN X COORDINATE
C DELTAY GRID SPACING IN Y COORDINATE
C DVUDY-POTENTIAL DERIVATIVE IN Y DIRECTION
C DVUDY-POTENTIAL DERIVATIVE IN Y DIRECTION
C EV= 8TH ORDER MONOENERGETIC VELOCITIES
C EV=8TH ORDER MONOENERGETIC WEIGHTS
C GAMMA TEMPERATURE RATIO(GIVEN SPECIES TEMP/REF TEMP)
C IFL FLAG FOR FINE STRUCTURE (SECTORS)
C IFLG=FLAG FOR INCLUDING IONS,ELECTRONS,PHOTONS,ETC
C IGEOM IS FLAG FOR GEOMETRY OF SPACECRAFT
C IGEOM=1 THE CRAFT IS AN INFINITE CYLINDER
C IGEOM=2 THE CRAFT IS A PROLATE SPHEROID
C ILEV FACTOR OF DIVISION OF VELOCITY LEVELS
C IPOIS IS A FLAG USED IN SUBROUTINE GEOMOD
C IPOIS=0 A GUESS FIELD IS COMPUTED USING LOCAL CURRENT BALANCE
C IPOIS=1 POISSON EQUATION SOLVED USING UPDATED DATA
C IPOIS=2 RESTART THE PROGRAM AT THE LAST ITERATION
C ISTABLE IS FLAG INDICATING STABILITY FROM ONE ITERATION TO NEXT
C ITER IS NUMBER OF MAJOR ION CYCLES
C ISYM=0 CORRESPONDS TO NO AXIAL SYMMETRY
C ISYM=2 THE FIRST GRID POINT MAKES AN ANGLE EQUAL TO ANGO WITH
C THE SUBSOLAR POINT

```

```

C      IROUT=FLAG INDICATING CONVERGENCE AT A GIVEN GRID POINT
C      M=INITIAL STEP IN ORBIT INTEGRATION
C      LUN3 LOGICAL UNIT 3(DATABZ)
C      LUN4 LOGICAL UNIT 4(STATUS FOR CURRENT DUE TO SECONDARIES)
C      LUN5 LOGICAL UNIT 5(DATIN)
C      LUN6 LOGICAL UNIT 6(CUT-OFF BOUNDARIES -ACCEPTANCE ANGLES
C      FOR PRIMARY PARTICLES)
C      LUN7 LOGICAL UNIT 7(MISCELLANEOUS)
C      LUN8 LOGICAL UNIT 8(POTOUT)
C      LUN9 LOGICAL UNIT 9(OUTPUT)
C      LUN10 LOGICAL UNIT 10(POTIN)
C      MNUMBER=NUMBER OF UNKNOWN IN I DIRECTION (RADIAL)
C      NPOINT=NUMBER OF UNKNOWN IN J DIRECTION (ANGLE)
C      NANG THE VELOCITY SPACE IS DIVIDED INTO 2*NANG-1 INTERVALS
C      FOR ANGLES USED FOR SECONDARY ARRIVING PARTICLES)
C      NVAL NUMBER OF VELOCITY LEVELS -NATIVES+NSAMP
C      NTINES FACTOR OF MULTIPLICATION OF NUMBER OF VELOCITY LEVELS
C      NSAMP=NUMBER OF VELOCITY LEVELS AT OUR DISPOSAL.

```

```

C PERSEC=NUMBER OF GRID POINTS PER SECTOR
C PSECTR=SURFACE POTENTIAL FOR A GIVEN SECTOR
C PBOUND=POTENTIAL ON OUTER BOUNDARY (USUALLY ZERO)
C PMI=POTENTIAL OF SPACECRAFT SURFACE AT GRID POINTS
C RATIO=0.1*(2)/(0.2)*(1). SEE SUBROUTINE GENRAT
C RAD=RADIUS OF SPACECRAFT
C SBOUND=LINQUOTER BOUNDARY RADIUS/SPACECRAFT RADIUS)
C SECMC=CONTAINS INDICES OF GRID POINTS PER SECTOR

```

```

C SECPRI=EMITTED SECONDARY CURRENT DUE TO PROTONS
C SECPRN=TOTAL SECONDARY CURRENT DUE TO PROTONS
C SUNANG=ANGLE OF SUN RELATIVE TO HORIZONTAL AXIS
C TEMPB=BSCATTER ELECTRON TEMPERATURE IN EV
C TEMPE1=PRIMARY ELECTRON TEMPERATURE IN EV
C TEMPE2=PRIMARY ELECTRON TEMPERATURE IN EV CORRESPONDING
C          TO HIGHER ENERGY POPULATION
C TEMPI1=ION TEMPERATURE IN EV FOR HIGH ENERGY SPECIES

```

```

C      TEMP= PHOTOELECTRON TEMP IN EV
C      INPR=REFERENCE TEMPERATURE TAKEN AS 1000EV
C      TEMP2=SECONDARY ELECTRON TEMP IN EV
C      TEMPSP=TEMPERATURE OF SECONDARY ELECTRONS PRODUCED BY
C              PROTON IMPACTS
C      XS,XSS RADIAL DISTANCE
C      Y=SURFACE ANGLE(DEFINED IN GENWORD)
C      IMPORTANT CONSTANTS DEFINED ELSEWHERE

```

```

C ACCTRIN IS TOLERANCE FOR ACCEPTANCE ANGLE(DEFINED IN S/P GEOMD)
C MCNMS DEFINES INITIAL STEP SIZE FOR ORBITS /S/P GEOMD AND PROLAT)
C TOL IS TOLERANCE FOR ORBIT INTEGRATION (DEFINED IN S/P ORBIT)
C VACC1 IS ACCURACY FOR VELOCITY SPACE MINIMA (S/P ION AND ELEC)
C FTERMSALS
C-----
C          BSCATN
C          DATA

```

```
C DATED
C DTIME
C FILE
C EIPRN
C FINGRD
C FLWOP
C FIFOLDN
```

[illegible][illegible]

```
COMMON/BLK2/ IELP(16),EXMF(16)
1 DIMENSION INAM1,INAM2,INAM3,INAM4,INAM5,INAM6,INAM7,INAM8,
1 INAM9,INAM10,INAM11,INAM12,INAM13,INAM14,INAM15,INAM16,
2 INAM17,INAM18,INAM19,INAM20
COMMON/BLK4/CE,CURENT
```

```
COMMON/BLK6/TEMPE,TEMP1,DEN,RATE,NUM,NTOUR,UZERO,K,TZERO,VMI
1 UMD
DIMENSION NAM6(3),NAM7(3)
DIMENSION NAME1(3),NAME2(3),NAME3(3),NAME4(3),NAME5(3)
DIMENSION NAME11(3),NAME14(3),NAME15(3),NAME16(3)
```

```
DATA NAME 1/2HIA,2HIR,2HD /
DATA NAME 2/2HFO,2HIS,2HS /
DATA NAME 3/2HIO,2HNC,2HC /
DATA NAME 4/2HFI,2HOT,2HO /
DATA NAME 5/2HGU,2HFS,2HS /
```

```
DATA NAM6/2HDI+2HUP+2HT /
DATA NAM7/2HSU+2HNC+2MK /
DATA NAM13/2HEL+2HEC+2HC /
DATA NAM14/2HSE+2HCO+2HN /
DATA NAM15/2HRS+2HCA+2HT /
```

```
DATA NARI6/2HEL...PRJ2HN /
LUN3=13
LUN4=1
LUN5=5
LUN6=1
```

```

LUN7=1
LUN8=1
LUN9=1
LUN10=10
C BRANCHING INSTRUCTIONS FOR SEGMENTATION

```

```
IF (INAM2.EQ.1) GO TO 9002
IF (INAM3.EQ.1) GO TO 9003
IF (INAM4.EQ.1) GO TO 9004
IF (INAM5.EQ.1) GO TO 9005
IF (INAM6.EQ.1) GO TO 9006
```

```
IF (INAM7.EQ.1) GO TO 9007
IF (INAM13.EQ.1) GO TO 9013
IF (INAM14.EQ.1) GO TO 9014
IF (INAM15.EQ.1) GO TO 9015
IF (INAM16.EQ.1) GO TO 9016
```

```
LUN10=12
RPI=3.141592600
RPI2=2.000#RPI
RPIHAF=RPI/2.000
SQTP1=DSORT(RPI)
```

```

      SAY=1.000/SQRT(1
      ACUCY=1.0

      RAD=1.0
      FBOUND=0.0

```

```

      SO=0.0
      ILEV=1
      ITRACE=1

```

```

C
C
C
C READ IN DATA AND ORGANIZE ESCIORS

```

```
CALL EXEC(B,NAME1)
9001 INAM1=0
      IDIMY=M+2
C
C
```

```

      N=NPPOINT
C INITIALIZE ARRAYS
      DO 1 J=1,NPPOINT
        IROD(J)=0
        CION(J)=0.
      1
    
```

```

      DELT(I)=0.
      CPHOTO(J)=0.
      CSFF(I)=0.
      CPSCAT(I)=0.
      SECPRM(J)=0.

```

```

      CPNU(I,J)=0.
      CPHN(J)=0.
      CSECTR(J)=0.
      PHN(I)=0.0
1 CONTINUE

```

[illegible]

[illegible]

```

      READ(LUN9,20) (IPANEL(I),I=1,NSECT)
      DO 100 I=1,NSECT
      IF(IPANEL(I))
      READ(LUN9,20) (PERFAN(I),I=1,NPOINT)
      WRITE(LUN9,20) (IPANEL(I),PERFAN(I),I=1,NPOINT)
100 CONTINUE
901 FORMAT(1X,SECTOR NUMBER 8,12,8 NUMBER OF PANELS 8,12,
1 8 NR OF GRID POINTS PER PANEL 8,414)
      READ(LUN9,20) (PANIND(I),I=1,NPOINT)
      IF(IPANEL(1).EQ.0) RETURN
      READ(LUN9,20) (IDTL(I),I=1,NSECT)
      WRITE(LUN9,20) (IDTL(I),I=1,NSECT)
900 FORMAT(1X,10X,SECTORS WHERE WE WANT A FINE STRUCTURE(1614))
C
      READ(LUN9,20) (JDTL(J),J=1,NPOINT)
      WRITE(LUN9,20) (JDTL(J),J=1,NPOINT)
902 FORMAT(1X,10X,GRID POINTS WHERE WE WANT A FINE STRUCTURE(1616))
      RETURN
99 WRITE(LUN9,30)
10 FORMAT(8,ERROR IN SECTOR DATA,/)
      WRITE(LUN9,35)NPOINT
15 FORMAT(8,NUMBER OF INDICES 8,13,8 IS NOT EQUAL
170 NUMBER OF POINTS 8,13)
C
      STOP
98 WRITE(LUN9,30)
      WRITE(LUN9,31)I,J,SECIND(J)
31 FORMAT(8,INDEX(8,13,8) 8,INDEX(8,13,8) 8,13)
C
      STOP
97 WRITE(LUN9,30)
      WRITE(LUN9,32)I,SECIND(I)
32 FORMAT(8,INDEX(8,13,8) 8,13,8 IS LESS THAN UNITY)
C
      STOP
96 WRITE(LUN9,30)
      WRITE(LUN9,33)I,SECIND(I),NPOINT
33 FORMAT(8,INDEX(8,13,8) 8,13,8 IS GREATER THAN
170E NUMBER OF POINTS 8,13)
C
      STOP
      END
      SUBROUTINE FINGERD
C
C PURPOSE:
C-----
C TO RESET ALL ARRAYS FOR A FINE DETAIL STRUCTURE OF SURFACE
C IN ORDER TO RESPECT GEOMETRY,INTERVALS ARE DIVIDED BY THREE.
C
      INTEGER PERSEC,SECIND,PERPAN,PANIND
      COMMON PSAVE(144,10),CSAVE(144,10),PSECTR(144),CSECTR(144),
1DELEC(20),DELMAX(144),ENAX(144),ETA(20),BSCAT(144),
2BSCAT2(144),BSCAT3(144),PHO(20,40),
1ANG(40),CPHOTO(144),SUMANG,ANGD,BOUNDL(20,40),BOUNDI(20,40),
2ANGL(20,40),VIE(20,40),ICHECK(20,40),RATIO(13),IROOT(144),
3IFAU(14),JLOCAL(144),ICOM(144),
1VIE(20),EV(8),NLEV,NFINES,ILEV,TIMIN(20),TIMAX(20),VINUM(20),
2A(144),B(144),C(144),BB(144),BM(144),TM(144),DM(144),
3EM(144),TWOCOS(700),
1IFLG,NPOINT,M,ICOM,IS/M,IPDIS,NSECT,NPEROD,NPEROD,IDINY,
2GAMMA,DVUX(70,48),DVY(70,48),Y(144),DELTAK,DELTAY,
3YS(64,48),XS(64),XSS(70),
1VARIABLE(4),T,DELT,SBOUND,NDIR,POT,M,J1,RPI,RP12,RPINAF,SOTPI,
2SAY,TEMP1,TEMP2,DEME1,DEME2,DEMI1,DEMI2,TEMP11,TEMP12,
3TEMP,LUM3,LUM4,LUM5,LUM6,LUM7,LUM8,LUM9,LUM10,
1IDTL(144),JDTL(144),PERSEC(144),SECIND(144),IPANEL(144),
2PERPAN(144,4),PANIND(144),
1ICION(144),CELEC(144),CSECT(144),CSECT(144),CPHOTO(144),
2CPHOT1(144),CBSCAT(144),CBSCAT(144),SECPRI(144),SECPRI(144),
3PMI(144),CGUM(144),
1KASE,JOM,DPI,NANG,RAD,PBOUND,OMEGA,ALPHA,SO,JP,IS,ECS,
2XPU12(20),EFTVI(20),IERROR,TETMIN,TETMAX,BETA1,BETA2,JLESS,
3L2,CARRIV,CPH,XI,CSECEL,CSECEI,CS,CB,CSI,CBI
      EQUIVALENCE (IROOT(1),IDUMY(1))
C
C=====
C
      IOLD=NSECT
      JOLD=NPOINT
      NPOINT=3*JOLD
      ANG=ANGD/3.0
      SUMANG=SUMANG/3.0
C
C FIND NEW FLAGS OF CORRESPONDING GRID POINTS
CFIRST SAVE OLD VALUES
C
      DO 100 J=1,JOLD
      IF(JDTL(J).EQ.0) GO TO 102
      IDUMY(J83-2)=1
      IDUMY(J83-1)=1
      IDUMY(J83)=1
      GO TO 100
102 IDUMY(J83-2)=0
      IDUMY(J83-1)=1
      IDUMY(J83)=0
100 CONTINUE
C
C
C
C NOW RESET ARRAY
      DO 110 J=1,NPOINT
      110 JDTL(J)=IDUMY(J)
C
C
C FIND NEW INDICES OF CORRESPONDING GRID POINTS
      L=0
      II=0
      DO 112 I=1,IOLD
      K=PERSEC(I)
      N2=L+K
      N1=L+1
      DO 113 N=1,N2
      J=PERIND(N)
      IF(ICOM(I).EQ.0.AND.ISYM.EQ.2) GO TO 1100
      IDUMY(NJ83-2)=J83-2
      IDUMY(NJ83-1)=J83-1
      IDUMY(NJ83)=J83
      II=II+3
      GO TO 113
1100 II=II+6
      IDUMY(II-5)=J83-2
      IDUMY(II-4)=PERIND(NJ83-2)
      IDUMY(II-3)=J83-1
      IDUMY(II-2)=J83-1
      IDUMY(II-1)=J83-1
      IDUMY(II)=J83
      GO TO 250
111 CONTINUE
      L=L+K
112 CONTINUE
C
C NOW RESET ARRAY
      DO 114 J=1,NPOINT
      SECIND(J)=IDUMY(J)
114 CONTINUE
C
C SET UP NEW INDICES OF GRID POINTS PER PANEL(PANIND)
      L=0
      II=0
      DO 151 I=1,IOLD
      K=PERSEC(I)
      N2=L+K
      N1=L+1
      DO 150 N=1,N2
      J=PERIND(N)
      IF(ICOM(I).EQ.0.AND.ISYM.EQ.2) GO TO 2500
      IDUMY(NJ83-2)=J83-2
      IDUMY(NJ83-1)=J83-1
      IDUMY(NJ83)=J83
      II=II+3
      GO TO 250
2500 II=II+6
      IDUMY(II-5)=J83-2
      IDUMY(II-4)=PANIND(NJ83-2)
      IDUMY(II-3)=J83-1
      IDUMY(II-2)=PANIND(NJ83-1)
      IDUMY(II-1)=J83
      IDUMY(II)=PANIND(NJ83-2)
      GO TO 2501
250 CONTINUE
2501 CONTINUE
      L=L+K
251 CONTINUE
C
C RESET ARRAY
      DO 260 J=1,NPOINT
      260 PANIND(J)=IDUMY(J)
C
C
C FIND NEW NUMBER OF POINTS (PERSEC) PER NEW SECTOR
C IF AN OLD SECTOR IS INSULATOR,IT IS BROKEN INTO 3 NEW SECTORS
C
      L=0
      II=0
      DO 120 I=1,IOLD
      K=PERSEC(I)
      IF(ICOM(I).EQ.1) II=II+1
      IF(ICOM(I).EQ.1) IDUMY(II)=38K
      IF(ICOM(I).EQ.1) GO TO 120
      II=II+3
      IDUMY(II-2)=1
      IF(ISYM.EQ.0) IDUMY(II-2)=2
      IDUMY(II-1)=K
      IDUMY(II)=1
      IF(ISYM.EQ.0) IDUMY(II)=2
120 CONTINUE
C
      NSECT=II
C
C
C NOW REORGANIZE ARRAYS
      DO 130 I=1,NSECT
      130 PERSEC(I)=IDUMY(I)
C
C
C
C SET NEW FLAGS IDTL FOR SECTORS
      II=0
      DO 140 I=1,IOLD
      IF(ICOM(I).EQ.1) II=II+1
      IF(ICOM(I).EQ.1) IDUMY(II)=1
      IF(ICOM(I).EQ.0.AND.IDTL(I).EQ.0) GO TO 150
      IF(ICOM(I).EQ.0.AND.IDTL(I).EQ.1) GO TO 160
      GO TO 140
150 II=II+3
      IDUMY(II-2)=0
      IDUMY(II-1)=1
      IDUMY(II)=0
      GO TO 140
160 II=II+3
      IDUMY(II-2)=1
      IDUMY(II-1)=1
      IDUMY(II)=1
140 CONTINUE
C
C
C NOW REORGANIZE ARRAY
      DO 170 I=1,NSECT
      170 IDTL(I)=IDUMY(I)
C
C
C
C SET UP NEW NUMBER OF GRID POINTS PER PANEL
      II=0
      DO 270 I=1,IOLD
      IP=IPANEL(I)
      IF(ICOM(I).EQ.1) II=II+1
      IF(ICOM(I).EQ.1) IDUMY(II)=IP
      IF(ICOM(I).EQ.1) GO TO 280
      II=II+3
      IDUMY(II-2)=1
      IF(ISYM.EQ.0) IDUMY(II-2)=2
      IDUMY(II-1)=IP
      IDUMY(II)=1
      IF(ISYM.EQ.0) IDUMY(II)=2
      ID=IDUMY(II-2)
      DO 275 L=1,10
      IDUM(II-2,L)=1
275 IDUM(II)=L)=1
C
      DO 280 L=1,10
      IF(ICOM(I).EQ.1) IDUM(II,L)=PERPAN(I,L)
      IF(ICOM(I).EQ.0) IDUM(II,L)=PERPAN(I,L)
280 CONTINUE
270 CONTINUE
C
C
C NOW RESET ARRAYS
      DO 284 I=1,NSECT

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1 IPANEL(I)=IDUMY(I)
2 IF(IPANEL(I)
3 DO 205 I=1,IP
4 PERPAN(I,L)=IDUMY(I,L)
5 CONTINUE
6
7 CONDUCTIVITY OF NEW SECTORS
8 I=0
9 DO 300 I=1,IOLD
10 IF (ICOM(I),EQ.1) II=II+1
11 IF (ICOM(I),EQ.1) IDUMY(II)=1
12 IF (ICOM(I),EQ.1) GO TO 300
13 I=I+3
14 IDUMY(II-2)=0
15 IDUMY(II-1)=0
16 IDUMY(II)=0
17 CONTINUE
18
19 NON REDEANIZE ARRAYS
20 DO 310 I=1,NSECT
21 ICOM(I)=IDUMY(I)
22 CONTINUE
23
24 NOW RESET SURFACE PROPERTIES
25
26 FIRST SAVE OLD J VALUES
27 DO 450 J=1,JOLD
28 IDUMY(J)=JLOCAL(J)
29 CONTINUE
30
31 DO 460 J=1,JOLD
32 JLOCAL(J83-2)=IDUMY(J)
33 JLOCAL(J83-1)=IDUMY(J)
34 JLOCAL(J83)=IDUMY(J)
35 CONTINUE
36
37 FIND NEW SURFACE PROPERTIES
38
39 DO 470 J=1,NPOINT
40 REWIND LUN3
41 READ(LUN3,500) JFIRST
42 FORMAT(12)
43 IF(JLOCAL(J),NE,JFIRST) GO TO 480
44 READ(LUN3,301) DELMAX(J),ENAX(J),CPHOMX(J)
45 FORMAT(3X,3F10,3)
46 READ(LUN3,301) BSCAT2(J),BSCAT3(J),BSCAT3(J)
47 READ(LUN3,301) DELP(J),EXPM(J)
48 CONTINUE
49
50 WRITE(LUN9,900)
51 FORMAT(//10X,THE FINAL DETAIL STRUCTURE IS NOW SET UP//10X,40
52 I(8-8))
53
54 WRITE NEW VALUES
55
56 WRITE(LUN9,901) (JDTL(J),J=1,NPOINT)
57 WRITE(LUN9,902) (SECIND(J),J=1,NPOINT)
58 WRITE(LUN9,901) (PERSEC(I),I=1,NSECT)
59 WRITE(LUN9,902) (J2=SECIND(I))
60 WRITE(LUN9,901) (IDTL(I),I=1,NSECT)
61 WRITE(LUN9,902) (PANIND(J),J=1,NPOINT)
62 WRITE(LUN9,901) (ICOM(I),I=1,NSECT)
63 WRITE(LUN9,902)
64 902 FORMAT(//)
65 901 FORMAT(32I2)
66 DO 903 I=1,NSECT
67 IP=IPANEL(I)
68 WRITE(LUN9,902) (PERPAN(I,L),L=1,IP)
69 CONTINUE
70
71 RETURN
72 END
73 SUBROUTINE INTPOL(DUMMY)
74
75 DIMENSION DUMMY(1)
76 DIMENSION XX(144),YY(144),D(144)
77 INTEGER PERSEC,SECTIND,PERPAN,PANIND
78 COMMON PNAME(144,10),CBANE(144,10),PSECTR(144),CSECTR(144),
79 IDELETE(20),DELMAX(144),ENAX(144),ETA(20),BSCAT1(144),
80 BSCAT2(144),BSCAT3(144),PHO(20,40),
81 IANG(40),CPHOMX(144),SUMANG,ANGD,BOUNDL(20,40),BOUND2(20,40),
82 ZAWGL(20,40),V11(20,40),ICHECK(20,40),RATIO(13),IROOT(144),
83 3FAC(144),JLOCAL(144),ICOM(144),
84 IVS(20),EV(8),MLEV,NTINES,ILEV,TIMIN(20),TIMAX(20),VNUM(20),
85 2M(144),B(144),C(144),DB(144),BU(144),TW(144),DW(144),
86 SEW(144),TWOCD(700),
87 IFLD,NPOINT,N,IGCOM,ISYR,IPDIS,NSECT,NPEROD,NPEROD,IDINY,
88 20ANNA,DBUX(70,40),DUDY(70,40),Y(144),DELTA,DELTA,
89 3YANNA,DBUX(70,40),DUDY(70,40),Y(144),DELTA,DELTA,
90 IVARBLE(4),T,DELTA,BOUND,NBIN,POT,N,J1,RPI,RPI2,RPINAF,BOTPI,
91 2WAY,TEMP1,TEMP2,DEME1,DEME2,DEMI1,DEMI2,TEMP11,TEMP12,
92 3FAC(LUN3,LUN4,LUN5,LUN6,LUN7,LUN8,LUN9,LUN10),
93 IDTL(144),JDTL(144),PERSEC(144),SECIND(144),IPANEL(144),
94 2PERPAN(144,4),PANIND(144),
95 ICOM(144),CELEC(144),CSECT(144),CSECT(144),CPHOTO(144),
96 2CSCAT(144),CBSCAT(144),CBSCAT(144),SECPRN(144),SECPRN(144),
97 3PHI(144),COUN(144),
98 IBASE,JOML,BPHI,MANG,RAD,POLUNG,OMEGA,ALPHA,B0,JP,IS,EC5,
99 2EXPV12(20),EFTV1(20),IERROR,TETHIN,TETMAX,BETA1,BETA2,JLESS,
100 3LC,CARRIV,CPH,XI,CSECEL,CSECEL,CS,CP,CB,CB1
101 EQUIVALENCE (XX(1),A(1)),(YY(1),B(1)),(D(1),C(1))
102
103 IF SECTORS ARE CONDUCTORS,INTERPOLATION IS DONE PER PANEL
104 IF SECTORS ARE INSULATORS,INTERPOLATION IS DONE BETWEEN ADJACENT SECT
105
106 DESCRIPTION OF VARIABLES
107 JSTART=INDEX WHERE TO FIND FIRST GRID POINT OF SECTOR
108 XX AND YY:TEMPORARY STORAGE FOR INTERPOLATION
109 B,C,D COEFFICIENT FOR SPLINE
110
111 JSTART=1
112 I=0
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[illegible]

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      INTEGER PERSEC,SECIND,PERPAN,PANIND
      COMMON PSAVE(144,10),CSAVE(144,10),PSECTR(144),CSECTR(144),
      1DELEE(20),DELMAX(144),EMAX(144),ETA(20),BSCAT(144),
      1BSCAT(144),BSCAT3(144),PHO(20,40),
      1ANG(40),CPHOMX(144),SUNANG,ANG0,BOUNDL(20,40),BOUND(20,40),
      1ANGL(20,40),V(1,20,40),ICHECK(20,40),RATIO(13),IROOT(144),
      1TIFAULT(14),JLOCAL(144),ICON(144),
      1V(20),EV(8),NLEV,NTIMES,ILEV,TIMIN(20),TIMAX(20),VINUM(20),
      1TA(144),B(144),C(144),BB(144),BM(144),TM(144),DM(144),
      1SEM(144),TWCOS(700),
      1IFLG,NPOINT,N,IGEDN,ISYN,IPOTS,NSECT,NPEROD,NPEROD,INDIN,
      12GAMMA,DVUX(70,48),DVUY(70,48),Y(144),DELTA,DELTA,
      13YS(66,48),XS(66),XSS(70),
      1VARIABLE(4),T,DELTA,SBOUND,NDIN,POT,M,J1,RP1,RP12,RP1HAF,SOTPI,
      1CSA,TENP1,TENP2,DEME1,DEME2,DEME1,DEME2,TENP1,TENP2,
      13TENPR,LUN3,LUN4,LUN5,LUN6,LUN7,LUN8,LUN9,LUN10,
      1IDTL(144),JDTL(144),PERSEC(144),SECIND(144),IPANEL(144),
      1PERPAN(144,4),PANIND(144),
      1ICDM(144),CSECL(144),CSECI(144),CSECI(144),CPHOT(144),
      12CPHOT(144),CBSCAT(144),CBSCA(144),SECPRN(144),SECPRI(144),
      13PHI(144),CGUN(144),
      1KASE,JOHL,DPHI,NANG,RAD,PBOUND,OMEGA,ALPHA,SO,JP,IS,ECS,
      1CEPV(20),EFTVI(20),IERROR,TETMIN,TETMAX,BETA1,BETA2,JLESS,
      13L,CARRIV,CPH,CI,CSECL,CSECI,CS,CS,CS,CS,
C THIS SUBROUTINE CALCULATES THE SECONDARY CURRENT CSEC
C CSEC CONSISTS OF TWO PARTS:CSEC,MAIN SECONDARY CURRENT
C LEAVING A LOCATION AND CARRIV,SECONDARY
C CURRENT ARRIVING AT A LOCATION FROM OTHER PORTIONS OF THE CRAFT
C PHI IS POTENTIAL ON SPACECRAFT SURFACE
C N IS NUMBER OF GRID POINTS ON SPACECRAFT SURFACE
C NANG IS NUMBER OF INTERVALS THAT HALF-ANGLE (RPI/2) GRID FOR
C SECONDARYS IS DIVIDED INTO. NANG SHOULD BE ODD SO THAT THERE IS
C A GRID POINT FOR RPI/2
C NLEV IS NUMBER OF VELOCITY LEVELS USED
C PHO IS ACTUAL CONTRIBUTION AT EACH POINT
C ANG IS LOCATION OF EACH GRID POINT. NOTE THAT ANG AND PHO ARE
C NLEV X NANG MATRICES.
      DATA DANG/0.017/
      DATA FAC/1.0/DVI/0.01/
      DATA AL/O/
      DATA RATIO(3)
      NDIN=3
      DELANG=.5RPI/Float(NANG-1)
      L1=2NANG-1
      L2=L1-1
C GENERATE COEFFICIENTS PHO(I,L) AND ANG(L) FOR USE IN CALCULATING
C SECONDARY CURRENT DUE TO SECONDARYS ARRIVING FROM OTHER
C PORTIONS OF THE SPACECRAFT
      IOHL=1
      DO 300 I=1,NLEV
      DO 191 L=1,L1
      IF (AL.EQ.0) ICHECK(I,L)=1
      IF (AL.EQ.1) ICHECK(I,L)=0
      PHO(I,L)=0.0
      IF (IOHL.EQ.0) GO TO 191
      ANG(L)=DELANG*Float(L-1)
      BETA1=V(1,182+PHI(J)/GAMMA
      IF (BETA1.LT.0.0) GO TO 180
      VARIABLE(1)=SO
      VARIABLE(2)=ANG(L)
      VARIABLE(3)=Y(J)
      COSA=COS(ANG(L))
      DBETA=COSARVDV(1,J)/(2.0*V(1,182+GAMMA)+COSA
      IF (L.EQ.1.AND.DBETA.LT.0.0) GO TO 180
      IF (L.EQ.L1.AND.DBETA.GT.0.0) GO TO 180
      T=0.
      CALL ORBIT(SO,BETA1,J)
      IF (VARIABLE(1).GE.(SBOUND-DELTA)) GO TO 190
      IF (ABS(PHI(J)-POT)/RATIO(3)).LT.100.)
      1 PHO(I,L)=2.0CSEC(1,J)*EXP((POT-PHI(J))/RATIO(3))/
      2 SOTPI
      IF (PHO(I,L).EQ.0.0) ICHECK(I,L)=1
      GO TO 190
180 PHO(I,L)=2.0CSEC(1,J)/SOTPI
190 CONTINUE
191 CONTINUE
      IOHL=0
      DO 300 L=1,L1
      IF (PHO(I,L).NE.0.0) IOHL=IOHL+1
300 CONTINUE
C
C
      DO 197 L=1,L1
      DO 197 I=1,NLEV
      BOUNDL(I,L)=PHO(I,L)
      BOUND(I,L)=PHO(I,L)
      V(1,L)=V(1,I)
      ANG(L)=ANG(L)
197 CONTINUE
C
C
      IF (AL.EQ.0) GO TO 2100
      DO 200 I=1,NLEV
      DO 200 L=1,L2
      IF (ICHECK(I,L).EQ.1.OR.ICHECK(I,L+1).EQ.1) GO TO 200
      IF (PHO(I,L).EQ.0.0.AND.PHO(I,L+1).NE.0.0) GO TO 201
      IF (PHO(I,L).NE.0.0.AND.PHO(I,L+1).EQ.0.0) GO TO 202
      GO TO 200
201 LCUT=L
      ANG=ANG(L)
      ANGB=ANG(L+1)
      GO TO 203
202 LCUT=L+1
      ANG=ANG(L+1)
      ANGB=ANG(L)
      ANGB=0.5(ANG+ANGB)
203 ANGLE=0.5(ANG+ANGB)
204 AQLD=ANGLE
      VARIABLE(1)=SO
      VARIABLE(2)=ANGLE
      VARIABLE(3)=Y(J)
      T=0.0
      BETA1=V(1,182+V(1,I)+PHI(J)/GAMMA
      IF (BETA1.LT.0.0) BOUNDL(I,LCUT)=2.0CSEC(1,J)/SOTPI
      IF (BETA1.LT.0.0) GO TO 207
      CALL ORBIT(SO,BETA1,J)
      IF (VARIABLE(1).GE.(SBOUND-DELTA)) GO TO 204
      IF (ABS(PHI(J)-POT)/RATIO(3)).LT.100.)
      1 BOUNDL(I,LCUT)=2.0CSEC(1,J)*EXP((POT-PHI(J))/GAMMA)/SOTPI
207 ANGB=ANGLE
      GO TO 205
204 ANGB=ANGLE
205 ANGLE=0.5(ANG+ANGB)
      IF (ABS(ANGLE-AQLD).GT.DANG) GO TO 204
      ANG(L)=ANGLE
206 CONTINUE
C
C
      NLEV=NLEV-1
      DO 210 L=1,L1
      DO 210 I=1,NLEV
      IF (IROOT(I,L).EQ.1.AND.ICHECK(I,L).EQ.1) GO TO 210
      IF (PHO(I,L).EQ.0.0.AND.PHO(I,L+1).EQ.0.0) GO TO 210
      IF (PHO(I,L).NE.0.0.AND.PHO(I,L+1).EQ.0.0) GO TO 210
      GO TO 210
211 ICUT=1
      VARIABLE(1)
      VARIABLE(2)
      GO TO 213
212 ICUT=1+1
      VARIABLE(1)
      VARIABLE(2)
      GO TO 213
213 V(1,0.58(VIA+VIB)
214 V(1,0.58(VIA+VIB)
      BETA1=V(1,182+PHI(J)/GAMMA
      IF (BETA1.LT.0.0) BOUNDL(I,LCUT)=2.0CSEC(1,J)/SOTPI
      IF (BETA1.LT.0.0) GO TO 217
      VARIABLE(1)=SO
      VARIABLE(2)=ANG(L)
      VARIABLE(3)=Y(J)
      T=0.0
      CALL ORBIT(SO,BETA1,J)
      IF (VARIABLE(1).GE.(SBOUND-DELTA)) GO TO 214
      IF (ABS(PHI(J)-POT)/RATIO(3)).LT.100.)
      1 BOUNDL(I,LCUT)=2.0CSEC(1,J)*EXP((POT-PHI(J))/GAMMA)/SOTPI
217 V(1,0.58(VIA+VIB)
      GO TO 215
214 VIA=VIA
      GO TO 215
215 V(1,0.58(VIA+VIB)
      IF (ABS(PHI(J)-POT)/RATIO(3)).GT.DVIB(V(1,I)+V(1,I+1)) GO TO 216
      V(1,LCUT)=VIA
216 CONTINUE
C
C
2100 CONTINUE
C
C
C CALCULATE CSEC
      CURRIN=0.
      CURRAX=0.
      CURRIV=0.
      IF (IFALT(7).EQ.0) GO TO 4000
      CPH=0.0
      DO 350 L=1,L1
      IF (PHO(I,L).NE.0.0.OR.PHI(J).GT.0.0)
      1 CPH=2.0CSEC(1,J)/SOTPI
350 CONTINUE
      WRITE (LUN6,6000) J
6000 FORMAT (/1X,PSAMPLING IN VELOCITY SPACE FOR SECONDARYS FOR J=,
      1 13X)
      WRITE (LUN6,600) ((PHO(I,L),I=1,NLEV),L=1,L1)
600 FORMAT (8(1X,1PE9.2))
359 CONTINUE
      CALL FT(L2,CARRIV,CURRIN,CURRAX,J,CPH,PHI,N,GAMMA)
4000 CONTINUE
360 CSEC(J)=CSEC(J)-CARRIV
400 CONTINUE
      RETURN
      SUBROUTINE BSCAT(N,NANG,PHI,CBSCAT,ITER,IGEDN,OMEGA,SO,J,CBSCA1)
      INTEGER PERSEC,SECIND,PERPAN,PANIND
      COMMON PSAVE(144,10),CSAVE(144,10),PSECTR(144),CSECTR(144),
      1DELEE(20),DELMAX(144),EMAX(144),ETA(20),BSCAT(144),
      1BSCAT(144),BSCAT3(144),PHO(20,40),
      1ANG(40),CPHOMX(144),SUNANG,ANG0,BOUNDL(20,40),BOUND(20,40),
      1ANGL(20,40),V(1,20,40),ICHECK(20,40),RATIO(13),IROOT(144),
      1TIFAULT(14),JLOCAL(144),ICON(144),
      1V(20),EV(8),NLEV,NTIMES,ILEV,TIMIN(20),TIMAX(20),VINUM(20),
      1TA(144),B(144),C(144),BB(144),BM(144),TM(144),DM(144),
      1SEM(144),TWCOS(700),
      1IFLG,NPOINT,N,IGEDN,ISYN,IPOTS,NSECT,NPEROD,NPEROD,INDIN,
      12GAMMA,DVUX(70,48),DVUY(70,48),Y(144),DELTA,DELTA,
      13YS(66,48),XS(66),XSS(70),
      1VARIABLE(4),T,DELTA,SBOUND,NDIN,POT,M,J1,RP1,RP12,RP1HAF,SOTPI,
      1CSA,TENP1,TENP2,DEME1,DEME2,DEME1,DEME2,TENP1,TENP2,
      13TENPR,LUN3,LUN4,LUN5,LUN6,LUN7,LUN8,LUN9,LUN10,
      1IDTL(144),JDTL(144),PERSEC(144),SECIND(144),IPANEL(144),
      1PERPAN(144,4),PANIND(144),
      1ICDM(144),CSECL(144),CSECI(144),CSECI(144),CPHOT(144),
      12CPHOT(144),CBSCAT(144),CBSCA(144),SECPRN(144),SECPRI(144),
      13PHI(144),CGUN(144),
      1KASE,JOHL,DPHI,NANG,RAD,PBOUND,OMEGA,ALPHA,SO,JP,IS,ECS,
      1CEPV(20),EFTVI(20),IERROR,TETMIN,TETMAX,BETA1,BETA2,JLESS,
      13L,CARRIV,CPH,CI,CSECL,CSECI,CS,CS,CS,CS,
C THIS SUBROUTINE CALCULATES THE BSCATTER CURRENT CBSCAT
C CBSCAT CONSISTS OF TWO PARTS:CBSCAT,MAIN BSCATTER CURRENT
C LEAVING A LOCATION AND CARRIV,BSCATTER
C CURRENT ARRIVING AT A LOCATION FROM OTHER PORTIONS OF THE CRAFT
C PHI IS POTENTIAL ON SPACECRAFT SURFACE
C N IS NUMBER OF GRID POINTS ON SPACECRAFT SURFACE
C NANG IS NUMBER OF INTERVALS THAT HALF-ANGLE (RPI/2) GRID FOR
C BSCATTERS IS DIVIDED INTO. NANG SHOULD BE ODD SO THAT THERE IS
C A GRID POINT FOR RPI/2
C NLEV IS NUMBER OF VELOCITY LEVELS USED
C PHO IS ACTUAL CONTRIBUTION AT EACH POINT
C ANG IS LOCATION OF EACH GRID POINT. NOTE THAT ANG AND PHO ARE
C NLEV X NANG MATRICES.
      DATA DANG/0.017/
      DATA FAC/1.0/DVI/0.01/
      DATA AL/O/
      DATA RATIO(4)
      DELANG=.5RPI/Float(NANG-1)
      L1=2NANG-1
      L2=L1-1
      NDIN=3
C GENERATE COEFFICIENTS PHO(I,L) AND ANG(L) FOR USE IN CALCULATING
C BSCATTER CURRENT DUE TO BSCATTERS ARRIVING FROM OTHER
C PORTIONS OF THE SPACECRAFT
      IOHL=1
      DO 300 I=1,NLEV
      DO 190 L=1,L1
      IF (AL.EQ.0) ICHECK(I,L)=1
      IF (AL.EQ.1) ICHECK(I,L)=0
      PHO(I,L)=0.0
      IF (IOHL.EQ.0) GO TO 190
      ANG(L)=DELANG*Float(L-1)
      BETA1=V(1,182+PHI(J)/GAMMA
      IF (BETA1.LT.0.0) GO TO 180
      VARIABLE(1)=SO
      VARIABLE(2)=ANG(L)
      VARIABLE(3)=Y(J)
      COSA=COS(ANG(L))
      DBETA=COSARVDV(1,J)/(2.0*V(1,182+GAMMA)+COSA
      IF (L.EQ.1.AND.DBETA.LT.0.0) GO TO 180
      IF (L.EQ.L1.AND.DBETA.GT.0.0) GO TO 180
      T=0.
      CALL ORBIT(SO,BETA1,J)
      IF (VARIABLE(1).GE.(SBOUND-DELTA)) GO TO 190
      IF (ABS(PHI(J)-POT)/RATIO(4)).LT.100.)
      1 PHO(I,L)=2.0CBSCA(1,J)*EXP((POT-PHI(J))/RATIO(4))/
      2 SOTPI
      IF (PHO(I,L).EQ.0.0) ICHECK(I,L)=1
      GO TO 190
180 PHO(I,L)=2.0CBSCA(1,J)/SOTPI
190 CONTINUE
191 CONTINUE
      IOHL=0
      DO 300 L=1,L1
      IF (PHO(I,L).NE.0.0) IOHL=IOHL+1
300 CONTINUE
C
C
      DO 197 L=1,L1
      DO 197 I=1,NLEV
      BOUNDL(I,L)=PHO(I,L)
      BOUND(I,L)=PHO(I,L)
      V(1,L)=V(1,I)
      ANG(L)=ANG(L)
197 CONTINUE
C
C
      IF (AL.EQ.0) GO TO 2100
      DO 200 I=1,NLEV
      DO 200 L=1,L2
      IF (ICHECK(I,L).EQ.1.OR.ICHECK(I,L+1).EQ.1) GO TO 200
      IF (PHO(I,L).EQ.0.0.AND.PHO(I,L+1).NE.0.0) GO TO 201
      IF (PHO(I,L).NE.0.0.AND.PHO(I,L+1).EQ.0.0) GO TO 202
      GO TO 200
201 LCUT=L
      ANG=ANG(L)
      ANGB=ANG(L+1)
      GO TO 203
202 LCUT=L+1
      ANG=ANG(L+1)
      ANGB=ANG(L)
      ANGB=0.5(ANG+ANGB)
203 ANGLE=0.5(ANG+ANGB)
204 AQLD=ANGLE
      VARIABLE(1)=SO
      VARIABLE(2)=ANGLE
      VARIABLE(3)=Y(J)
      T=0.0
      BETA1=V(1,182+V(1,I)+PHI(J)/GAMMA
      IF (BETA1.LT.0.0) BOUNDL(I,LCUT)=2.0CBSCA(1,J)/SOTPI
      IF (BETA1.LT.0.0) GO TO 207
      CALL ORBIT(SO,BETA1,J)
      IF (VARIABLE(1).GE.(SBOUND-DELTA)) GO TO 204
      IF (ABS(PHI(J)-POT)/RATIO(4)).LT.100.)
      1 BOUNDL(I,LCUT)=2.0CBSCA(1,J)*EXP((POT-PHI(J))/GAMMA)/SOTPI
207 ANGB=ANGLE
      GO TO 205
204 ANGB=ANGLE
205 ANGLE=0.5(ANG+ANGB)
      IF (ABS(ANGLE-AQLD).GT.DANG) GO TO 204
      ANG(L)=ANGLE
206 CONTINUE
C
C
      NLEV=NLEV-1
      DO 210 L=1,L1
      DO 210 I=1,NLEV
      IF (IROOT(I,L).EQ.1.AND.ICHECK(I,L).EQ.1) GO TO 210
      IF (PHO(I,L).EQ.0.0.AND.PHO(I,L+1).EQ.0.0) GO TO 210
      IF (PHO(I,L).NE.0.0.AND.PHO(I,L+1).EQ.0.0) GO TO 210
      GO TO 210
211 ICUT=1
      VARIABLE(1)
      VARIABLE(2)
      GO TO 213
212 ICUT=1+1
      VARIABLE(1)
      VARIABLE(2)
      GO TO 213
213 V(1,0.58(VIA+VIB)
214 V(1,0.58(VIA+VIB)
      BETA1=V(1,182+PHI(J)/GAMMA
      IF (BETA1.LT.0.0) BOUNDL(I,LCUT)=2.0CBSCA(1,J)/SOTPI
      IF (BETA1.LT.0.0) GO TO 217
      VARIABLE(1)=SO
      VARIABLE(2)=ANG(L)
      VARIABLE(3)=Y(J)
      T=0.0
      CALL ORBIT(SO,BETA1,J)
      IF (VARIABLE(1).GE.(SBOUND-DELTA)) GO TO 214
      IF (ABS(PHI(J)-POT)/RATIO(4)).LT.100.)
      1 BOUNDL(I,LCUT)=2.0CBSCA(1,J)*EXP((POT-PHI(J))/GAMMA)/SOTPI
217 V(1,0.58(VIA+VIB)
      GO TO 215
214 VIA=VIA
      GO TO 215
215 V(1,0.58(VIA+VIB)
      IF (ABS(PHI(J)-POT)/RATIO(4)).GT.DVIB(V(1,I)+V(1,I+1)) GO TO 216
      V(1,LCUT)=VIA
216 CONTINUE
C
C
2100 CONTINUE

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190 PHO(I,L)=2.08ECSA1(J)/SOTPI
190 CONTINUE
191 IOML=0
DO 100 L=1,L1
IF (PHO(I,L).NE.0.0) IOML=IOML+1
300 CONTINUE
C
DO 197 L=1,L1
DO 197 I=1,MLEV
BOUNDL(I,L)=PHO(I,L)
BOUNDI(I,L)=PHO(I,L)
VII(I,L)=VI(I)
ANG(L,I,L)=ANG(L)
197 CONTINUE
C
IF (KL.EQ.0) GO TO 2100
DO 200 I=1,MLEV
DO 200 L=1,L2
IF (ICHECK(I,L).EQ.1.OR.ICHECK(I+1,L).EQ.1) GO TO 200
IF (PHO(I,L).EQ.0.0.AND.PHO(I+1,L).NE.0.0) GO TO 201
IF (PHO(I,L).NE.0.0.AND.PHO(I+1,L).EQ.0.0) GO TO 202
GO TO 200
201 LCUT=L
ANGA=ANG(L)
ANGB=ANG(L+1)
GO TO 203
202 LCUT=L+1
ANGA=ANG(L+1)
ANGB=ANG(L)
203 ANGLE=0.5*(ANGA+ANGB)
204 AOL=ANGLE
VARBLE(1)=50
VARBLE(2)=ANGLE
VARBLE(3)=Y(J)
T=0.0
BETA=VI(I)*VII(I)+PHI(J)/GAMMA
IF (BETA.LT.0.0) BOUNDL(I,LCUT)=2.08ECSA1(J)/SOTPI
IF (BETA.LT.0.0) GO TO 207
CALL ORBIT(SO,BETA,J)
IF (VARBLE(1).GE.(SBOUND-DELTA)) GO TO 204
IF (ABS(PHI(J)-POT)/GAMMA.LT.100.0)
1 BOUNDL(I,LCUT)=2.08ECSA1(J)*EXP((POT-PHI(J))/GAMMA)/SOTPI
204 ANGB=ANGLE
GO TO 205
205 ANGA=ANGLE
205 ANGLE=0.5*(ANGA+ANGB)
IF (ABS(ANGLE-AOL).GT.DANG) GO TO 204
ANG(L,I,LCUT)=ANGLE
200 CONTINUE
C
MLEV1=MLEV-1
DO 210 L=1,L1
DO 210 I=1,MLEV1
IF (ICHECK(I,L).EQ.1.OR.ICHECK(I+1,L).EQ.1) GO TO 210
IF (PHO(I,L).EQ.0.0.AND.PHO(I+1,L).NE.0.0) GO TO 211
IF (PHO(I,L).NE.0.0.AND.PHO(I+1,L).EQ.0.0) GO TO 212
GO TO 210
211 ICUT=I
VIA=VI(I)
VIB=VI(I+1)
GO TO 213
212 ICUT=I+1
VIA=VI(I+1)
VIB=VI(I)
213 VIN=0.5*(VIA+VIB)
214 VIOL=VIN
BETA=VIN*82*PHI(J)/GAMMA
IF (BETA.LT.0.0) BOUNDI(ICUT,L)=2.08ECSA1(J)/SOTPI
IF (BETA.LT.0.0) GO TO 217
VARBLE(1)=50
VARBLE(2)=ANG(L)
VARBLE(3)=Y(J)
T=0.0
CALL ORBIT(SO,BETA,J)
IF (VARBLE(1).GE.(SBOUND-DELTA)) GO TO 214
IF (ABS(PHI(J)-POT)/GAMMA.LT.100.0)
1 BOUNDI(ICUT,L)=2.08ECSA1(J)*EXP((POT-PHI(J))/GAMMA)/SOTPI
217 VIB=VIN
GO TO 215
214 VIA=VIN
GO TO 215
215 VIN=0.5*(VIA+VIB)
IF (ABS(VIN-VIOL).GT.DVIS(VI(I+1)-VI(I))) GO TO 216
VII(ICUT,L)=VIN
210 CONTINUE
C
2100 CONTINUE
C CALCULATE CSBSCAT
CURRIN=0.
CURRAX=0.
CARRIV=0.
IF (IFAIL(18).EQ.0) GO TO 4000
CPH=0.0
DO 350 L=1,L1
IF (PHO(I,L).NE.0.0.OR.PHI(J).GT.0.0)
1 CPH=2.08ECSA1(J)/SOTPI
350 CONTINUE
WRITE (LUNG,6000) J
4000 FORMAT (1X,50SAMPLING IN VELOCITY SPACE FOR SCATTERERS AT J=8,
1 13)
WRITE (LUNG,6001) (PHO(I,L),I=1,MLEV),L=1,L1
400 FORMAT (8(1X,1PE9.2))
CALL FIT(12,CARRIV,CURRIN,CURRAX,J,CPH,PHI,N,GAMMA)
4000 CONTINUE
401 FORMAT (//)
360 CSBSCAT(J)=CSBSCAT(J)+CARRIV
400 CONTINUE
RETURN
END
SUBROUTINE FLPRN(N,HANG,PHI,SECPH,ITER,IBCON,OMEGA,SO,J,SECPRI)
INTER=PERSEC*SECONB*PERPAN*PANIND
COMMON PSAVE(144,10),CSAVE(144,10),PSECTR(144),CSECTR(144),
IDLEE(20),DELMAX(144),EMAX(144),ETA(20),BSCAT(144),
2BSCAT2(144),BSCAT3(144),PHO(20,40),
1AND(40),CPHMAX(144),SUNANG,ANGB,BOUNDL(20,40),
2ANGD(20,40),VII(20,40),ICHECK(20,40),RATIO(13),IROOT(144),
3IFAIL(144),JLOCAL(144),ICOM(144),
1VI(20),FV(8),MLEV,NTIME,LEV,TIN(20),TMAX(20),VINUN(20),
2AI(44),BI(44),C(144),BB(144),MU(144),TU(144),DU(144),
3FU(144),TUOCD(700),
11710,MPDINT,N,IBCON,ISYN,IPDIS,NSECT,NPEROD,NPEROD,IBIRY,
2OHANG,BUDY(70,48),DUDY(70,48),Y(144),DELTA,DELTA,
3Y(44,48),X(44),XS(70),
1VARB(4),T,DELT,SBOUND,NDIR,POT,N,J1,RP1,RP12,RP1HAF,SOTPI,
2SAY,TEMP1,TEMP2,DEHE1,DEHE2,DEH1,DEH2,TEMP11,TEMP12,
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MP646,TEMP647,TEMP648,TEMP649,TEMP650,TEMP651,TEMP652,TEMP653,TEMP654,TEMP655,TEMP656,TEMP657,TEMP658,TEMP659,TEMP660,TEMP661,TEMP662,TEMP663,TEMP664,TEMP665,TEMP666,TEMP667,TEMP668,TEMP669,TEMP670,TEMP671,TEMP672,TEMP673,TEMP674,TEMP675,TEMP676,TEMP677,TEMP678,TEMP679,TEMP680,TEMP681,TEMP682,TEMP683,TEMP684,TEMP685,TEMP686,TEMP687,TEMP688,TEMP689,TEMP690,TEMP691,TEMP692,TEMP693,TEMP694,TEMP695,TEMP696,TEMP697,TEMP698,TEMP699,TEMP700,TEMP701,TEMP702,TEMP703,TEMP704,TEMP705,TEMP706,TEMP707,TEMP708,TEMP709,TEMP710,TEMP711,TEMP712,TEMP713,TEMP714,TEMP715,TEMP716,TEMP717,TEMP718,TEMP719,TEMP720,TEMP721,TEMP722,TEMP723,TEMP724,TEMP725,TEMP726,TEMP727,TEMP728,TEMP729,TEMP730,TEMP731,TEMP732,TEMP733,TEMP734,TEMP735,TEMP736,TEMP737,TEMP738,TEMP739,TEMP740,TEMP741,TEMP742,TEMP743,TEMP744,TEMP745,TEMP746,TEMP747,TEMP748,TEMP749,TEMP750,TEMP751,TEMP752,TEMP753,TEMP754,TEMP755,TEMP756,TEMP757,TEMP758,TEMP759,TEMP760,TEMP761,TEMP762,TEMP763,TEMP764,TEMP765,TEMP766,TEMP767,TEMP768,TEMP769,TEMP770,TEMP771,TEMP772,TEMP773,TEMP774,TEMP775,TEMP776,TEMP777,TEMP778,TEMP779,TEMP780,TEMP781,TEMP782,TEMP783,TEMP784,TEMP785,TEMP786,TEMP787,TEMP788,TEMP789,TEMP790,TEMP791,TEMP792,TEMP793,TEMP794,TEMP795,TEMP796,TEMP797,TEMP798,TEMP799,TEMP800,TEMP801,TEMP802,TEMP803,TEMP804,TEMP805,TEMP806,TEMP807,TEMP808,TEMP809,TEMP810,TEMP811,TEMP812,TEMP813,TEMP814,TEMP815,TEMP816,TEMP817,TEMP818,TEMP819,TEMP820,TEMP821,TEMP822,TEMP823,TEMP824,TEMP825,TEMP826,TEMP827,TEMP828,TEMP829,TEMP830,TEMP831,TEMP832,TEMP833,TEMP834,TEMP835,TEMP836,TEMP837,TEMP838,TEMP839,TEMP840,TEMP841,TEMP842,TEMP843,TEMP844,TEMP845,TEMP846,TEMP847,TEMP848,TEMP849,TEMP850,TEMP851,TEMP852,TEMP853,TEMP854,TEMP855,TEMP856,TEMP857,TEMP858,TEMP859,TEMP860,TEMP861,TEMP862,TEMP863,TEMP864,TEMP865,TEMP866,TEMP867,TEMP868,TEMP869,TEMP870,TEMP871,TEMP872,TEMP873,TEMP874,TEMP875,TEMP876,TEMP877,TEMP878,TEMP879,TEMP880,TEMP881,TEMP882,TEMP883,TEMP884,TEMP885,TEMP886,TEMP887,TEMP888,TEMP889,TEMP890,TEMP891,TEMP892,TEMP893,TEMP894,TEMP895,TEMP896,TEMP897,TEMP898,TEMP899,TEMP900,TEMP901,TEMP902,TEMP903,TEMP904,TEMP905,TEMP906,TEMP907,TEMP908,TEMP909,TEMP910,TEMP911,TEMP912,TEMP913,TEMP914,TEMP915,TEMP916,TEMP917,TEMP918,TEMP919,TEMP920,TEMP921,TEMP922,TEMP923,TEMP924,TEMP925,TEMP926,TEMP927,TEMP928,TEMP929,TEMP930,TEMP931,TEMP932,TEMP933,TEMP934,TEMP935,TEMP936,TEMP937,TEMP938,TEMP939,TEMP940,TEMP941,TEMP942,TEMP943,TEMP944,TEMP945,TEMP946,TEMP947,TEMP948,TEMP949,TEMP950,TEMP951,TEMP952,TEMP953,TEMP954,TEMP955,TEMP956,TEMP957,TEMP958,TEMP959,TEMP960,TEMP961,TEMP962,TEMP963,TEMP964,TEMP965,TEMP966,TEMP967,TEMP968,TEMP969,TEMP970,TEMP971,TEMP972,TEMP973,TEMP974,TEMP975,TEMP976,TEMP977,TEMP978,TEMP979,TEMP980,TEMP981,TEMP982,TEMP983,TEMP984,TEMP985,TEMP986,TEMP987,TEMP988,TEMP989,TEMP990,TEMP991,TEMP992,TEMP993,TEMP994,TEMP995,TEMP996,TEMP997,TEMP998,TEMP999,TEMP1000,TEMP1001,TEMP1002,TEMP1003,TEMP1004,TEMP1005,TEMP1006,TEMP1007,TEMP1008,TEMP1009,TEMP1010,TEMP1011,TEMP1012,TEMP1013,TEMP1014,TEMP1015,TEMP1016,TEMP1017,TEMP1018,TEMP1019,TEMP1020,TEMP1021,TEMP1022,TEMP1023,TEMP1024,TEMP1025,TEMP1026,TEMP1027,TEMP1028,TEMP1029,TEMP1030,TEMP1031,TEMP1032,TEMP1033,TEMP1034,TEMP1035,TEMP1036,TEMP1037,TEMP1038,TEMP1039,TEMP1040,TEMP1041,TEMP1042,TEMP1043,TEMP1044,TEMP1045,TEMP1046,TEMP1047,TEMP1048,TEMP1049,TEMP1050,TEMP1051,TEMP1052,TEMP1053,TEMP1054,TEMP1055,TEMP1056,TEMP1057,TEMP1058,TEMP1059,TEMP1060,TEMP1061,TEMP1062,TEMP1063,TEMP1064,TEMP1065,TEMP1066,TEMP1067,TEMP1068,TEMP1069,TEMP1070,TEMP1071,TEMP1072,TEMP1073,TEMP1074,TEMP1075,TEMP1076,TEMP1077,TEMP1078,TEMP1079,TEMP1080,TEMP1081,TEMP1082,TEMP1083,TEMP1084,TEMP1085,TEMP1086,TEMP1087,TEMP1088,TEMP1089,TEMP1090,TEMP1091,TEMP1092,TEMP1093,TEMP1094,TEMP1095,TEMP1096,TEMP1097,TEMP1098,TEMP1099,TEMP1100,TEMP1101,TEMP1102,TEMP1103,TEMP1104,TEMP1105,TEMP1106,TEMP1107,TEMP1108,TEMP1109,TEMP1110,TEMP1111,TEMP1112,TEMP1113,TEMP1114,TEMP1115,TEMP1116,TEMP1117,TEMP1118,TEMP1119,TEMP1120,TEMP1121,TEMP1122,TEMP1123,TEMP1124,TEMP1125,TEMP1126,TEMP1127,TEMP1128,TEMP1129,TEMP1130,TEMP1131,TEMP1132,TEMP1133,TEMP1134,TEMP1135,TEMP1136,TEMP1137,TEMP1138,TEMP1139,TEMP1140,TEMP1141,TEMP1142,TEMP1143,TEMP1144,TEMP1145,TEMP1146,TEMP1147,TEMP1148,TEMP1149,TEMP1150,TEMP1151,TEMP1152,TEMP1153,TEMP1154,TEMP1155,TEMP1156,TEMP1157,TEMP1158,TEMP1159,TEMP1160,TEMP1161,TEMP1162,TEMP1163,TEMP1164,TEMP1165,TEMP1166,TEMP1167,TEMP1168,TEMP1169,TEMP1170,TEMP1171,TEMP1172,TEMP1173,TEMP1174,TEMP1175,TEMP1176,TEMP1177,TEMP1178,TEMP1179,TEMP1180,TEMP1181,TEMP1182,TEMP1183,TEMP1184,TEMP1185,TEMP1186,TEMP1187,TEMP1188,TEMP1189,TEMP1190,TEMP1191,TEMP1192,TEMP1193,TEMP1194,TEMP1195,TEMP1196,TEMP1197,TEMP1198,TEMP1199,TEMP1200,TEMP1201,TEMP1202,TEMP1203,TEMP1204,TEMP1205,TEMP1206,TEMP1207,TEMP1208,TEMP1209,TEMP1210,TEMP1211,TEMP1212,TEMP1213,TEMP1214,TEMP1215,TEMP1216,TEMP1217,TEMP1218,TEMP1219,TEMP1220,TEMP1221,TEMP1222,TEMP1223,TEMP1224,TEMP1225,TEMP1226,TEMP1227,TEMP1228,TEMP1229,TEMP1230,TEMP1231,TEMP1232,TEMP1233,TEMP1234,TEMP1235,TEMP1236,TEMP1237,TEMP1238,TEMP1239,TEMP1240,T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96,TEMP1797,TEMP1798,TEMP1799,TEMP1800,TEMP1801,TEMP1802,TEMP1803,TEMP1804,TEMP1805,TEMP1806,TEMP1807,TEMP1808,TEMP1809,TEMP1810,TEMP1811,TEMP1812,TEMP1813,TEMP1814,TEMP1815,TEMP1816,TEMP1817,TEMP1818,TEMP1819,TEMP1820,TEMP1821,TEMP1822,TEMP1823,TEMP1824,TEMP1825,TEMP1826,TEMP1827,TEMP1828,TEMP1829,TEMP1830,TEMP1831,TEMP1832,TEMP1833,TEMP1834,TEMP1835,TEMP1836,TEMP1837,TEMP1838,TEMP1839,TEMP1840,TEMP1841,TEMP1842,TEMP1843,TEMP1844,TEMP1845,TEMP1846,TEMP1847,TEMP1848,TEMP1849,TEMP1850,TEMP1851,TEMP1852,TEMP1853,TEMP1854,TEMP1855,TEMP1856,TEMP1857,TEMP1858,TEMP1859,TEMP1860,TEMP1861,TEMP1862,TEMP1863,TEMP1864,TEMP1865,TEMP1866,TEMP1867,TEMP1868,TEMP1869,TEMP1870,TEMP1871,TEMP1872,TEMP1873,TEMP1874,TEMP1875,TEMP1876,TEMP1877,TEMP1878,TEMP1879,TEMP1880,TEMP1881,TEMP1882,TEMP1883,TEMP1884,TEMP1885,TEMP1886,TEMP1887,TEMP1888,TEMP1889,TEMP1890,TEMP1891,TEMP1892,TEMP1893,TEMP1894,TEMP1895,TEMP1896,TEMP1897,TEMP1898,TEMP1899,TEMP1900,TEMP1901,TEMP1902,TEMP1903,TEMP1904,TEMP1905,TEMP1906,TEMP1907,TEMP1908,TEMP1909,TEMP1910,TEMP1911,TEMP1912,TEMP1913,TEMP1914,TEMP1915,TEMP1916,TEMP1917,TEMP1918,TEMP1919,TEMP1920,TEMP1921,TEMP1922,TEMP1923,TEMP1924
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      VARI(2)=ANG(L)
      VARI(3)=V(I)
      I=0
      CALL ORBIT(SO,RETAL,J)
      IF (VARI(1).GE.(SBOUND-DELTA)) GO TO 214
      VIR=VIR
      SECPN(1,0)=WEIGHT*SECPN(J)+WEIGHT*SECPN(J2)
      BOUND(1,CUT-L)=2.0*SECPNEXP(POT-PHI(J)/GAMMA)/SQRTI
      GO TO 215
214 VIA=VIR
      GO TO 215
215 VIR=0.5*(VIA+VIR)
      IF (ABS(VIR-VOLD).GT.DVIR*(V(I+1)-V(I))) GO TO 216
217 VII(CUT,L)=VIR
210 CONTINUE
C
C
C
2100 CONTINUE
C
C CALCULATE SECPN
      CURRINO=0.
      CURRAX=0.
      CURRIV=0.
      IF (IFAU(8).EQ.0) GO TO 4000
      CPH=0.
      DO 350 L=1,L1
      IF (PHO(I,L).NE.0.0.DR.PHI(J).GT.0.0)
      1 CPH=2.0*SECPN(J)/SQRTI
350 CONTINUE
      WRITE (LUNG,6000) J
4000 FORMAT (1X,'SAMPLING IN VELOCITY SPACE FOR ELEC INDUCED AT J= ',
      1 13)
      WRITE (LUNG,6000) (PHO(I,L),I=1,NLEV),L=1,L1
400 FORMAT (81X,1PE9.2)
      CALL FIT(L2,CARRIV,CURRIN,CURRAX,J,CPH,PHI,H,GAMMA)
4000 CONTINUE
360 SECPN(J)=SECPN(J)+CARRIV
400 CONTINUE
      RETURN
      END
      SUBROUTINE GUM
      C=====
      C PURPOSE: TO COMPUTE THE CURRENT DUE TO THE EMISSION OF A GUM
      C=====
      COMMON/COM/CIOM(144),CELEC(144),CSECI(144),CSECI(144),CHOTO(144)
      1 CPHOTI(144),CBSCAT(144),CBSCAI(144),SECPN(144),SECPRI(144),
      2 PHI(144),CUM(144)
      RETURN
      END
      SUBROUTINE FIT(L2,CARRIV,CURRIN,CURRAX,J,PHO,PHI,H,GAMMA)
      C=====
      C THIS SUBROUTINE CALCULATES SECONDARY CURRENT FROM OTHER POINTS.
      C IT IS USED IN THE COMPUTATION OF PHOTOELECTRONS,SECONDARIES,AND
      C BACKSCATTERED ELECTRONS.
      C
      C PURPOSE
      C
      C TO COMPUTE THE CURRENT DENSITY=SUM OVER I(VELOCITY) AND SUM OVER L
      C (ANGLE) OF (A+B*ANG*E*VELOCITY+D*ANGLE*VELOCITY)*EXP(-VELOCITY**2)*
      C (VELOCITY**2)*SIN(ANGLE)*DB(ANGLE)*DB(VELOCITY)
      C TACKING INTO ACCOUNT THE FACT THAT FOR CERTAIN INCIDENT ENERGIES
      C AND CERTAIN DIRECTIONS, ELECTRON ORBITS DO CONNECT BACK TO THE AMBIENT
      C PLASMA.
      C DESCRIPTION OF THE VARIABLES
      C CARRIV: TOTAL ARRIVING SECONDARY CURRENT AT A GIVEN GRID POINT
      C CURRIN: ARRIVING CURRENT FOR ONE ELEMENTARY CELL IN VELOCITY SPACE
      C PHO(I,L): WEIGHTING FACTORS IN CURRENT INTEGRATION
      C A,B,C,D: COEFFICIENTS IN BILINEAR INTERPOLATION
      C ANGLE: SAMPLING ANGLE IN VELOCITY SPACE, ANGLES ARE SAMPLED FROM 0 TO
      C ZERO TO PI
      C VII: SAMPLING IN KINETIC VELOCITY
      C NLEV: NUMBER OF ENERGY LEVELS USED IN THE COMPUTATION
      C L2: NUMBER OF ANGLES IN VELOCITY SPACE USED IN THE COMPUTATION
      C
      INTEGER PERSEC,SECINO,PERPAH,PAHINO
      COMMON PPAVE(144,10),CBAVE(144,10),PSPECTR(144),CSECTR(144),
      1 DELEC(20),DELMAX(144),ENAX(144),ETA(20),BSCAT(144),
      2 BSCAT2(144),BSCAT3(144),PHO(20,40),
      1 ANGB(40),CPHOB(144),SUMANG,ANGD,BOUNBL(20,40),BOUNDI(20,40),
      2 ANGL(20,40),VUI(20,40),ICHECK(20,40),RATIO(13),IROOT(144),
      3 IFAU(144),LOCAL(144),ICON(144),
      4 IUI(20),EUI(8),NLEV,HTINES,ILEV,TININ(20),TINAX(20),VINUM(20),
      5 PA(144),BI(144),CI(144),BB(144),BU(144),TU(144),DU(144),
      6 SEU(144),THUCOS(700)
      1 IFLO,MPINT,H,ISEM,ISYN,IPDS,ISPECT,NPEROD,NPEROD,IDIHY,
      2 GAMMA,BVBY(70,40),BVBY(70,40),Y(144),DELTA,DELTA,
      3 YR(46,40),XR(46),XSR(70),
      4 VARI(4),T,DEL,BOUND,HBIN,POT,H,J1,RP1,RP12,RPINAF,SDPTI,
      5 DAY,TEMP1,TEMP2,BENI,BENI2,BENI2,TEMP1,TEMP2,
      6 STEPFR,LUNG,LUNG,LUNG,LUNG,LUNG,LUNG,LUNG,LUNG,LUNG,LUNG,
      7 IJTL(144),JDTL(144),PERSEC(144),SECINO(144),IPANEL(144),
      8 PERPAH(144,4),PAHINO(144),
      9 CIOM(144),CELEC(144),CSECI(144),CSECI(144),CPHOTI(144),
      10 CPHOTI(144),CBSCAT(144),CBSCAI(144),SECPN(144),SECPRI(144),
      11 PHI(144),CUM(144),
      12 INASE,JOH,BPHI,HANG,RAD,PBOUND,ONEBA,ALPHA,BO,JP,IS,ECS,
      13 EXPVIZ(20),EFTVI(20),TERROR,TETIN,TETAX,BETA1,BETA2,A,EBB,
      14 CARRIV,CPH,XI,CSECEL,CSECI,CB,CB,CB,CB1
      C
      DATA KSTEP/5/
      C
      DO 390 I=1,NLEV
      DO 340 L=1,L2
      IF (I.GT.1) GO TO 320
      IF (PHI(J)/GAMMA.LT.0.0) GO TO 340
      IF (PHO(I,L).EQ.0.0.AND.PHO(I,L+1).EQ.0.0) GO TO 340
      DENOM=VUI(13)*(ANG(L)-ANG(L+1))
      A=PHO
      B=0.0
      C=(PHO(I,L+1)*BANG(L)-PHO(I,L)*BANG(L+1))+PHO(I,L)*BANG(L+1)-
      1 BANG(L+1)*DENOM
      D=(PHO(I,L+1)*BANG(L+1)-PHO(I,L+1)*BANG(L+1))/DENOM
      UPRI=(A+B*ANG(L))*COS(ANG(L))-(A+B*ANG(L+1))*
      1 COS(ANG(L+1))+B*SIN(ANG(L+1))-SIN(ANG(L))
      CURRENT=UPRI*(0.5*VUI(13)*EXPVIZ(13)+0.25*SDPTI*EFTVI(13))
      UPRI=0.5*(EXPVIZ(13)*EFTVI(13)+0.25*SDPTI*EFTVI(13))
      CURRENT=CURRENT*UPRI*(C1*(COS(ANG(L))-COS(ANG(L+1))+SIN(ANG(L+1))-SIN(ANG(L))))
      1 COS(ANG(L))-ANG(L+1)*COS(ANG(L+1))+SIN(ANG(L+1))-SIN(ANG(L))
      CARRIV=CARRIV+CURRENT
      C
      GO TO 340
      C
      340 CONTINUE
      BETA=VUI(13)*0.5*PHI(J)/GAMMA
      IF (BETA.LT.0.0) GO TO 340
      DENOM=(ANG(L)-ANG(L+1))*VUI(13)-VUI(13)
      IF (PHO(I,L+1).EQ.0.0.AND.PHO(I,L+1).EQ.0.0.AND.PHO(I,L).EQ.0.0)
      1 AND.PHO(I,L).EQ.0.0) GO TO 340
      C
      CASE 1
      IF (PHO(I,L+1).EQ.0.0.AND.PHO(I,L).EQ.0.0.AND.PHO(I,L+1).EQ.0.0)
      1 AND.PHO(I,L+1).EQ.0.0.AND.ICHECK(I,L+1).EQ.0.0)
      2 GO TO 400
      C
      CASE 2
      IF (PHO(I,L+1).EQ.0.0.AND.PHO(I,L).EQ.0.0.AND.PHO(I,L+1).EQ.0.0)
      1 AND.PHO(I,L+1).EQ.0.0.AND.ICHECK(I,L+1).EQ.0.0.AND.
      2 ICHECK(I,L).EQ.0.0) GO TO 410
      C
      CASE 3
      IF (PHO(I,L+1).EQ.0.0.AND.PHO(I,L).EQ.0.0.AND.PHO(I,L+1).EQ.0.0)
      1 AND.PHO(I,L+1).EQ.0.0.AND.ICHECK(I,L+1).EQ.0.0.AND.
      2 ICHECK(I,L).EQ.0.0.AND.ICHECK(I,L+1).EQ.0.0) GO TO 420
      C
      CASE 4
      IF (PHO(I,L+1).EQ.0.0.AND.PHO(I,L).EQ.0.0.AND.PHO(I,L+1).EQ.0.0)
      1 AND.PHO(I,L+1).EQ.0.0.AND.ICHECK(I,L+1).EQ.0.0.AND.
      2 ICHECK(I,L).EQ.0.0.AND.ICHECK(I,L+1).EQ.0.0) GO TO 430
      C
      CASE 5
      IF (PHO(I,L+1).EQ.0.0.AND.PHO(I,L).EQ.0.0.AND.PHO(I,L+1).EQ.0.0)
      1 AND.PHO(I,L+1).EQ.0.0.AND.ICHECK(I,L).EQ.0.0) GO TO
      2 440
      C
      CASE 6
      IF (PHO(I,L+1).EQ.0.0.AND.PHO(I,L+1).EQ.0.0.AND.PHO(I,L).EQ.0.0)
      1 AND.PHO(I,L+1).EQ.0.0.AND.ICHECK(I,L+1).EQ.0.0.AND.
      2 ICHECK(I,L+1).EQ.0.0) GO TO 450
      C
      CASE 7
      IF (PHO(I,L+1).EQ.0.0.AND.PHO(I,L+1).EQ.0.0.AND.PHO(I,L).EQ.0.0)
      1 AND.PHO(I,L+1).EQ.0.0.AND.ICHECK(I,L+1).EQ.0.0.AND.
      2 ICHECK(I,L).EQ.0.0) GO TO 460
      C
      IF (PHO(I,L+1).EQ.0.0.AND.PHO(I,L+1).EQ.0.0.AND.PHO(I,L).EQ.0.0)
      1 AND.PHO(I,L+1).EQ.0.0.AND.ICHECK(I,L+1).EQ.0.0.AND.PHO(I,L).EQ.0.0)
      2 GO TO 340
      C
      START COMPUTATION FOR THE REGULAR CASE
      9999 A=(PHO(I,L)*BANG(L+1)*VUI(13)-PHO(I,L)*BANG(L+1)*VUI(13)-PHO(I,
      1 L+1)*BANG(L)*VUI(13)+PHO(I,L+1)*BANG(L)*VUI(13))/DENOM
      B=(VUI(13)*(PHO(I,L+1)-PHO(I,L+1))-VUI(13)*(PHO(I,L+1)-PHO(I,L+1))
      1 /DENOM
      C=(ANG(L)*BANG(L+1)-PHO(I,L+1)-PHO(I,L+1)-ANG(L)*BANG(L+1)-PHO(I,
      1 L+1))/DENOM
      D=(PHO(I,L+1)-PHO(I,L+1)-PHO(I,L+1)+PHO(I,L+1))/DENOM
      UPRI=(A+B*ANG(L))*COS(ANG(L))-(A+B*ANG(L+1))*COS(ANG(L+1))+
      1 COS(ANG(L+1))+B*SIN(ANG(L+1))-SIN(ANG(L))
      CURRENT=UPRI*(0.5*VUI(13)*EXPVIZ(13)+0.25*SDPTI*EFTVI(13))
      UPRI=0.5*(EXPVIZ(13)*EFTVI(13)+0.25*SDPTI*EFTVI(13))
      CURRENT=CURRENT*UPRI*(C1*(COS(ANG(L))-COS(ANG(L+1))+SIN(ANG(L+1))-SIN(ANG(L))))
      1 ANG(L)-ANG(L+1)*COS(ANG(L+1))+SIN(ANG(L+1))-SIN(ANG(L))
      CARRIV=CARRIV+CURRENT
      GO TO 340
      C
      START COMPUTATIONS FOR THE NONREGULAR CASE
      C
      CASE NO 1-----
      400 CONTINUE
      PA=BOUNDI(I,L+1)
      PB=BOUND(I,L+1)
      PD=(PHO(I,L+1)-PHO(I,L+1))/(ANG(L+1)-ANG(L))
      1 (ANG(L+1)-ANG(L))+PHO(I,L+1)
      C
      REGION 1
      C-----
      D1=(PB-PD)*PHO(I,L+1)+PHO(I,L+1)/(ANG(L+1)-ANG(L))*VUI(13)-
      1 VUI(13)
      C1=(ANG(L+1)*BANG(L+1)-PHO(I,L+1)-PHO(I,L+1)-ANG(L)*BANG(L+1))/
      1 (ANG(L+1)-ANG(L))+VUI(13)-VUI(13)
      D1=(PB-PD)*PHO(I,L+1)/(ANG(L+1)-ANG(L))-D1*VUI(13)
      A1=PB-B1*ANG(L+1)-C1*VUI(13)-D1*ANG(L+1)*VUI(13)
      C
      REGION 2
      C-----
      VA=VUI(I,L+1)
      ANGB=ANG(I,L+1)
      D1=(PB-PD)*VA-VUI(13)/(PA-PHO(I,L+1))*VUI(13)-VUI(13)/
      1 (VA-VUI(13))*VUI(13)-VUI(13)*BANG(ANG(L+1))
      C1=(PB-PD)*BANG(L+1)*VA-VUI(13)/(PA-PHO(I,L+1))*BANG(ANG(L+1))-
      1 VUI(13)/(VA-VUI(13))*VUI(13)-VUI(13)*BANG(ANG(L+1))-ANG(L)
      D1=(PB-PHO(I,L+1))/ANG(ANG(L+1))-D1*VUI(13)
      A1=PHO(I,L+1)-D1*ANG(L+1)-C1*VUI(13)-D1*VUI(13)*BANG(ANG(L+1))
      C
      UPRI=(A1+B1*ANG(L+1))*COS(ANG(L+1))-(A1+B1*ANG(L+1))*COS(ANG(L+1))+
      1 B1*(SIN(ANG(L+1))-SIN(ANG(L)))
      CURRENT=UPRI*(0.5*VUI(13)*EXPVIZ(13)+0.25*SDPTI*EFTVI(13))
      UPRI=0.5*(EXPVIZ(13)*EFTVI(13)+0.25*SDPTI*EFTVI(13))
      CURRENT=CURRENT*UPRI*(C1*(COS(ANG(L+1))-COS(ANG(L+1))+SIN(ANG(L+1))-SIN(ANG(L+1)))
      1 B1*(SIN(ANG(L+1))-SIN(ANG(L)))
      2 -ANG(L)*COS(ANG(L+1))+SIN(ANG(L+1))-SIN(ANG(L+1))
      C
      STEP=(ANG(L+1)-ANG(L))/FLOAT(KSTEP)
      STEP=ANGD
      STEP=(VUI(I,L+1)-VUI(I))/FLOAT(KSTEP)
      STEP=VUI(I)
      C
      DO 401 K=1,KSTEP
      STEP=STEP+STEP
      UPRI=(A2+B2*STEP)*COS(STEP)-(A2+B2*STEP)*COS(STEP)+
      1 B2*(SIN(STEP)-SIN(STEP))
      CURRENT=CURRENT*UPRI*(0.5*VUI(13)*EXPVIZ(13)+0.25*SDPTI*EFTVI(13))
      UPRI=0.5*(EXPVIZ(13)*EFTVI(13)+0.25*SDPTI*EFTVI(13))
      CURRENT=CURRENT*UPRI*(C2*(COS(STEP)-COS(STEP))+
      1 B2*(STEP*COS(STEP)-STEP*COS(STEP)+SIN(STEP)-SIN(STEP)))
      STEP=STEP+STEP
      401 CONTINUE
      CARRIV=CARRIV+CURRENT
      C
      901 FORMAT(9,101,313,1PE10.3)
      WRITE(9,901) J,I,L,CUM
      C
      GO TO 340
      C
      CASE NO 2-----
      410 B1=(BOUNDI(I,L+1)-PHO(I,L+1))*VUI(13)-VUI(13)/(VUI(13)-VUI(13))
      1 VUI(13)*BANG(ANG(L+1)-PHO(I,L+1))/(ANG(L+1)-VUI(13)-VUI(13))
      2 (VUI(13)-VUI(13))+ANG(L+1)*VUI(13)-VUI(13)*VUI(13)
      3 VUI(13)
      C1=(BOUNDI(I,L+1)-PHO(I,L+1)+BANG(L+1)*VUI(13)-VUI(13))/(VUI(13)-
      1 VUI(13))
      B1=(PHO(I,L+1)-PHO(I,L+1)-BANG(L+1)*VUI(13)-VUI(13))/(ANG(L+1)-
      1 ANG(L+1))
      A=PHO(I,L+1)-BANG(L+1)-C1*VUI(13)-BANG(L+1)*VUI(13)
      CURRENT=0.5*
      UPRI=(A1+B1*ANG(L+1))*COS(ANG(L+1))-(A1+B1*ANG(L+1))*COS(ANG(L+1))+
      1 B1*(SIN(ANG(L+1))-SIN(ANG(L)))
      STEP=(ANG(L+1)-ANG(L))/FLOAT(KSTEP)
      STEP=ANGD
      STEP=(VUI(I,L+1)-VUI(I))/FLOAT(KSTEP)
      STEP=VUI(I)
      C
      DO 401 K=1,KSTEP
      STEP=STEP+STEP
      UPRI=(A2+B2*STEP)*COS(STEP)-(A2+B2*STEP)*COS(STEP)+
      1 B2*(SIN(STEP)-SIN(STEP))
      CURRENT=CURRENT*UPRI*(0.5*VUI(13)*EXPVIZ(13)+0.25*SDPTI*EFTVI(13))
      UPRI=0.5*(EXPVIZ(13)*EFTVI(13)+0.25*SDPTI*EFTVI(13))
      CURRENT=CURRENT*UPRI*(C2*(COS(STEP)-COS(STEP))+
      1 B2*(STEP*COS(STEP)-STEP*COS(STEP)+SIN(STEP)-SIN(STEP)))
      STEP=STEP+STEP
      401 CONTINUE
      CARRIV=CARRIV+CURRENT
      C
      901 FORMAT(9,101,313,1PE10.3)
      WRITE(9,901) J,I,L,CUM
      C
      GO TO 340
      C
      CASE NO 3-----
      410 B1=(BOUNDI(I,L+1)-PHO(I,L+1))*VUI(13)-VUI(13)/(VUI(13)-VUI(13))
      1 VUI(13)*BANG(ANG(L+1)-PHO(I,L+1))/(ANG(L+1)-VUI(13)-VUI(13))
      2 (VUI(13)-VUI(13))+ANG(L+1)*VUI(13)-VUI(13)*VUI(13)
      3 VUI(13)
      C1=(BOUNDI(I,L+1)-PHO(I,L+1)+BANG(L+1)*VUI(13)-VUI(13))/(VUI(13)-
      1 VUI(13))
      B1=(PHO(I,L+1)-PHO(I,L+1)-BANG(L+1)*VUI(13)-VUI(13))/(ANG(L+1)-
      1 ANG(L+1))
      A=PHO(I,L+1)-BANG(L+1)-C1*VUI(13)-BANG(L+1)*VUI(13)
      CURRENT=0.5*
      UPRI=(A1+B1*ANG(L+1))*COS(ANG(L+1))-(A1+B1*ANG(L+1))*COS(ANG(L+1))+
      1 B1*(SIN(ANG(L+1))-SIN(ANG(L)))
      STEP=(ANG(L+1)-ANG(L))/FLOAT(KSTEP)
      STEP=ANGD
      STEP=(VUI(I,L+1)-VUI(I))/FLOAT(KSTEP)
      STEP=VUI(I)
      C
      DO 401 K=1,KSTEP
      STEP=STEP+STEP
      UPRI=(A2+B2*STEP)*COS(STEP)-(A2+B2*STEP)*COS(STEP)+
      1 B2*(SIN(STEP)-SIN(STEP))
      CURRENT=CURRENT*UPRI*(0.5*VUI(13)*EXPVIZ(13)+0.25*SDPTI*EFTVI(13))
      UPRI=0.5*(EXPVIZ(13)*EFTVI(13)+0.25*SDPTI*EFTVI(13))
      CURRENT=CURRENT*UPRI*(C2*(COS(STEP)-COS(STEP))+
      1 B2*(STEP*COS(STEP)-STEP*COS(STEP)+SIN(STEP)-SIN(STEP)))
      STEP=STEP+STEP
      401 CONTINUE
      CARRIV=CARRIV+CURRENT
      C
      901 FORMAT(9,101,313,1PE10.3)
      WRITE(9,901) J,I,L,CUM
      C
      GO TO 340
      C
      CASE NO 4-----
      410 B1=(BOUNDI(I,L+1)-PHO(I,L+1))*VUI(13)-VUI(13)/(VUI(13)-VUI(13))
      1 VUI(13)*BANG(ANG(L+1)-PHO(I,L+1))/(ANG(L+1)-VUI(13)-VUI(13))
      2 (VUI(13)-VUI(13))+ANG(L+1)*VUI(13)-VUI(13)*VUI(13)
      3 VUI(13)
      C1=(BOUNDI(I,L+1)-PHO(I,L+1)+BANG(L+1)*VUI(13)-VUI(13))/(VUI(13)-
      1 VUI(13))
      B1=(PHO(I,L+1)-PHO(I,L+1)-BANG(L+1)*VUI(13)-VUI(13))/(ANG(L+1)-
      1 ANG(L+1))
      A=PHO(I,L+1)-BANG(L+1)-C1*VUI(13)-BANG(L+1)*VUI(13)
      CURRENT=0.5*
      UPRI=(A1+B1*ANG(L+1))*COS(ANG(L+1))-(A1+B1*ANG(L+1))*COS(ANG(L+1))+
      1 B1*(SIN(ANG(L+1))-SIN(ANG(L)))
      STEP=(ANG(L+1)-ANG(L))/FLOAT(KSTEP)
      STEP=ANGD
      STEP=(VUI(I,L+1)-VUI(I))/FLOAT(KSTEP)
      STEP=VUI(I)
      C
      DO 401 K=1,KSTEP
      STEP=STEP+STEP
      UPRI=(A2+B2*STEP)*COS(STEP)-(A2+B2*STEP)*COS(STEP)+
      1 B2*(SIN(STEP)-SIN(STEP))
      CURRENT=CURRENT*UPRI*(0.5*VUI(13)*EXPVIZ(13)+0.25*SDPTI*EFTVI(13))
      UPRI=0.5*(EXPVIZ(13)*EFTVI(13)+0.25*SDPTI*EFTVI(13))
      CURRENT=CURRENT*UPRI*(C2*(COS(STEP)-COS(STEP))+
      1 B2*(STEP*COS(STEP)-STEP*COS(STEP)+SIN(STEP)-SIN(STEP)))
      STEP=STEP+STEP
      401 CONTINUE
      CARRIV=CARRIV+CURRENT
      C
      901 FORMAT(9,101,313,1PE10.3)
      WRITE(9,901) J,I,L,CUM
      C
      GO TO 340
      C
      CASE NO 5-----
      410 B1=(BOUNDI(I,L+1)-PHO(I,L+1))*VUI(13)-VUI(13)/(VUI(13)-VUI(13))
      1 VUI(13)*BANG(ANG(L+1)-PHO(I,L+1))/(ANG(L+1)-VUI(13)-VUI(13))
      2 (VUI(13)-VUI(13))+ANG(L+1)*VUI(13)-VUI(13)*VUI(13)
      3 VUI(13)
      C1=(BOUNDI(I,L+1)-PHO(I,L+1)+BANG(L+1)*VUI(13)-VUI(13))/(VUI(13)-
      1 VUI(13))
      B1=(PHO(I,L+1)-PHO(I,L+1)-BANG(L+1)*VUI(13)-VUI(13))/(ANG(L+1)-
      1 ANG(L+1))
      A=PHO(I,L+1)-BANG(L+1)-C1*VUI(13)-BANG(L+1)*VUI(13)
      CURRENT=0.5*
      UPRI=(A1+B1*ANG(L+1))*COS(ANG(L+1))-(A1+B1*ANG(L+1))*COS(ANG(L+1))+
      1 B1*(SIN(ANG(L+1))-SIN(ANG(L)))
      STEP=(ANG(L+1)-ANG(L))/FLOAT(KSTEP)
      STEP=ANGD
      STEP=(VUI(I,L+1)-VUI(I))/FLOAT(KSTEP)
      STEP=VUI(I)
      C
      DO 401 K=1,KSTEP
      STEP=STEP+STEP
      UPRI=(A2+B2*STEP)*COS(STEP)-(A2+B2*STEP)*COS(STEP)+
      1 B2*(SIN(STEP)-SIN(STEP))
      CURRENT=CURRENT*UPRI*(0.5*VUI(13)*EXPVIZ(13)+0.25*SDPTI*EFTVI(13))
      UPRI=0.5*(EXPVIZ(13)*EFTVI(13)+0.25*SDPTI*EFTVI(13))
      CURRENT=CURRENT*UPRI*(C2*(COS(STEP)-COS(STEP))+
      1 B2*(STEP*COS(STEP)-STEP*COS(STEP)+SIN(STEP)-SIN(STEP)))
      STEP=STEP+STEP
      401 CONTINUE
      CARRIV=CARRIV+CURRENT
      C
      901 FORMAT(9,101,313,1PE10.3)
      WRITE(9,901) J,I,L,CUM
      C
      GO TO 340
      C
      CASE NO 6-----
      410 B1=(BOUNDI(I,L+1)-PHO(I,L+1))*VUI(13)-VUI(13)/(VUI(13)-VUI(13))
      1 VUI(13)*BANG(ANG(L+1)-PHO(I,L+1))/(ANG(L+1)-VUI(13)-VUI(13))
      2 (VUI(13)-VUI(13))+ANG(L+1)*VUI(13)-VUI(13)*VUI(13)
      3 VUI(13)
      C1=(BOUNDI(I,L+1)-PHO(I,L+1)+BANG(L+1)*VUI(13)-VUI(13))/(VUI(13)-
      1 VUI(13))
      B1=(PHO(I,L+1)-PHO(I,L+1)-BANG(L+1)*VUI(13)-VUI(13))/(ANG(L+1)-
      1 ANG(L+1))
      A=PHO(I,L+1)-BANG(L+1)-C1*VUI(13)-BANG(L+1)*VUI(13)
      CURRENT=0.5*
      UPRI=(A1+B1*ANG(L+1))*COS(ANG(L+1))-(A1+B1*ANG(L+1))*COS(ANG(L+1))+
      1 B1*(SIN(ANG(L+1))-SIN(ANG(L)))
      STEP=(ANG(L+1)-ANG(L))/FLOAT(KSTEP)
      STEP=ANGD
      STEP=(VUI(I,L+1)-VUI(I))/FLOAT(KSTEP)
      STEP=VUI(I)
      C
      DO 401 K=1,KSTEP
      STEP=STEP+STEP
      UPRI=(A2+B2*STEP)*COS(STEP)-(A2+B2*STEP)*COS(STEP)+
      1 B2*(SIN(STEP)-SIN(STEP))
      CURRENT=CURRENT*UPRI*(0.5*VUI(13)*EXPVIZ(13)+0.25*SDPTI*EFTVI(13))
      UPRI=0.5*(EXPVIZ(13)*EFTVI(13)+0.25*SDPTI*EFTVI(13))
      CURRENT=CURRENT*UPRI*(C2*(COS(STEP)-COS(STEP))+
      1 B2*(STEP*COS(STEP)-STEP*COS(STEP)+SIN(STEP)-SIN(STEP)))
      STEP=STEP+STEP
      401 CONTINUE
      CARRIV=CARRIV+CURRENT
      C
      901 FORMAT(9,101,313,1PE10.3)
      WRITE(9,901) J,I,L,CUM
      C
      GO TO 340
      C
      CASE NO 7-----
      410 B1=(BOUNDI(I,L+1)-PHO(I,L+1))*VUI(13)-VUI(13)/(VUI(13)-VUI(13))
      1 VUI(13)*BANG(ANG(L+1)-PHO(I,L+1))/(ANG(L+1)-VUI(13)-VUI(13))
      2 (VUI(13)-VUI(13))+ANG(L+1)*VUI(13)-VUI(13)*VUI(13)
      3 VUI(13)
      C1=(BOUNDI(I,L+1)-PHO(I,L+1)+BANG(L+1)*VUI(13)-VUI(13))/(VUI(13)-
      1 VUI(13))
      B1=(PHO(I,L+1)-PHO(I,L+1)-BANG(L+1)*VUI(13)-VUI(13))/(ANG(L+1)-
      1 ANG(L+1))
      A=PHO(I,L+1)-BANG(L+1)-C1*VUI(13)-BANG(L+1)*VUI(13)
      CURRENT=0.5*
      UPRI=(A1+B1*ANG(L+1))*COS(ANG(L+1))-(A1+B1*ANG(L+1))*COS(ANG(L+1))+
      1 B1*(SIN(ANG(L+1))-SIN(ANG(L)))
      STEP=(ANG(L+1)-ANG(L))/FLOAT(KSTEP)
      STEP=ANGD
      STEP=(VUI(I,L+1)-VUI(I))/FLOAT(KSTEP)
      STEP=VUI(I)
      C
      DO 401 K=1,KSTEP
      STEP=STEP+STEP
      UPRI=(A2+B2*STEP)*COS(STEP)-(A2+B2*STEP)*COS(STEP)+
      1 B2*(SIN(STEP)-SIN(STEP))
      CURRENT=CURRENT*UPRI*(0.5*VUI(13)*EXPVIZ(13)+0.25*SDPTI*EFTVI(13))
      UPRI=0.5*(EXPVIZ(13)*EFTVI(13)+0.25*SDPTI*EFTVI(13))
      CURRENT=CURRENT*UPRI*(C2*(COS(STEP)-COS(STEP))+
      1 B2*(STEP*COS(STEP)-STEP*COS(STEP)+SIN(STEP)-SIN(STEP)))
      STEP=STEP+STEP
      401 CONTINUE
      CARRIV=CARRIV+CURRENT
      C
      901 FORMAT(9,101,313,1PE10.3)
      WRITE(9,901) J,I,L,CUM
      C
      GO TO 340
      C
      CASE NO 8-----
      410 B1=(BOUNDI(I,L+1)-PHO(I,L+1))*VUI(13)-VUI(13)/(VUI(13)-VUI(13))
      1 VUI(13)*BANG(ANG(L+1)-PHO(I,L+1))/(ANG(L+1)-VUI(13)-VUI(13))
      2 (VUI(13)-VUI(13))+ANG(L+1)*VUI(13)-VUI(13)*VUI(13)
      3 VUI(13)
      C1=(BOUNDI(I,L+1)-PHO(I,L+1)+BANG(L+1)*VUI(13)-VUI(13))/(VUI(13)-
      1 VUI(13))
      B1=(PHO(I,L+1)-PHO(I,L+1)-BANG(L+1)*VUI(13)-VUI(13))/(ANG(L+1)-
      1 ANG(L+1))
      A=PHO(I,L+1)-BANG(L+1)-C1*VUI(13)-BANG(L+1)*VUI(13)
      CURRENT=0.5*
      UPRI=(A1+B1*ANG(L+1))*COS(ANG(L+1))-(A1+B1*ANG(L+1))*COS(ANG(L+1))+
      1 B1*(SIN(ANG(L+1))-SIN(ANG(L)))
      STEP=(ANG(L+1)-ANG(L))/FLOAT(KSTEP)
      STEP=ANGD
      STEP=(VUI(I,L+1)-VUI(I))/FLOAT(KSTEP)
      STEP=VUI(I)
      C
      DO 401 K=1,KSTEP
      STEP=STEP+STEP
      UPRI=(A2+B2*STEP)*COS(STEP)-(A2+B2*STEP)*COS(STEP)+
      1 B2*(SIN(STEP)-SIN(STEP))
      CURRENT=CURRENT*UPRI*(0.5*VUI(13)*EXPVIZ(13)+0.25*SDPTI*EFTVI(13))
      UPRI=0.5*(EXPVIZ(13)*EFTVI(13)+0.25*SDPTI*EFTVI(13))
      CURRENT=CURRENT*UPRI*(C2*(COS(STEP)-COS(STEP))+
      1 B2*(STEP*COS(STEP)-STEP*COS(STEP)+SIN(STEP)-SIN(STEP)))
      STEP=STEP+STEP
      401 CONTINUE
      CARRIV=CARRIV+CURRENT
      C
      901 FORMAT(9,101,313,1PE10.3)
      WRITE(9,901) J,I,L,CUM
      C
      GO TO 340
      C
      CASE NO 9-----
      410 B1=(BOUNDI(I,L+1)-PHO(I,L+1))*VUI(13)-VUI(13)/(VUI(13)-VUI(13))
      1 VUI(13)*BANG(ANG(L+1)-PHO(I,L+1))/(ANG(L+1)-VUI(13)-VUI(13))
      2 (VUI(13)-VUI(13))+ANG(L+1)*VUI(13)-VUI(13)*VUI(13)
      3 VUI(13)
      C1=(BOUNDI(I,L+1)-PHO(I,L+1)+BANG(L+1)*VUI(13)-VUI(13))/(VUI(13)-
      1 VUI(13))
      B1=(PHO(I,L+1)-PHO(I,L+1)-BANG(L+1)*VUI(13)-VUI(13))/(ANG(L+1)-
      1 ANG(L+1))
      A=PHO(I,L+1)-BANG(L+1)-C1*VUI(13)-BANG(L+1)*VUI(13)
      CURRENT=0.5*
      UPRI=(A1+B1*ANG(L+1))*COS(ANG(L+1))-(A1+B1*ANG(L+1))*COS(ANG(L+1))+
      1 B1*(SIN(ANG(L+1))-SIN(ANG(L)))
      STEP=(ANG(L+1)-ANG(L))/FLOAT(KSTEP)
      STEP=ANGD
      STEP=(VUI(I,L+1)-VUI(I))/FLOAT(KSTEP)
      STEP=VUI(I)
      C
      DO 401 K=1,KSTEP
      STEP=STEP+STEP
      UPRI=(A2+B2*STEP)*COS(STEP)-(A2+B2*STEP)*COS(STEP)+
      1 B2*(SIN(STEP)-SIN(STEP))
      CURRENT=CURRENT*UPRI*(0.5*VUI(13)*EXPVIZ(13)+0.25*SDPTI*EFTVI(13))
      UPRI=0.5*(EXPVIZ(13)*EFTVI(13)+0.25*SDPTI*EFTVI(13))
      CURRENT=CURRENT*UPRI*(C2*(COS(STEP)-COS(STEP))+
      1 B2*(STEP*COS(STEP)-STEP*COS(STEP)+SIN(STEP)-SIN(STEP)))
      STEP=STEP+STEP
      401 CONTINUE
      CARRIV=CARRIV+CURRENT
      C
      901 FORMAT(9,101,313,1PE10.3)
      WRITE(9,901) J,I,L,CUM
      C
      GO TO 340
      C
      CASE NO 10-----
      410 B1=(BOUNDI(I,L+1)-PHO(I,L+1))*VUI(13)-VUI(13)/(VUI(13)-VUI(13))
      1 VUI(13)*BANG(ANG(L+1)-PHO(I,L+1))/(ANG(L+1)-VUI(13)-VUI(13))
      2 (VUI(13)-VUI(13))+ANG(L+1)*VUI(13)-VUI(13)*VUI(13)
      3 VUI(13)
      C1=(BOUNDI(I,L+1)-PHO(I,L+1)+BANG(L+1)*VUI(13)-VUI(13))/(VUI(13)-
      1 VUI(13))
      B1=(PHO(I,L+1)-PHO(I,L+1)-BANG(L+1)*VUI(13)-VUI(13))/(ANG(L+1)-
      1 ANG(L+1))
      A=PHO(I,L+1)-BANG(L+1)-C1*VUI(13)-BANG(L+1)*VUI(13)
      CURRENT=0.5*
      UPRI=(A1+B1*ANG(L+1))*COS(ANG(L+1))-(A1+B1*ANG(L+1))*COS(ANG(L+1))+
      1 B1*(SIN(ANG(L+1))-SIN(ANG(L)))
      STEP=(ANG(L+1)-ANG(L))/FLOAT(KSTEP)
      STEP=ANGD
      STEP=(VUI(I,L+1)-VUI(I))/FLOAT(KSTEP)
      STEP=VUI(I)
      C
      DO 401 K=1,KSTEP
      STEP=STEP+STEP
      UPRI=(A2+B2*STEP)*COS(STEP)-(A2+B2*STEP)*COS(STEP)+
      1 B2*(SIN(STEP)-SIN(STEP))
      CURRENT=CURRENT*UPRI*(0.5*VUI(13)*EXPVIZ(13)+0.25*SDPTI*EFTVI(13))
      UPRI=0.5*(EXPVIZ(13)*EFTVI(13)+0.25*SDPTI*EFTVI(13))
      CURRENT=CURRENT*UPRI*(C2*(COS(STEP)-COS(STEP))+
      1 B2*(STEP*COS(STEP)-STEP*COS(STEP)+SIN(STEP)-SIN(STEP)))
      STEP=STEP+STEP
      401 CONTINUE
      CARRIV=CARRIV+CURRENT
      C
      901 FORMAT(9,101,313,1PE10.3)
      WRITE(9,901) J,I,L,CUM
      C
      GO TO 340
      C
      CASE NO 11-----
      410 B1=(BOUNDI(I,L+1)-PHO(I,L+1))*VUI(13)-VUI(13)/(VUI(13)-VUI(13))
      1 VUI(13)*BANG(ANG(L+1)-PHO(I,L+1))/(ANG(L+1)-VUI(13)-VUI(13))
      2 (VUI(13)-VUI(13))+ANG(L+1)*VUI(13)-VUI(13)*VUI(13)
      3 VUI(13)
      C1=(BOUNDI(I,L+1)-PHO(I,L+1)+BANG(L+1)*VUI(13)-VUI(13))/(VUI(13)-
      1 VUI(13))
      B1=(PHO(I,L+1)-PHO(I,L+1)-BANG(L+1)*VUI(13)-VUI(13))/(ANG(L+1)-
      1 ANG(L+1))
      A=PHO(I,L+1)-BANG(L+1)-C1*VUI(13)-BANG(L+1)*VUI(13)
      CURRENT=0.5*
      UPRI=(A1+B1*ANG(L+1))*COS(ANG(L+1))-(A1+B1*ANG(L+1))*COS(ANG(L+1))+
      1 B1*(SIN(ANG(L+1))-SIN(ANG(L)))
      STEP=(ANG(L+1)-ANG(L))/FLOAT(KSTEP)
      STEP=ANGD
      STEP=(VUI(I,L+1)-VUI(I))/FLOAT(KSTEP)
      STEP=VUI(I)
      C
      DO 401 K=1,KSTEP
      STEP=STEP+STEP
      UPRI=(A2+B2*STEP)*COS(STEP)-(A2+B2*STEP)*COS(STEP)+
      1 B2*(SIN(STEP)-SIN(STEP))
      CURRENT=CURRENT*UPRI*(0.5*VUI(13)*EXPVIZ(13)+0.25*SDPTI*EFTVI(13))
      UPRI=0.5*(EXPVIZ(13)*EFTVI(13)+0.25*SDPTI*EFTVI(13))
      CURRENT=CURRENT*UPRI*(C2*(COS(STEP)-COS(STEP))+
      1 B2*(STEP*COS(STEP)-STEP*COS(STEP)+SIN(STEP)-SIN(STEP)))
      STEP=STEP+STEP
      401 CONTINUE
      CARRIV=CARRIV+CURRENT
      C
      901 FORMAT(9,101,313,1PE10.3)
      WRITE(9,901) J,I,L,CUM
      C
      GO TO 340
      C
      CASE NO 12-----
      410 B1=(BOUNDI(I,L+1)-PHO(I,L+1))*VUI(13)-VUI(13)/(VUI(13)-VUI(13))
      1 VUI(13)*BANG(ANG(L+1)-PHO(I,L+1))/(ANG(L+1)-VUI(13)-VUI(13))
      2 (VUI(13)-VUI(13))+ANG(L+1)*VUI(13)-VUI(13)*VUI(13)
      3 VUI(13)
      C1=(BOUNDI(I,L+1)-PHO(I,L+1)+BANG(L+1)*VUI(13)-VUI(13))/(VUI(13)-
      1 VUI(13))
      B1=(PHO(I,L+1)-PHO(I,L+1)-BANG(L+1)*VUI(13)-VUI(13))/(ANG(L+1)-
      1 ANG(L+1))
      A=PHO(I,L+1)-BANG(L+1)-C1*VUI(13)-BANG(L+1)*VUI(13)
      CURRENT=0.5*
      UPRI=(A1+B1*ANG(L+1))*COS(ANG(L+1))-(A1+B1*ANG(L+1))*COS(ANG(L+1))+
      1 B1*(SIN(ANG(L+1))-SIN(ANG(L)))
      STEP=(ANG(L+1)-ANG(L))/FLOAT(KSTEP)
      STEP=ANGD
      STEP=(VUI(I,L+1)-VUI(I))/FLOAT(KSTEP)
      STEP=VUI(I)
      C
      DO 401 K=1,KSTEP
      STEP=STEP+STEP
      UPRI=(A2+B2*STEP)*COS(STEP)-(A2+B2*STEP)*COS(STEP)+
      1 B2*(SIN(STEP)-SIN(STEP))
      CURRENT=CURRENT*UPRI*(0.5*VUI(13)*EXPVIZ(13)+0.25*SDPTI*EFTVI(13))
      UPRI=0.5*(EXPVIZ(13)*EFTVI(13)+0.25*SDPTI*EFTVI(13))
      CURRENT=CURRENT*UPRI*(C2*(COS(STEP)-COS(STEP))+
      1 B2*(STEP*COS(STEP)-STEP*COS(STEP)+SIN(STEP)-SIN(STEP)))
      STEP=STEP+STEP
      401 CONTINUE
      CARRIV=CARRIV+CURRENT
      C
      901 FORMAT(9,101,3
```

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STEP=ANG(I)
STEP=-(VII(I+1)-VII(I-1))/FLOAT(ASSTEP)
STEP=VII(I-1)

DO 411 K=1,ASTEP
  STEP=STEP+STEP
  WPRIME=(A+B*STEP)*COS(STEP)-(A+B*STEP)*COS(STEP)
  I=B*(SIN(STEP)-SIN(STEP))
  CURENT=CURENT+WPRIME*(0.5*(VI(I-1)*EXPV2(I-1)-STEPD*EXP
  I=-(STEPD*2)+0.25*STP*(EFT(STEP)-EFT(I-1)))
  WPRIME=0.5*(EXPV2(I-1)*1.0*(VI(I-1)*82)-EXP(STEPD*2)
  I=1.0*(STEPD*2))
  CURENT=CURENT+WPRIME*(C*(COS(STEP)-COS(STEP))+D*(STEP+COS(STEP)
  I=-(STEP+COS(STEP)+SIN(STEP)-SIN(STEP)))
  STEP=STEP
  STEPD=STEPD+STEP
411 CONTINUE
  CARRIV=CARRIV+CURENT
  CUR=CURENT
  IF(J.EQ.1) WRITE(9,902) J,I,L,CUR2
902 FORMAT(8, CUR2,313,1PE10.3)
GO TO 340

C-----CASE NB 3-----
420 D=(BOUND(I-1,L+1)-PHO(I-1,L)*B(VII(I,L)-VI(I-1))
  I=BOUND(I-1,L)-BOUND(I-1,L+1)*B(VII(I,L)-VI(I-1)*BANG(L)
  I=BOUND(I-1,L)-BOUND(I-1,L+1)*B(VII(I,L)-VI(I-1)*BANG(L)
  I=BOUND(I-1,L)-BOUND(I-1,L+1)*B(VII(I,L)-VI(I-1)*BANG(L)
  C=(BOUND(I-1,L)-PHO(I-1,L)-DBVI(I,L)*BANG(L))/VII(I,L)
  B=0.0
  A=PHO(I-1,L)
  STEP=(ANG(I-1,L+1)-ANG(I-1,L))/FLOAT(ASSTEP)
  STEP=ANG(I-1,L)
  CURENT=0.0
  STEP=-(VII(I-1)-VII(I-1))/FLOAT(ASSTEP)
  STEP=VII(I-1)

C
DO 421 K=1,ASTEP
  STEP=STEP+STEP
  WPRIME=(A+B*STEP)*COS(STEP)-(A+B*STEP)*COS(STEP)
  I=B*(SIN(STEP)-SIN(STEP))
  CURENT=CURENT+WPRIME*(0.5*(VI(I-1)*EXPV2(I-1)-STEPD*EXP
  I=-(STEPD*2)+0.25*STP*(EFT(STEP)-EFT(I-1)))
  WPRIME=0.5*(EXPV2(I-1)*1.0*(VI(I-1)*82)-EXP(STEPD*2)
  I=1.0*(STEPD*2))
  CURENT=CURENT+WPRIME*(C*(COS(STEP)-COS(STEP))+D*(STEP+COS(STEP)
  I=-(STEP+COS(STEP)+SIN(STEP)-SIN(STEP)))
  STEP=STEP
  STEPD=STEPD+STEP
421 CONTINUE
  CARRIV=CARRIV+CURENT
  CUR=CURENT
  IF(J.EQ.1) WRITE(9,903) J,I,L,CUR3
903 FORMAT(8, CUR3,313,1PE10.3)
GO TO 340

C-----CASE NB 4-----
430 D=(BOUND(I-1,L+1)-PHO(I-1,L)*B(VII(I,L)-VI(I-1))
  I=BOUND(I-1,L)-BOUND(I-1,L+1)*B(VII(I,L)-VI(I-1)*BANG(L)
  I=BOUND(I-1,L)-BOUND(I-1,L+1)*B(VII(I,L)-VI(I-1)*BANG(L)
  I=BOUND(I-1,L)-BOUND(I-1,L+1)*B(VII(I,L)-VI(I-1)*BANG(L)
  C=(BOUND(I-1,L)-PHO(I-1,L)-DBVI(I,L)*BANG(L))/VII(I,L)
  B=0.0
  A=PHO(I-1,L)
  STEP=(ANG(I-1,L+1)-ANG(I-1,L))/FLOAT(ASSTEP)
  STEP=ANG(I-1,L)
  CURENT=0.0
  STEP=-(VII(I-1)-VII(I-1))/FLOAT(ASSTEP)
  STEP=VII(I-1)

C
DO 431 K=1,ASTEP
  STEP=STEP+STEP
  WPRIME=(A+B*STEP)*COS(STEP)-(A+B*STEP)*COS(STEP)
  I=B*(SIN(STEP)-SIN(STEP))
  CURENT=CURENT+WPRIME*(0.5*(VI(I-1)*EXPV2(I-1)-STEPD*EXP
  I=-(STEPD*2)+0.25*STP*(EFT(STEP)-EFT(I-1)))
  WPRIME=0.5*(EXPV2(I-1)*1.0*(VI(I-1)*82)-EXP(STEPD*2)
  I=1.0*(STEPD*2))
  CURENT=CURENT+WPRIME*(C*(COS(STEP)-COS(STEP))+D*(STEP+COS(STEP)
  I=-(STEP+COS(STEP)+SIN(STEP)-SIN(STEP)))
  STEP=STEP
  STEPD=STEPD+STEP
431 CONTINUE
  CARRIV=CARRIV+CURENT
  CUR=CURENT
  IF(J.EQ.1) WRITE(9,904) J,I,L,CUR4
904 FORMAT(8, CUR4,313,1PE10.3)
GO TO 340

C-----CASE NB 5-----
440 CONTINUE
  PD=BOUND(I-1,L+1)-PHO(I-1,L)/(ANG(L+1)-ANG(L))*B(ANG(I-1,L)-ANG(L))
  I=PHO(I-1,L)
  B1=BOUND(I-1,L)-PD-PHO(I-1,L)*B(VII(I-1,L)-VI(I-1)*BANG(L)
  I=ANG(L)-ANG(L+1)
  C1=(BOUND(I-1,L)-PD-B1*ANG(L))/VII(I-1,L)
  B1=PHO(I-1,L)-BOUND(I-1,L)-D1*ANG(L)*B(VII(I-1,L)-VI(I-1)*BANG(L)
  I=ANG(L)-ANG(L+1)
  CURENT=0.0
  A1=PHO(I-1,L)-B1*ANG(L)-C1*VI(I-1,L)-B1*ANG(L)*B(VII(I-1,L)-VI(I-1)*BANG(L)
  WPRIME=(A1+B1*ANG(L)+C1*VI(I-1,L)-B1*ANG(L)*B(VII(I-1,L)-VI(I-1)*BANG(L)
  I=COS(ANG(L+1))+B1*(SIN(ANG(L+1))-SIN(ANG(L)))
  CURENT=CURENT+WPRIME*(0.5*(VI(I-1)*EXPV2(I-1)-STEPD*EXP
  I=-(STEPD*2)+0.25*STP*(EFT(VI(I-1))-EFT(I-1)))
  WPRIME=0.5*(EXPV2(I-1)*1.0*(VI(I-1)*82)-EXPV2(I)
  I=1.0*(VI(I-1)*82))
  CURENT=CURENT+WPRIME*(C1*(COS(ANG(L+1))-COS(ANG(L)))
  I=ANG(L)-ANG(L+1)*COS(ANG(L+1))+B1*(SIN(ANG(L+1))-SIN(ANG(L)))
  I=SIN(ANG(L+1))-SIN(ANG(L))
440 CONTINUE
  IF(ANG(I-1,L).EQ.ANG(L)) GO TO 440
  D2=(BOUND(I-1,L)-PD)*B(VII(I-1,L)-VI(I-1)*BANG(L)
  I=VI(I-1)-VI(I-1)*B(VII(I-1,L)-VI(I-1)*BANG(L)
  I=VI(I-1)-VI(I-1)*B(VII(I-1,L)-VI(I-1)*BANG(L)
  C2=(PHO(I-1,L)-BOUND(I-1,L)-D2*ANG(L))/VII(I-1,L)
  I=VI(I-1,L)
  D2=PD-PHO(I-1,L)-D2*ANG(L)*B(VII(I-1,L)-VI(I-1)*BANG(L)
  I=ANG(L)-ANG(L+1)
  A2=PHO(I-1,L)-D2*ANG(L)-C2*VI(I-1,L)-D2*ANG(L)*B(VII(I-1,L)-VI(I-1)*BANG(L)
  STEP=(ANG(I-1,L)-ANG(L))/FLOAT(ASSTEP)
  STEP=ANG(L)
  STEPD=-(VII(I-1)-VII(I-1))/FLOAT(ASSTEP)
  STEP=VII(I-1)

C
NO 441 K=1,ASTEP

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[illegible]

GUESS FIELD COMPUTATION

GUESS FIELD COMPUTATION

[illegible]

```

C CSEC N-D SEC CURRENT
C BSCAT BACA-SCATTER ELECTRON CURRENT
C CPHOTO N-D PHOTO ELECTRON CURRENT
C CETT NET CURRENT
C SECPRN N-D SEC ELECTRON CURRENT INDUCED BY PROTONS
C XI N-D POTENTIAL
C *****
C INTEGER PERSEC,SECIND,PERPAN,PANIND
C COMMON PSAVE(144,10),CSAVE(144,10),PSECTR(144),CSECTR(144),
C IDELEE(20),DELMAX(144),ENAX(144),ETA(20),BSCAT(144),
C BSCAT2(144),BSCAT3(144),PHO(20,40),
C IANG(40),CPHONX(144),SUMANG,ANGD,BOUNDL(20,40),BOUNDI(20,40),
C ZANGL(20,40),V1I(20,40),ICHECK(20,40),RATIO(13),IROOT(144),
C IFALT(144),JLDCAL(144),ICOW(144),
C IUI(20),EV(8),MLEV,NTINES,ILEV,TININ(20),TINAX(20),VINUM(20),
C ZAI(144),BI(144),C(144),BB(144),BU(144),TU(144),DU(144),
C JEM(144),TWCOS(700),
C IIFLG,NPOINT,N,IGDEM,ISYN,IPOIS,HSECT,NPEROD,NPEROD,INDIN,
C ZGAMMA,DVUX(70,40),DVUY(70,40),Y(144),DELTA,DELTAT,
C YS(46,40),XS(66),XSS(70),
C IVARBLE(4),T,DELT,SBOUND,NDIN,POT,H,J1,RPI,RP12,RPIMAF,SOTPI,
C ZSAY,TEMP1,TEMP2,DEME1,DEME2,DENI1,DENI2,TEMP11,TEMP12,
C STEPR,LUN3,LUN4,LUN5,LUN6,LUN7,LUN8,LUN9,LUN10,
C IOTL(144),JOTL(144),PERSEC(144),SECIND(144),IPANEL(144),
C 2PERPAN(144,4),PANIND(144),
C ICION(144),CELEC(144),CSEC(144),CSECI(144),CPHOTO(144),
C 2CPHOT(144),CBSCAT(144),CBSCAI(144),SECPRN(144),SECPR1(144),
C 3PHI(144),COUN(144),
C IKASE,JOML,DPMI,HAND,RAD,PBOUND,OMEGA,ALPHA,SO,JP,IS,ECS,
C 2EXPVIZ(20),EFTVI(20),IERROR,TETMIN,TETMAX,BETA1,BETA2,JLESS,
C 3L2,CARRIV,CPH,XI,CSECEL,CSECEI,CB,CB,CB1,CB1
C *****
C IF (IFALT(1),EQ.0) CION(J)=0.0
C IF (IFALT(2),EQ.0) CELEC(J)=0.0
C IF (IFALT(3),EQ.0) CSEC(J)=0.0
C IF (IFALT(4),EQ.0) CBSCAT(J)=0.0
C IF (IFALT(5),EQ.0) CPHOTO(J)=0.0
C CPHOTO(J)=CPHOTO(J)/RATIO(9)
C CPHOTO(J)=CPHOTO(J)/RATIO(9)
C IF (IFALT(9),EQ.0) SECPRN(J)=0.0
C CETT=CION(J)+CELEC(J)+CSEC(J)+CBSCAT(J)+CPHOTO(J)+SECPRN(J)
C WRITE (LUN4,400) J,PHI(J),CETT,CION(J),CELEC(J),CPHOTO(J),CPHOT(J)
C 1,CSEC(J),CSEC(J),CBSCAT(J),CBSCAI(J),SECPRN(J),SECPR1(J)
C 400 FORMAT(13,12)PE10,3)
C RETURN
C *****
C SUBROUTINE CBS(XI,J,CS,CB,CB1,CB1)
C *****
C C PURPOSE IS TO FIND THE CONTRIBUTION OF SEC AND BACA ELECTRONS TO THE
C GUESS FIELD.
C *****
C *****
C INTEGER PERSEC,SECIND,PERPAN,PANIND
C COMMON PSAVE(144,10),CSAVE(144,10),PSECTR(144),CSECTR(144),
C IDELEE(20),DELMAX(144),ENAX(144),ETA(20),BSCAT(144),
C BSCAT2(144),BSCAT3(144),PHO(20,40),
C IANG(40),CPHONX(144),SUMANG,ANGD,BOUNDL(20,40),BOUNDI(20,40),
C ZANGL(20,40),V1I(20,40),ICHECK(20,40),RATIO(13),IROOT(144),
C IFALT(144),JLDCAL(144),ICOW(144),
C IUI(20),EV(8),MLEV,NTINES,ILEV,TININ(20),TINAX(20),VINUM(20),
C ZAI(144),BI(144),C(144),BB(144),BU(144),TU(144),DU(144),
C JEM(144),TWCOS(700),
C IIFLG,NPOINT,N,IGDEM,ISYN,IPOIS,HSECT,NPEROD,NPEROD,INDIN,
C ZGAMMA,DVUX(70,40),DVUY(70,40),Y(144),DELTA,DELTAT,
C YS(46,40),XS(66),XSS(70),
C IVARBLE(4),T,DELT,SBOUND,NDIN,POT,H,J1,RPI,RP12,RPIMAF,SOTPI,
C ZSAY,TEMP1,TEMP2,DEME1,DEME2,DENI1,DENI2,TEMP11,TEMP12,
C STEPR,LUN3,LUN4,LUN5,LUN6,LUN7,LUN8,LUN9,LUN10,
C IOTL(144),JOTL(144),PERSEC(144),SECIND(144),IPANEL(144),
C 2PERPAN(144,4),PANIND(144),
C ICION(144),CELEC(144),CSEC(144),CSECI(144),CPHOTO(144),
C 2CPHOT(144),CBSCAT(144),CBSCAI(144),SECPRN(144),SECPR1(144),
C 3PHI(144),COUN(144),
C IKASE,JOML,DPMI,HAND,RAD,PBOUND,OMEGA,ALPHA,SO,JP,IS,ECS,
C 2EXPVIZ(20),EFTVI(20),IERROR,TETMIN,TETMAX,BETA1,BETA2,JLESS,
C 3L2,CARRIV,CPH,XI,CSECEL,CSECEI,CB,CB,CB1,CB1
C *****
C DO 710 J=1,2
C IF(JJ,NE.1) GO TO 711
C GAMMA=RATIO(2)
C TEMPE=TEMP1
C RATE=RATIO(4)
C DEN=DEME1/DENI1
C GO TO 712
C 711 GAMMA=RATIO(10)
C TEMPE=TEMP2
C RATE=RATIO(11)
C DEN=DEME2/DENI1
C 712 CONTINUE
C IF(DEN,EG.0.0) GO TO 710
C NUM=1
C VZERO=0.0
C IF (XI,NE.0.0)
C VZERO=MAX1(0.0,-XI/GAMMA*SORT(ABS(XI/GAMMA)))/ABS(XI/GAMMA)
C 1)
C DO 705 I=1,MLEV,ILEV
C BETA1=VI(1)82
C BETA2=BETA1-XI/GAMMA
C IF (BETA2,LE.0.0) GO TO 705
C NUM=NUM+1
C VINUM(NUM)=SORT(BETA2)
C DELEE(NUM)=7.48DELMAX(J)*BETA2*TEMP*EXP(-2.08SORT(BETA2*TEMP/
C 1 ENAX(J))/ENAX(J)
C BSC=BSCAT3(J)*BETA2*GAMMA
C ETA(NUM)=BSCAT1(J)
C IF (BSC,LE.100.0)
C 1 ETA(NUM)=BSCAT1(J)-BSCAT2(J)*EXP(-BSC)
C 705 CONTINUE
C IF (NUM,EG.1) GO TO 710
C VINUM(1)=VZERO
C BETA2=VZERO82
C DELEE(1)=7.48DELMAX(J)*BETA2*TEMP*EXP(-2.08SORT(BETA2*TEMP/
C 1 ENAX(J))/ENAX(J)
C BSC=BSCAT3(J)*BETA2*GAMMA
C ETA(1)=BSCAT1(J)
C IF (BSC,LE.100.0)
C 1 ETA(1)=BSCAT1(J)-BSCAT2(J)*EXP(-BSC)
C NUM1=NUM-1
C CUR2=0.0
C CUR3=0.0
C COEF1=EXP(-XI/GAMMA)/SOTPI
C ABEL0=0.0
C BDEL0=0.0
C ASCA0=0.0
C BSCA0=0.0
C *****
C DO 814 I=1,NUM1
C DENOM=VINUM(I+1)-VINUM(I)
C ABEL1=(DELEE(I+1)-DELEE(I))/DENOM
C BDEL1=(DELEE(I)-ABEL1*VINUM(I)
C ABEL1=2.08ABEL1
C BDEL1=2.08BDEL1
C CUR2=CUR2+EXP(-VINUM(I)*82)*B((ABEL1-ABEL0)*B(1.0+VINUM(I)*82)
C 1 + (BDEL1-BDEL0)*B(VINUM(I)+COEFF(VINUM(I))))
C ABEL0=ABEL1
C BDEL0=BDEL1
C 814 CONTINUE
C CUR2=CUR2
C CUR3=CUR3
C IF (XI,LE.0.0) GO TO 817
C CUR2=(2.08SAY(SORT(-XI/RATIO(3)))*COEFF(SORT(-XI/RATIO(3))))*8
C 1 CUR2*EXP(XI/RATIO(3))
C CUR3=(2.08SAY(SORT(-XI/RATIO(4)))*COEFF(SORT(-XI/RATIO(4))))*8
C 1 CUR3*EXP(XI/RATIO(4))
C 817 CONTINUE
C IF (IFALT(3),EQ.0.0) CUR2=0.0
C IF (IFALT(4),EQ.0.0) CUR3=0.0
C CS=RATE*COEF1*CUR2*DEN+CS
C CB=RATE*COEF1*CUR3*DEN+CB
C CB1=CS1+RATE*COEF1*CUR2*DEN
C CB1=CB1+RATE*COEF1*CUR3*DEN
C 710 CONTINUE
C RETURN
C *****
C SUBROUTINE BECEL(XI,CSECEL,CSECEI)
C *****
C C *****
C C PURPOSE TO COMPUTE SECONDARY ELECTRONS INDUCED BY PROTONS FOR THE
C GUESS FIELD
C *****
C C *****
C C EXTERNALS NONE
C *****
C *****
C INTEGER PERSEC,SECIND,PERPAN,PANIND
C COMMON PSAVE(144,10),CSAVE(144,10),PSECTR(144),CSECTR(144),
C IDELEE(20),DELMAX(144),ENAX(144),ETA(20),BSCAT(144),
C BSCAT2(144),BSCAT3(144),PHO(20,40),
C IANG(40),CPHONX(144),SUMANG,ANGD,BOUNDL(20,40),BOUNDI(20,40),
C ZANGL(20,40),V1I(20,40),ICHECK(20,40),RATIO(13),IROOT(144),
C IFALT(144),JLDCAL(144),ICOW(144),
C IUI(20),EV(8),MLEV,NTINES,ILEV,TININ(20),TINAX(20),VINUM(20),
C ZAI(144),BI(144),C(144),BB(144),BU(144),TU(144),DU(144),
C JEM(144),TWCOS(700),
C IIFLG,NPOINT,N,IGDEM,ISYN,IPOIS,HSECT,NPEROD,NPEROD,INDIN,
C ZGAMMA,DVUX(70,40),DVUY(70,40),Y(144),DELTA,DELTAT,
C YS(46,40),XS(66),XSS(70),
C IVARBLE(4),T,DELT,SBOUND,NDIN,POT,H,J1,RPI,RP12,RPIMAF,SOTPI,
C ZSAY,TEMP1,TEMP2,DEME1,DEME2,DENI1,DENI2,TEMP11,TEMP12,
C STEPR,LUN3,LUN4,LUN5,LUN6,LUN7,LUN8,LUN9,LUN10,
C IOTL(144),JOTL(144),PERSEC(144),SECIND(144),IPANEL(144),
C 2PERPAN(144,4),PANIND(144),
C ICION(144),CELEC(144),CSEC(144),CSECI(144),CPHOTO(144),
C 2CPHOT(144),CBSCAT(144),CBSCAI(144),SECPRN(144),SECPR1(144),
C 3PHI(144),COUN(144),
C IKASE,JOML,DPMI,HAND,RAD,PBOUND,OMEGA,ALPHA,SO,JP,IS,ECS,
C 2EXPVIZ(20),EFTVI(20),IERROR,TETMIN,TETMAX,BETA1,BETA2,JLESS,
C 3L2,CARRIV,CPH,XI,CSECEL,CSECEI,CB,CB,CB1,CB1
C *****
C CSECEI=0.0
C CSECEL=0.0
C DO 710 J=1,2
C IF(JJ,NE.1) GO TO 711
C GAMMA=RATIO(8)
C TEMPI=TEMP11
C DEN=DEME1/DENI1
C RATE=RATIO(7)
C GO TO 712
C 711 CONTINUE
C GAMMA=RATIO(1)
C TEMPI=TEMP12
C DEN=DEME2/DENI1
C RATE=RATIO(12)
C 712 CONTINUE
C IF(TEMP1,EG.0.0) GO TO 710
C NUM=1
C VZERO=0.0
C IF(XI,NE.0.0)
C 1 VZERO=MAX1(0.0,-XI/GAMMA*SORT(ABS(XI/GAMMA)))/
C 2 ABS(XI/GAMMA)
C *****
C DO 700 I=1,MLEV,ILEV
C BETA1=VI(1)82
C BETA2=BETA1-XI/GAMMA
C IF (BETA2,LE.0.0) GO TO 700
C NUM=NUM+1
C VINUM(NUM)=SORT(BETA2)
C DELEE(NUM)=BETP(J)*SORT(0.0018BETA2*TEMP1)/(1.0+BETA2*TEMP1/
C 1 EXP(J))
C 700 CONTINUE
C *****
C IF (NUM,EG.1) GO TO 710
C VINUM(1)=VZERO
C BETA2=VINUM(1)82
C DELEE(1)=BETP(J)*SORT(0.0018BETA2*TEMP1)/(1.0+BETA2*TEMP1/
C 1 EXP(J))
C *****
C CUR2=0.0
C COFF1=EXP(-XI/GAMMA)/SOTPI
C ABEL0=0.0
C BDEL0=0.0
C NUM1=NUM-1
C DO 814 I=1,NUM1
C DENOM=VINUM(I+1)-VINUM(I)
C ABEL1=(DELEE(I+1)-DELEE(I))/DENOM
C BDEL1=(DELEE(I)-ABEL1*VINUM(I)
C ABEL1=2.08ABEL1
C BDEL1=2.08BDEL1
C CUR2=CUR2+EXP(-VINUM(I)*82)*B((ABEL1-ABEL0)*B(1.0+VINUM(I)*82)
C 1 + (BDEL1-BDEL0)*B(VINUM(I)+COEFF(VINUM(I))))
C ABEL0=ABEL1
C BDEL0=BDEL1
C 814 CONTINUE
C CUR2=CUR2
C CUR3=CUR3
C IF (XI,EG.0.0) CUR2=(2.08SAY(SORT(-XI/RATIO(13)))*
C 1 COEFF(SORT(-XI/RATIO(13))))*EXP(XI/RATIO(13))*CUR2
C CSECEL=CSECEL+COFF1*CUR2*RATE*DEN
C CSECEI=CSECEI+COFF1*CUR3*RATE*DEN
C 710 CONTINUE
C RETURN
C *****
C SUBROUTINE POT(IIFLG,NPEROD,N,NPEROD,H,A,B,C,INDIN,Y,IERROR,U)
C *****

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PROGRAM TPILOT
C THIS PROGRAM SOLVES POISSON'S EQUATION OUTSIDE A CIRCLE(SPACECRAFT)
C IN WHICH POTENTIAL IS GIVEN VS ANGLE, AND GENERATES A CONTOUR MAP
C OF THE RESULT.
C TEMPR=REFERENCE TEMPERATURE(VOLTS),
C RAD=SPACECRAFT RADIUS(IN FEET),
C IGEOM=MEANS GEOMETRY IS [INFINITE-CYLINDRICAL,
C IDEOM=2 MEANS GEOMETRY IS PROLATE SPHEROIDAL,
C RPLOT IS PLOTTED SPACECRAFT RADIUS(IN LINES),
C SIGMA=MAJOR-TO-MINOR-AXIS RATIO OF PROLATE SPHEROID,
C SBOUND=NATURAL LOG OF [OUTER GRID BOUNDARY RADIUS/SPACECRAFT RADIUS],
C IF IGEOM=1
C PBOUND=POTENTIAL AT OUTER BOUNDARY(IN MV),
C CNT IS THE SAME AS THE PARAMETER 'SEP' USED BY SUBROUTINE 'CNTOUR'.
C ITS VALUE DETERMINES WHETHER AND HOW CONTOURS ARE LABELLED.
C DANGO IS THE ANGLE(IN DEGREES) BETWEEN THE ORIGIN OF ANGLES AND J=1.
C N IS NUMBER OF UNKNOWN INTERIOR GRID NODES IN I-DIRECTION(RADIAL
C DIRECTION), I.E., IT IS THE NUMBER OF NODES NOT INCLUDING THE
C SPACECRAFT SURFACE OR THE OUTER GRID BOUNDARY.
C M IS THE NUMBER OF UNKNOWN GRID POINTS IN J-DIRECTION(AN ANGLE).
C KSPOTS=0 MEANS SURFACE POTENTIAL VALUES ARE READ IN.
C ASPOTS=1 MEANS HALF OF THEM ARE READ IN AND SYMMETRY IS USED
C TO GENERATE THE OTHER HALF.
C KSPOTS AT LEAST 2 MEANS THEY ARE GENERATED BY SUBROUTINE 'SPOTS'.
C MODCHG=0 MEANS ZERO SPACE CHARGE IS ASSUMED,MODCHG=1 MEANS LINEAR
C SPACE CHARGE IS ASSUMED.
C ISCALE=0 MEANS RADIAL SCALE IS LOGARITHMIC IN REAL RADIUS,
C ISCALE=1 MEANS RADIAL SCALE IS PROPORTIONAL TO REAL RADIUS.
C NCN IS THE NUMBER OF POTENTIAL VALUES FOR WHICH EQUIPOTENTIAL
C CONTOURS ARE TO BE PLOTTED.
C CNK(1),...,CNK(N) ARE POTENTIAL VALUES (IN KV) FOR WHICH CONTOURS
C TO BE PLOTTED.
C TENP1,...,DENI2 ARE TEMPERATURES (IN VOLTS) AND DENSITIES (IN
C PARTICLES PER CUBIC METER) FOR ELECTRONS AND IONS IN ASSUMED
C DOUBLE-MAXWELLIAN VELOCITY DISTRIBUTIONS.
C PHI(1),2,...,N) ARE SURFACE POTENTIAL VALUES(IN KV).
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
COMMON /CTRACE/RATIO(10),ROUTE(32),ITRACE,IFAUULT(10),JLOCAL(10)
COMMON /CPDIS/A(66),B(66),C(66),TWOCOS(1500),IFLG
COMMON /POISA/N,N,KSPOTS,MODCHG
COMMON /CDIV/Y(66,180),XS(70),SY(66,181)
COMMON /CORB/VARIABLE(4),T,DELTA,SBOUND,FUNC(4),DKUTA(4),M
COMMON /PIE / RP1,RP12,RPHMF,SOTP1,SAY
COMMON /POT/DAMMA,DELTAX,DELTAY,Y(180),RAD,RPLOT
COMMON /BLK1/TENP1,TENP2,DENE1,DENE2,DENI1,DENI2,TENP11,TENP12
1,TEMPR
COMMON /BLK2/PHI(180),DELPHI(180),CN(20),NCN,ISCALE
C
READ(5,40) TEMPR,RAD
40 FORMAT(2F10.1)
READ(5,41) IGEOM,RPLOT,SIGMA
41 FORMAT(I10,2F10.1)
READ(5,40) SBOUND,PBOUND
READ(5,42) CNT,DANGO,M,N,KSPOTS,MODCHG,ISCALE
42 FORMAT(2F6.2,2I4)
C
WRITE(6,50) TEMPR,RAD,IGEOM,RPLOT,SIGMA,SBOUND,PBOUND,CNT,DANGO,
M,N,KSPOTS,MODCHG,ISCALE
50 FORMAT(1X,'CYTLOT',//6X,'TEMPR',7X,'RAD',5X,'IGEOM',5X,'RPLOT',
15X,'SIGMA',4X,'SBOUND',4X,'PBOUND',7X,'CNT',5X,'DANGO',
22X,'M',7X,'N',2X,'KSPOTS',2X,'MODCHG',2X,'ISCALE'/
31X,'I10,3,I10,3,I10,3,I10,3')
READ(5,400) NCN
400 FORMAT(I2)
IF(MCN.NE.0) READ(5,401) (CN(K),K=1,MCN)
401 FORMAT(F10.7)
IF(MCN.NE.0) WRITE(6,402) (CN(K),K=1,MCN)
402 FORMAT(1X,'POTENTIAL CONTOURS IN KV',//(1X,10F10.5))
C
NPEROD IS ALWAYS ZERO, GIVES PERIODIC BOUNDARY CONDITION IN
ANGLE FOR POISSON-SOLVER.
C
NPEROD=0
RF1=3.1415926535897
RP12=2.08RP1
RPHMF=0.5ARP1
SOTP1=1.772453851
IPOIS=0
IFLG=0
SUMAMB=0.0
HCONS=10.0
SAY=1.0/SOTP1
500 FORMAT(4E11.3)
WRITE(6,600) TENP1,TENP2,DENE1,DENE2
600 FORMAT(1X,'4E11.3',DELTA,DELTAY,SHDENE1,7X,SHDENE2/SX,IP4E12.3/)
READ(5,500) TENP11,TENP12,DENI1,DENI2
WRITE(6,601) TENP11,TENP12,DENI1,DENI2
601 FORMAT(8X,ANTENP11,6X,ANTENP12,6X,SHDENI1,7X,SHDENI2/SX,IP4E12.3/)
ANG=DANGO+RP1/180.0
C
888 IF THE FIRST DIMENSION OF THE ARRAY YS IS CHANGED, IDINY MUST BE
CHANGED. 888
C
IDINY=66
NP2=NP12
IF(KSPOTS.EQ.0) READ(5,200) (PHI(J),J=1,N)
200 FORMAT(6E12.5)
IF(KSPOTS.NE.1) GO TO 202
NMHALF=M/2
READ(5,200) (PHI(J),J=1,NMHALF)
DO 203 J=1,NMHALF
PHI(N+1-J)=PHI(J)
203 CONTINUE
GO TO 204
202 IF(KSPOTS.GE.2) CALL SPOTS
204 WRITE(6,603)
603 FORMAT(//1X,'###SURFACE POTENTIALS IN KV###')
WRITE(6,201) (PHI(J),J=1,N)
201 FORMAT(1X,IP10E12.5)
IF(IGEOM.EQ.1)
1CALL GENGRID(TEMP1,TEMP2,DENSE1,SBOUND,PBOUND
1,N,HCONS,ANGD,IPOIS)
2CALL PHOAT(TEMP1,SBOUND,PBOUND,M,
2 HCONS,ANGD,IPOIS,SIGNA,RMAX,ONEGA,ALPHA,SMAX,SO)
CALL DANIER(NP2,M)
IF(MCN.EQ.0) STOP
CALL PLDPOT(SBOUND,PBOUND,N,N,SUMAMB,CNT)
CALL SADDIE
STOP
END
SUBROUTINE GENGRID(TEMP1,TEMP2,DENSE1,SBOUND,PBOUND,
1,N,HCONS,ANGD,IPOIS)
COMMON /POISA/N,N,KSPOTS,MODCHG
COMMON /CDIV/Y(66,180),XS(70),SY(66,181)
COMMON /PIE / RP1,RP12,RPHMF,SOTP1,SAY
COMMON /POT/DAMMA,DELTAX,DELTAY,Y(180),RAD,RPLOT
COMMON /BLK1/TENP1,TENP2,DENE1,DENE2,DENI1,DENI2,TENP11,TENP12
1,TEMPR
COMMON /BLK2/PHI(180),DELPHI(180),CN(20),NCN,ISCALE
IF(IFLG.EQ.1)GO TO 100
RLNDA=0.0
IF(NULHNG.EQ.0) GO TO 210
DEBYE=.687*ASORT(TEMPR1+.602E-19/(DENE1*.SBIE-.3))
RLNDA=(RAD/DEBYE)*.882(DENE1/TEMP1+DENE2/TEMP2+DENI1/TEMP11
1 DENI2/TEMP12) RIENPR/DENI1
RATIO=1.0/SDORT(RLNDA)
WRITE(6,211) RATIO
211 FORMAT(1X,'DEBYE LENGTH / SPACECRAFT RADIUS = *IPE10.3//')
212 DELTAX=SBOUND/FLOAT(N+1)
DELTAY=2.*RP1/FLOAT(N)
SYX=(DELTAY/DELTAX)*82
C
GENERATE GRID POINTS, COEFFICIENTS AND RHS OF EQUATION (I.ME.1)
C
100 NM1=N-1
DO 200 J=1,N
Y(J)=FLOAT(J-1)*DELTAY+ANGD
IF(Y(J).GT.RP12) Y(J)=Y(J)-RP12
YS(N,J)=SYX*PBUND
DO 210 I=2,NM1
YS(I,J)=0.
210 CONTINUE
200 CONTINUE
TLNDA=PLNDA*DELTAY*82
DO 220 I=1,M
XS(I)=FLOAT(I)*DELTAX
AI(I)=SYX
BI(I)=-2.*SYX-TLNDA*EXP(2.*XS(I))
CI(I)=SYX
220 CONTINUE
AI(0)=0.
CI(0)=0.
C
CALCULATION OF RHS OF EQUATION FOR I=1
C
300 DO 230 J=1,N
YS(1,J)=SYX*PHI(J)
230 CONTINUE
CALL POIS(IFLG,NPEROD,N,NPEROD,M,A,B,C,IDINY,YS,IERROR,TWOCOS)
WRITE(6,1001) IERROR
1001 FORMAT(1X,'THE ERROR FLAG IS ',I3)
WRITE(6,1002)
1002 FORMAT(1X,'###POTENTIAL PROFILE###')
DO 130 J=1,N
WRITE(6,120) J,(YS(I,J),I=1,M)
120 FORMAT(1X,2HJ=',I3',/(1X,IP1E10.3))
130 CONTINUE
RETURN
END
SUBROUTINE PROLAT (TENP1,SBOUND,PBOUND,
1 N,HCONS,ANGD,IPOIS,SIGNA,RMAX,ONEGA,ALPHA,SMAX,SO)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C PURPOSE
C TO GENERATE ARRAY OF GRID POINTS AND TO COMPUTE THE COEFFICIENTS
C OF THE POISSON EQUATION IN THE CASE OF A PROLATE SPHEROID.
C DESCRIPTION OF THE VARIABLES
C RMAX IS OUTER RADIUS AT WHICH POTENTIAL IS ASSUMED TO BE ZERO.
C SIGNA IS POLAR AXIS LENGTH TO EQUATORIAL AXIS LENGTH.
C EXTERNALS
C POI
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
COMMON /CPDIS/A(66),B(66),C(66),TWOCOS(1500),IFLG
COMMON /POISA/N,N,KSPOTS,MODCHG
COMMON /CDIV/Y(66,180),XS(70),SY(66,181)
COMMON /PIE / RP1,RP12,RPHMF,SOTP1,SAY
COMMON /POT/DAMMA,DELTAX,DELTAY,Y(180),RAD,RPLOT
COMMON /BLK1/TENP1,TENP2,DENE1,DENE2,DENI1,DENI2,TENP11,TENP12
1,TEMPR
COMMON /BLK2/PHI(180),DELPHI(180),CN(20),NCN,ISCALE
C
RLNDA=0.0
DELTAY=RP12/FLOAT(N)
TAUP=0.5*ALOG((SIGNA+1.0)/(SIGNA-1.0))
ALPHA=1.0/EVIN(TAUP)
ONEGA=COSH(TAUP)
BETA=EXP(TAUP)
SO=ALOG((BETA+1.0)/(BETA-1.0))
SO=0.
THETA=RMAX/ALPHA
TAUMAX=ALOG(THETA+SORT(THETA**2+1.0))
BETA=EXP(TAUMAX)
SMAX=ALOG((BETA+1.0)/(BETA-1.0))
SMAX=BETA
SBOUND=SMAX
DELTAX=(SMAX-SO)/FLOAT(N+1)
SYX=(DELTAY/DELTAX)*82
NM1=N-1
DO 200 J=1,N
Y(J)=FLOAT(J-1)*DELTAY+ANGD
IF(Y(J).GE.RP12) Y(J)=Y(J)-ANGD
IF(Y(J).LT.0.0) Y(J)=Y(J)+RP12
YS(N,J)=SYX*PBUND
DO 210 I=2,NM1
YS(I,J)=0.
210 CONTINUE
200 CONTINUE
NP2=NP12
DO 220 I=1,M
XS(I)=FLOAT(I)*DELTAX+SO
BETA=EXP(-XS(I))
TAU=ALOG((BETA+1.0)/(BETA-1.0))
PSI=1.0/COSH(TAU)*82
A(I)=SYX*PSI
B(I)=SYX*PSI
C(I)=SYX*PSI
220 CONTINUE
AI(0)=0.
CI(0)=0.
DO 230 J=1,N
YS(1,J)=SYX*PHI(J)
230 CONTINUE
CALL PHOAT(TEMP1,SBOUND,PBOUND,M,HCONS,ANGD,IPOIS,SIGNA,RMAX,ONEGA,ALPHA,SMAX,SO)

```

```

WRITE (X,*) 'MAGNETIC DELTAX=MAX(SO,OMEGA
FORMAT('X',IPE10.3))
M=(DELTA*DELTA)/(DELTA*DELTA+HCONS)
RETURN
END
SUBROUTINE PLOTP(SBOUND,FBOUND,M,MPINT,SUMANG,CNT)
C
C POTENTIAL CONTOURS AROUND A SPACECRAFT UNDER MAGNETOSPHERIC
C CONDITIONS.

```

```

DIMENSION X(10)
DIMENSION Y(181)
COMMON/CDIU/Y$(66,180),X$(70),SY$(66,181)
COMMON/PIE/MP1,MP2,RP1,RP2,SDP1,SDP2
COMMON/PUT/GAMMA,DEL TAX,DEL TAY,T(180),RAD,RPLDT
COMMON/BLK2/PHI(180),DELPHI(180),CNC(20),MNC,ISCALE
DATA /AC/1000./
NP=RPLDT
NI=NP/DINT(NI)
NP2=NP2
NP1=NP1
DEL TAX=SBOUND/FLOAT(NP2-1)

```

```

C
C RELOCATE ELEMENTS OF THE ARRAYS XS AND YS.
C

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```

DO 300 J=1,NPOINT
YS(MP2,J)=PBOWDEFAC
DO 310 I=2,MP1
IPA=MP2-I
IPB=IPA+1
YS(IPB,J)=YS(IPA,J)*SFAC
310 CONTINUE
YS(I,J)=PHI(I,J)*SFAC
300 CONTINUE
DO 320 I=1,MP2
320 XS(I)=DELTA*SFLOAT(I-1)
IF (DELTA*DELTA*LT.LT.1.6) GO TO 99

```

C GRID CELLS ARE TOO ELONGATED RADially. FIX THIS USING INTERPOLATION.

```

      NP1=NINO(NP2,44)
      NP2=NP1+1
      M=NP1-1
      NM1=M-1
      NM2=M-2
      DELTAX=DELTAX/.2
      DO 91 I=1,NP2*2
      IV=NP2*1-I
      KV=(IV+1)/2
      DO 91 J=1,NPOINT
91  YS(IV,J)=YS(KV,J)
      DO 92 J=1,NPOINT
      YS(2,J)=(.3,0YS(1,J)+.6,0YS(3,J)-YS(5,J))/B.O
      YS(4,J)=(.3,0YS(NP2,J)+.6,0YS(N,J)-YS(NM2,J))/B.O
      DO 92 I=4,NM1,2
      YS(I,J)=(.9,0YS(YS(I-1,J)+YS(YS(I+1,J))-YS(I-3,J)-YS(I+3,J))/16.O
      DO 93 I=1,NP2
      XS(I)=DELTAX*FLOAT(I-1)
      WRITE(4,90)
90  FORMAT('///1x',RADIAL GRID INTERVAL HALVED, NEW M =',I3)

```

```
C SET UP EXPANDED ARRAY OF POTENTIAL VALUES FOR USE BY PLOTTER.
```

```

99 DO 1 I=1,NP2
   SY(I,N1)=YS(I,1)
   DO 1 J=1,NPOINT
     SY(I,J)=YS(I,J)
   1 CONTINUE

```

```
C
C GENERATE GRID
```

```

C      DO 2 J=1,NPOINT
      YY(J)=Y(J)
2  CONTINUE
      YY(N1)=RP12+Y(1)
C

```

```
DO 3 I=1,MP2
  IF (ISCALE.EQ.0) X(I)=RPS(1.0+FLOAT(I-1)*DELTA)
  IF (ISCALE.EQ.1) X(I)=RPS*EXP(FLOAT(I-1)*DELTA)
3 CONTINUE
```

```
C
C INITIALIZE PLOTTER
C
```

```
CALL START
CALL SYMBOL(0.0,10.5,0.15,'PLEASE MOUNT BLACK FINE POINT PEN IN 1'
1,270.0,38)
CALL PLOT(1.0,0.0,-3)
CALL PLOT(8.0,5.5,-3)
```

```

C *** IF THE FIRST DIMENSION OF THE ARRAY BY IS CHANGED, IDX MUST BE
C     CHANGED ***

```

```
C  
C      CHANGED: 488  
  
      IDX=66  
      DO 100 I=1,MCM  
        CN(I)=CN(I)*SFAC  
        CALL CNTOUR (X,MPZ,YY,N1-SY,IDX,CN(I),CNT,CN(I))
```

```

C 100 CONTINUE
C
      AROMED=AMIN1(X(NP2)+DELTA*.65)
      SIZE=1.0
      CALL PLOT(AROMED*.0,0.3)
      CALL PLOT(AROMED*.375981ZE+.5681ZE,2)
      CALL PLOT(AROMED*.375981ZE+.25681ZE,2)
      CALL PLOT(AROMED*.7581ZE+.25681ZE,2)
      CALL PLOT(AROMED*.7581ZE-.25681ZE,2)
      CALL PLOT(AROMED*.375981ZE+.25681ZE,2)
      CALL PLOT(AROMED*.375981ZE-.5681ZE,2)
      CALL PLOT(AROMED*.0,0.2)

```

```
C
CALL SYMBOL(ARROWD-0.5*SIZE,0.625*SIZE,0.25*SIZE,'SUNLIGHT',0.0,0)
CALL SYMBOL(-0.75*SIZE,0.125*SIZE,0.25*SIZE,'SPACE',0.0,0)
CALL SYMBOL(-0.625*SIZE,-0.375*SIZE,0.25*SIZE,'CRAFT',0.0,5)
C
CALL CIRCLE(RP,0.0,0.360,0,RP,RP,0,0)
```

```
DO 102 I=1,NP2
DO 102 J=1,NP-DINT
rS(I,J)=YS(I,J)/FAC
```

```

102 CONTINUE
    RETURN
END
SUBROUTINE TOURT(XR,YR,XS,YS)
  RADR=YR
  RADS=YS
  YR=XR*SIN(RADR)
  XR=XR*COS(RADR)
  YS=XS*SIN(RADS)
  XS=XS*COS(RADS)
  RETURN
END

```

```

SUBROUTINE BARKER(NP2,N)
C
C *****
C PURPOSE
C   TO COMPUTE HEIGHT AND RADIAL DISTANCE OF POTENTIAL BARRIERS
C   BY FITTING A PARABOLA.
C DESCRIPTION OF THE VARIABLES
C   XBAR AND YBAR ARE BARRIER LOCATION AND HEIGHT
C EXTERNALS= NONE
C *****
COMMON/CDIV/YS(44,180),XS(70),SY(44,180)
COMMON/PIE/RPL1,NP12,RPINAF,SDTPI,SAT
COMMON/POT/GAMMA,DELTA,DELTA1,Y(180),RAD,RPL DT
DIMENSION BHADP(180),BRADIN(180),BDEGP(180),BDEGM(180),BPOTP(180),
1BPDI(180),IF(180),IN(180),JP(180),JM(180)
NP1=NP2-1
NPB=0
NMB=0
DO 400 J=1,N
  IF (YS(1,J),GT,YS(NP2,J))GO TO 405
  YMIN=YS(1,J)
  IRMIN=1
  YUMAX=YS(NP2,J)
  IRMAX=NP2
  GO TO 403
405 YUMAX=YS(1,J)
  IRMAX=1
  YMIN=YS(NP2,J)
  IRMIN=NP2
403 DO 410 I=2,NP1
  IF (YS(I,J),GT,YUMAX) IRMAX=I
  IF (Y(I,J),GT,YUMAX) YUMAX=YS(I,J)
  IF (YS(I,J),LT,YMIN) IRMIN=I
  IF (Y(I,J),LT,YMIN) YMIN=YS(I,J)
410 CONTINUE
  IF (IRMAX.EQ.1.AND,IRMIN.EQ.NP2)GO TO 400
  IF (IRMAX.EQ.NP2.AND,IRMIN.EQ.1)GO TO 400
C
C A BARRIER HAS BEEN FOUND AT ANGLE J.
C
  DO 400 K=1,2
    GO TO (401,402),K
  401 I=IRMAX
    NPB=NPB+1
    GO TO 460
  402 IF (IRMIN.EQ.1.OR,IRMIN.EQ.NP2) GO TO 400
    I=IRMIN
    NMB=NMB+1

```

```

C
C CALCULATION OF HEIGHT AND RADIAL LOCATION OF POTENTIAL BARRIER BY
C FITTING A PARABOLA TO THREE POINTS
C

```

```

460 DIMI=(YS(I,J)-YS(I-1,J))/DELTAX
DIPI=(YS(I+1,J)-YS(I,J))/DELTAX
APAR=(DIPI-DIMI)/(2.*DELTAX)
BPAR=DIPI-APAR*(XS(I)+XS(I+1))
CPAR=YS(I,J)-APAR*(XS(I)+BPAR*(XS(I)
XB=-BPAR/(2.*APAR)
YB=APAR*(XB+BPAR*(XB+CPAR
GO TO (411,412),K
411 IP(NP)=I
JP(NP)=J
BRADP(NP)=EXP(XB)
BDECP(NP)=Y(J)*180.0/RPI
SPOTD(NP)=YB
GO TO 400
412 IN(NB)=I
JN(NB)=J
BRADN(NB)=EXP(XB)
BDECN(NB)=Y(J)*180.0/RPI
SPOTD(NB)=YB
400 CONTINUE

```

```

C      IF(NPB.EQ.0) GO TO 421
      WRITE(6,422)
422  FORMAT('1X, POSITIVE BARRIERS')
      WRITE(6,423) (1P(L,I),BDEG(L),BDEG(L),BPOTH(L),L=1,NPB)
423  FORMAT('1X,3(4X,1X,3X,1X,2X,RAD/RS,1X,DEGREES,1X,1X)')
      1=MEIOM(KV)/7/1X,3(214,OF2R,3,1PE12,5))
424  IF(NPB.EQ.0) GO TO 423
      WRITE(6,424)
424  FORMAT('1X, NEGATIVE BARRIERS')
      WRITE(6,425) (1N(L,I),BDEG(L),BDEG(L),BPOTH(L),L=1,NPB)

```

```

C 423 RETURN
      END
      SUBROUTINE SADDLE
C PURPOSE IS TO IDENTIFY SADDLE POINTS
C

```

COMMON/CPOISA/N,N,KSPOTS,NODCHS
COMMON/CBIV/YSI(44,180),XS(70),SY(44,181)
COMMON/PIE/ RPI,RP12,RPIMAF,SOTPI,SAY
COMMON/POT/GAMMA,DELTA,X,DELTA,Y(100),RAB,RPLOT
COMMON/BLK2/PHI(180),DELPHI(100),CN(20),NCN,ISCALE
DIMENSION SX(44,180),DVB(180),DVBV(180)

```

DO 100 J=1,N
DUBY(J)=(-YS(3,J)+4.0*YS(2,J)-3.0*PHI(J))/(2.0*DELTA T*GRAB)
JP=J+1
JN=J-1
IF (JP.GT.N) JP=1
IF (JN.LE.0) JN=N
DUBY(J)=(PHI(JP)-PHI(JN))/(2.0*DELTA T*GRAB)

```

```

C 100 CONTINUE
      WRITE(6,600)
600  FORMAT('///1X',RADIAL ELECTRIC FIELD AT THE SURFACE ('R',N=1,N)
      WRITE(6,700)
700  FORMAT('10(1X,PE12.3)')
      WRITE(6,800)
800  FORMAT('///1X',TANGENTIAL ELECTRIC FIELD AT THE SURFACE,
      '1' ('R',N=1,N)
      WRITE(6,900)
900  FORMAT('///')

```

```

C      MP1=M+1
C      MP2=M+2
      DO 1 J=1,N
        DO 1 I=2,MP2
          SX(I,J)=XXX,
1 CONTINUE
C
C      DO 2 J=1,N
      DO 2 I=2,MP1
6 P=YS(I+1,J)-YS(I-1,J)/(2.000000LTX)
        JP=J*J
        IF (I.PN,M)  MP=I-1

```

```

      INI=J-1
      IF (J.EQ.1) JMI=N
      D=(YS(I,J)-YS(I,JMI))/(2.0*DELTA)
      PX=(YS(I,J)-2.0*YS(I,JMI)+YS(I-1,J))/(DELTA*DELTA)
      DY=(YS(I,J)-2.0*YS(I,JMI)+YS(I,JMI))/(DELTA*DELTA)
      PY=(YS(I,J)-YS(I-1,J)-YS(I+1,JMI)+YS(I-1,JMI))/
      2.0*DELTA
      DEN=PX*DY-DX*PY
      IF (DEN.NE.0.0) SX(I,J)=(OPX-PDY)/DEN
      IF (DEN.NE.0.0) SY(I,J)=(POX-OPY)/DEN
      IF (ABS(SX(I,J)).LT.DELTA.AND.ABS(SY(I,J)).LT.DELTA)
      1 GO TO 2
      SX(I,J)=999.
C
C 2 CONTINUE
C
C IF THERE IS NO SADDLE POINT, RETURN
C
      ICH=0
      DO 10 J=1,N
      DO 10 I=2,NP1
      IF (SX(I,J).EQ.999.0) ICH=ICH+1
10 CONTINUE
      IF (ICH.NE.0) GO TO 11
      WRITE(4,900)
900 FORMAT(IX,'NO SADDLE POINT FOUND')
      RETURN
C
C FIND ACCURATE LOCATION OF SADDLE POINTS
C
      11 DO 20 J=1,N
      JPI=J+1
      IF (J.EQ.N) JPI=1
      DO 20 I=1,NP1
C
C CHECK IF A SADDLE POINT HAS BEEN OBSERVED IN THE GRID CELL ABOVE
C AND TO THE RIGHT OF THE POINT(I,J).
C
      ANDYX=0.0
      ANDTY=0.0
      AN=0.0
      JMI=J-1
      IF (I.EQ.1) GO TO 22
      IF (SX(I,J).EQ.999.0.OR.SX(I,J).LT.0.0.OR.SY(I,J).LT.0.0)
      1 GO TO 21
      AN=AN+1.0
      ANDYX=ANDYX+SX(I,J)
      ANDTY=ANDTY+SY(I,J)
21 IF (SX(I,JPI).EQ.999.0.OR.SX(I,JPI).LT.0.0.OR.SY(I,JPI).GT.0.0)
      1 GO TO 22
      AN=AN+1.0
      ANDYX=ANDYX+SX(I,JPI)
      ANDTY=ANDTY+SY(I,JPI)+DELTA
C
22 IF (I.EQ.NP1) GO TO 24
      IF (SX(I+1,J).EQ.999.0.OR.SX(I+1,J).GT.0.0.OR.SY(I+1,J).LT.0.0)
      1 GO TO 23
      AN=AN+1.0
      ANDYX=ANDYX+SX(I+1,J)+DELTA
      ANDTY=ANDTY+SY(I+1,J)
23 IF (SX(I+1,JPI).EQ.999.0.OR.SX(I+1,JPI).GT.0.0.OR.SY(I+1,JPI).GT.
      1 GO TO 24
      AN=AN+1.0
      ANDYX=ANDYX+SX(I+1,JPI)+DELTA
      ANDTY=ANDTY+SY(I+1,JPI)+DELTA
24 CONTINUE
      IF (AN.EQ.0.0) GO TO 20
      AX=ANDYX/AN
      AY=ANDTY/AN
      AUX=AX+SX(I)
      AUY=AY+SY(J)
      XBS=AXS/DELTA
      YBS=AYS/DELTA
      SADDPOT=(YS(I+1,J)+XBS*YS(I,J)+S(1.0-XBS))*S(1.0-YBS)
      1+(YS(I+1,JPI)+XBS*YS(I,JPI)+S(1.0-XBS))*YBS
C
      SARRAD=EXP(AUX)
      SARRB=AYY/100.0/NP1
      WRITE(4,401) I,J,SARRAD,SARRB,SADDPOT,AN
401 FORMAT(IX,'SADDLE POINT DETECTED IN CELL',2I3,' RAD/RB= ',
      A7.3,' DEGREE= ',F7.3,' POTENTIAL(KV)= ',F12.5,
      5' NUMBER OF DETECTIONS ',F4.1)
      IF (AN.LT.4.0) GO TO 20
      IF (ISCALE.EQ.0) SPHAD=NPLOTS*(1.0+ANX)
      IF (ISCALE.EQ.1) SPHAD=NPLOTS*(1.0+ANX)
      SARR=SPHAD*SCUS(AUY)
      SARY=SPHAD*SH(AUY)
      IF (ABS(SARY).GT.5.25) GO TO 20
      IF (ABS(SARR).GT.5.0) GO TO 20
      CALL SYMBOL(SARR,SARY,0.20,4.45,0.0)
20 CONTINUE
      CALL FINISH
      RETURN
      END
      SUBROUTINE SPOTS
C
C THIS SUBROUTINE GETS THE SURFACE POTENTIAL VALUES PHI(1,2,.....N)
C IN A MANNER DEPENDING ON THE VALUE OF KSPOTS.
C
      COMMON/CP01SA/N,N,KSPOTS,NBCHS
      COMMON/BLK2/PHI(100),RELPHI(100),CH(20),NCH,ISCALE
C
      IF (KSPOTS.GT.2) GO TO 900
C
      IF (N.NE.100) GO TO 900
      DO 11 J=1,N
      PHI(J)=0.07
      IF (J.GE.1.AND.J.LE.8) PHI(J)=-0.05
      IF (J.GE.42.AND.J.LE.53) PHI(J)=0.05
      IF (J.GE.91.AND.J.LE.98) PHI(J)=-0.05
      IF (J.GE.129.AND.J.LE.139) PHI(J)=0.05
11 CONTINUE
      RETURN
C
900 WRITE(4,901) N,KSPOTS
901 FORMAT(IX,'SPOTS CALLED INCORRECTLY. N = ',I3,
      A' KSPOTS = ',I3)
      RETURN
      END
      END

```

E1

FIN4

SCHOLARSHIP

[illegible]

RE TURN
END
ENDS

```

C
      TENA(AMR1,O)
      PROGRAM SHAPF(5,150)
C
C THIS S/P GENERATES A MESH OF RECTANGULAR OR TRIANGULAR
C FINITE ELEMENTS IN AN INNERMOST MESH AND DEFINE THE
C NUMBERS OF THE NODES OF EACH ELEMENT. SURFACE MODE IS
C ALSO DETERMINED.
C
      COMMON/AMR1/XB(2540),YB(2540),IB(2540,4),IL(53,53),
      IIC(53,53),ICK(52,52)
      COMMON/CHEM/IRMIN,IRNMN,IRSMX,IRSMY,IRNO,JNO,BK,BY
      COMMON/CDS/MSDET(10),MSI(10),MSJ(10),ROUTER(10),AS(10),
      IAE(10),KAM(10),KAMA(10),NMI(10),NMA(10)
      COMMON/CMB2/MSMAX,MAXMOD,MAXELE,NOBOUT,MODIN,HELOUT
      INELIN,MODINS
      COMMON/CREF/LMRB,LMRP(32),LMRY(32),LMRY(32)
      COMMON/IDBT/LIN,LU,ITRACS
      COMMON/OBJ/NOBJ,CTEBO(5),ISPACE(64),XSBE(64),
      YSBE(64),XEBO(64),YEBO(64),ILP(64),IVEC(64),SLPREB(64),
      ZCOGN(5),COBY(5)
      COMMON/BLR4/IB(25),IBJ(25),IBUF3(25),IBUF4(25)
      DIMENSION IBUF(64),NMB(13)
      DATA NAME/2HLN,2HNE,2HF /
C
      WRITE(LIN,999)
999 FORMAT('0',2X,'SHAPF' STARTS',3X,20,'')
      DO 20 J=1,IRNMN
      DO 30 J=1,IRSMX
      J1=J+1
      IF(ICM(1,J),NE.-1) GO TO 30
      IF(ICM(1,J1),EQ.0) ICM(1,J1)=-1
30 CONTINUE
      DO 20 CONTINUE
C
      DO 40 I=1,IRMIN
      DO 50 J=1,IRNMN
      IF(ICK(I,J),EQ.-1) GO TO 50
      IF(ICK(I,J),EQ.1) GO TO 50
      IF(ICK(I,J),EQ.0,OR,ICK(I+1,J),EQ.0,OR,ICK(I+1,J1),EQ.0,
      OR,ICK(I,J1),EQ.0) GO TO 50
      ICK(I,J)=-1
50 CONTINUE
      DO 40 CONTINUE
C
      MN=1
      IF(MN,EQ.1) GO TO 60
      DO 1300 J=1,IRSMX
      J1=J+IRSMX+1-J
      WRITE(LIN,1350) (ICK(I,J),I=1,IRNMN)
1300 CONTINUE
      DO 1310 J=1,IRNMN
      J1=J+IRMIN+1-J
      WRITE(LIN,1350) (ICK(I,J),I=1,IRMIN)
1310 CONTINUE
      DO 1350 FORMAT(4I13)
C
      DO 60 NI=0
      N=0
      NBI=NOBOUT
      NIMAX=NHEST(1)
      IF(LMRB,NE.0) NIMAX=NIMAX-1
      IF(NIMAX,EQ.2) GO TO 45
      WRITE(LIN,943)
943 FORMAT('00 ERROR IS DETECTED IN S/P "SHAPF".')
      STOP
C
      DO 70 MIN=1,NIMAX
      IF(MIN,EQ.NIMAX) MODIN=NBI+1
      INNO=MIN
      INNE=INB-JX-MIN
      JNO=MIN
      JNE=JNOBX-MIN
      DO 72 I=INNO,INNE
      NBI=NBI+1
      IL(I,JNO)=NBI
      XS(NBI)=FLOAT(I-INB)OBX
      YS(NBI)=FLOAT(JNO-JO)OBY
72 CONTINUE
      DO 74 J=JNO,JNE
      NBI=NBI+1
      IL(INO+1,J)=NBI
      XS(NBI)=FLOAT(INNO+1-INB)OBX
      YS(NBI)=FLOAT(J-JO)OBY
74 CONTINUE
      DO 76 I=INNO,INNE
      IL(INO+1,I)=NBI
      XS(NBI)=FLOAT(I-INB)OBX
      YS(NBI)=FLOAT(JNO-JO)OBY
76 CONTINUE
      DO 78 J=JNO,JNE
      J1=JNO+JNE+1-J
      NBI=NBI+1
      IL(INO+1,J1)=NBI
      XS(NBI)=FLOAT(INNO-INB)OBX
      YS(NBI)=FLOAT(J1-JO)OBY
78 CONTINUE
      DO 70 CONTINUE
      INNO=INNO+1
      JNO=JNO+1
      J1=JNO-JNE+1
      JNE=JNE-1
C
      IF(LMRP,NE.0) GO TO 84
      DO 80 I=INNO,INNE
      DO 80 J=JNO,JNE
      IF(ICK(I,J),LE.-1) GO TO 80
      IF(ICK(I+1,J),EQ.-3,OR,ICK(I+1,J1),EQ.-3,OR,
      1 ICM(I,J1),EQ.-3,OR,ICK(I+1,J),EQ.-3,OR,
      2 ICM(I+1,J),EQ.-3,OR,ICK(I+1,J1),EQ.-3,OR,
      ICM(I,J),EQ.-3,OR,ICK(I+1,J),EQ.-3) ICM(I,J)=0
      DO CONTINUE
      GO TO 92
C
      DO 84 DO 85 I=INNO,INNE
      DO 85 J=JNO,JNE
      IF(ICK(I+1,J),LE.-1) GO TO 85
      IF(ICK(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      1 ICM(I+1,J),LE.-1,OR,ICK(I+1,J1),LE.-1,OR,
      2 ICM(I+1,J),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      ICM(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1) ICM(I,J)=0
      DO CONTINUE
      DO 84
      DO 85 I=INNO,INNE
      DO 85 J=JNO,JNE
      IF(ICK(I+1,J),LE.-1) GO TO 85
      IF(ICK(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      1 ICM(I+1,J),LE.-1,OR,ICK(I+1,J1),LE.-1,OR,
      2 ICM(I+1,J),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      ICM(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1) ICM(I,J)=0
      DO CONTINUE
      DO 84
      DO 85 I=INNO,INNE
      DO 85 J=JNO,JNE
      IF(ICK(I+1,J),LE.-1) GO TO 85
      IF(ICK(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      1 ICM(I+1,J),LE.-1,OR,ICK(I+1,J1),LE.-1,OR,
      2 ICM(I+1,J),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      ICM(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1) ICM(I,J)=0
      DO CONTINUE
      DO 84
      DO 85 I=INNO,INNE
      DO 85 J=JNO,JNE
      IF(ICK(I+1,J),LE.-1) GO TO 85
      IF(ICK(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      1 ICM(I+1,J),LE.-1,OR,ICK(I+1,J1),LE.-1,OR,
      2 ICM(I+1,J),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      ICM(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1) ICM(I,J)=0
      DO CONTINUE
      DO 84
      DO 85 I=INNO,INNE
      DO 85 J=JNO,JNE
      IF(ICK(I+1,J),LE.-1) GO TO 85
      IF(ICK(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      1 ICM(I+1,J),LE.-1,OR,ICK(I+1,J1),LE.-1,OR,
      2 ICM(I+1,J),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      ICM(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1) ICM(I,J)=0
      DO CONTINUE
      DO 84
      DO 85 I=INNO,INNE
      DO 85 J=JNO,JNE
      IF(ICK(I+1,J),LE.-1) GO TO 85
      IF(ICK(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      1 ICM(I+1,J),LE.-1,OR,ICK(I+1,J1),LE.-1,OR,
      2 ICM(I+1,J),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      ICM(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1) ICM(I,J)=0
      DO CONTINUE
      DO 84
      DO 85 I=INNO,INNE
      DO 85 J=JNO,JNE
      IF(ICK(I+1,J),LE.-1) GO TO 85
      IF(ICK(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      1 ICM(I+1,J),LE.-1,OR,ICK(I+1,J1),LE.-1,OR,
      2 ICM(I+1,J),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      ICM(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1) ICM(I,J)=0
      DO CONTINUE
      DO 84
      DO 85 I=INNO,INNE
      DO 85 J=JNO,JNE
      IF(ICK(I+1,J),LE.-1) GO TO 85
      IF(ICK(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      1 ICM(I+1,J),LE.-1,OR,ICK(I+1,J1),LE.-1,OR,
      2 ICM(I+1,J),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      ICM(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1) ICM(I,J)=0
      DO CONTINUE
      DO 84
      DO 85 I=INNO,INNE
      DO 85 J=JNO,JNE
      IF(ICK(I+1,J),LE.-1) GO TO 85
      IF(ICK(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      1 ICM(I+1,J),LE.-1,OR,ICK(I+1,J1),LE.-1,OR,
      2 ICM(I+1,J),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      ICM(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1) ICM(I,J)=0
      DO CONTINUE
      DO 84
      DO 85 I=INNO,INNE
      DO 85 J=JNO,JNE
      IF(ICK(I+1,J),LE.-1) GO TO 85
      IF(ICK(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      1 ICM(I+1,J),LE.-1,OR,ICK(I+1,J1),LE.-1,OR,
      2 ICM(I+1,J),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      ICM(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1) ICM(I,J)=0
      DO CONTINUE
      DO 84
      DO 85 I=INNO,INNE
      DO 85 J=JNO,JNE
      IF(ICK(I+1,J),LE.-1) GO TO 85
      IF(ICK(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      1 ICM(I+1,J),LE.-1,OR,ICK(I+1,J1),LE.-1,OR,
      2 ICM(I+1,J),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      ICM(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1) ICM(I,J)=0
      DO CONTINUE
      DO 84
      DO 85 I=INNO,INNE
      DO 85 J=JNO,JNE
      IF(ICK(I+1,J),LE.-1) GO TO 85
      IF(ICK(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      1 ICM(I+1,J),LE.-1,OR,ICK(I+1,J1),LE.-1,OR,
      2 ICM(I+1,J),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      ICM(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1) ICM(I,J)=0
      DO CONTINUE
      DO 84
      DO 85 I=INNO,INNE
      DO 85 J=JNO,JNE
      IF(ICK(I+1,J),LE.-1) GO TO 85
      IF(ICK(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      1 ICM(I+1,J),LE.-1,OR,ICK(I+1,J1),LE.-1,OR,
      2 ICM(I+1,J),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      ICM(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1) ICM(I,J)=0
      DO CONTINUE
      DO 84
      DO 85 I=INNO,INNE
      DO 85 J=JNO,JNE
      IF(ICK(I+1,J),LE.-1) GO TO 85
      IF(ICK(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      1 ICM(I+1,J),LE.-1,OR,ICK(I+1,J1),LE.-1,OR,
      2 ICM(I+1,J),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      ICM(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1) ICM(I,J)=0
      DO CONTINUE
      DO 84
      DO 85 I=INNO,INNE
      DO 85 J=JNO,JNE
      IF(ICK(I+1,J),LE.-1) GO TO 85
      IF(ICK(I+1,J1),LE.-1,OR,ICK(I+1,J),LE.-1,OR,
      1 ICM(I+1,J),LE.-1,OR,ICK(I
```



```

140 CONTINUE
150 IF (N1) GOTO 155
WRITE(LUN,73) NMAX,NODINO,NODINS
*FORMAT(88,0 OF CELLS IN AN INNERMOST NEST=,15/
155 NODINO=15/98 NODINS=15)
DO 500 J=1,INSMHX
DO 500 J=1,INSMHY
JJ=JCH(1,J)
IF(JJ.EQ.1.OR.JJ.EQ.-4) JCH(1,J)=0
500 CONTINUE

CALL EXEC(1,LU,IBUF+4,ITRACS+2,55)
IBUF(26)=NODINO
IBUF(27)=NODINS
IBUF(28)=NODINS-NODINO
CALL EXEC(2,LU,IBUF+4,ITRACS+2,55)
CALL EXEC(8,NAME)

C
STOP
END
ENDS

FTN4
SERNA(AENAI,0)
PROGRAM ASSIN(5,150)

C THIS S/P DOES RENUMBERING OF NODES AT THE SURFACE OF OBJECT
C SO THAT LAST 'NSURF' NODES ARE ALWAYS CORRESPONDING TO THE
C SURFACE NODES, WHERE 'NSURF' IS A TOTAL 0 OF SURFACE NODE.
C
COMMON/AENAI/XB(2560),YB(2560),ID(2560,4),JL(53,53),
IICH(53,53),JICH(52,52)
COMMON/CMESH/INSMIN,INSMIN,INSMHX,INSMHY,INO,JMO,DX,DY
COMMON/CNST2/NEBNAX,MAXNOB,MAXELE,NODOUT,NODIN,NELOUT,
IAELIN,NODINS
COMMON/IDOUT/LU,LU,ITRACS
COMMON/OBJ1/MOJCT,MSBO(5),ISPACE(44),JSPACE(44),XSBO(44),
YSBO(44),XSEB(44),YSEB(44),ISLP(44),IVEC(44),BLPSEB(44),
2CDOX(5),CDOY(5)
COMMON/OBJ2/KSP(128),YSP(128),XEP(128),YEP(128),HSP(128),
INEP(128),HNP(132),MPAT(5),MAXPAT
COMMON/BLK1/YS(15,4),YS(15,4),XE(15,4),YE(15,4),TY(15,7),
ITYN1(15,5),ITYN2(15,5)
COMMON/BLK4/IBUF1(25),IBUF2(25),NODE(25),IBUF4(25)
DIMENSION NSURF(128),IBUF(64),NAME(3),IAUX(128)
EQUIVALENCE (ICR,IAUX)
DATA NAME/2HML,2HMT,2HNE /
DATA NAME/2HML,2HMT,2HNE /

C
IFLG=0
WRITE(LUN,999)
999 FORMAT('//20','SX','ASSIN' STARTS','SX,20','')
NABA=0
IF(NABA.EQ.0) GO TO 490
ICASE=1
IF(INSMHX.GT.25) ICASE=2
DO 400 I=1,ICASE
IF(I1.EQ.2) GO TO 410
I1=1
I2=MINO(INSMHX,25)
GO TO 420
410 I1=25
I2=INSMHX
WRITE(LUN,979)
979 FORMAT('///')
420 DO 430 J=1,INSMHX
J1=JSMHX(1,J)
WRITE(LUN,982) (IL(I,J),I=1,I2)
982 FORMAT(25I3)
430 CONTINUE
400 CONTINUE

C
WRITE(LUN,470) ((I1(I,J),J=1,4),I=KELIN,MAXELE)
WRITE(LUN,480) (I,XB(I),YB(I),I=NODIN,MAXNOB)
470 FORMAT(24I5)
480 FORMAT(8I4,2F6,2)
490 IPAT=0
LA=NODINS
LB=MAXNOB
MAXSEB=MSBO(NODJCT)
DO 1000 M=1,MAXSEB
RND=0
IS=(SLP(N)
IV=IVEC(N)
H1=XSEB(N)
H2=XSEB(N)
H3=YSEB(N)
H4=YSEB(N)
H5=YSBO(N)
IF(I1.EQ.0) GO TO 40
IF(IS.EQ.3) GO TO 40
G=PLDA(18)/2.0
IF(IP.EQ.1) GO TO 20
IF(IS.LT.0) GO TO 10
DO 100 L=L+LB
IF(XB(L).GE.H11.AND.XB(L).LE.H12) GO TO 110
GO TO 100
110 IF(YB(L).GE.HJ1.AND.YB(L).LE.HJ2) GO TO 120
GO TO 100
120 IF(ABS(GB(XB(L)-H11)+HJ1-YB(L)).LE.0.018DY) GO TO 125
GO TO 100
125 N=M+1
NODE(N)=L
100 CONTINUE
N2=1
GO TO 400
10 DO 130 L=L+LB
IF(XB(L).GE.H11.AND.XB(L).LE.H12) GO TO 140
GO TO 130
140 IF(YB(L).GE.HJ1.AND.YB(L).LE.HJ2) GO TO 145
GO TO 130
145 IF(ABS(GB(XB(L)-H11)+HJ1-YB(L)).LE.0.018DY) GO TO 147
GO TO 130
147 N=M+1
NODE(N)=L
130 CONTINUE
N2=2
GO TO 400
20 IF(IS.GT.0) GO TO 30
DO 150 L=L+LB
IF(YB(L).GE.H12.AND.XB(L).LE.H11) GO TO 160
GO TO 150
160 IF(YB(L).GE.HJ1.AND.YB(L).LE.HJ2) GO TO 170
GO TO 150
170 IF(ABS(GB(XB(L)-H11)+HJ1-YB(L)).LE.0.018DY) GO TO 175
GO TO 150
175 N=M+1
NODE(N)=L
150 CONTINUE

```

```

      N1=NSURF-1
      M=1
      1 N1=M+1
      2 IF (NSURF(M).LE.NSURF(M1)) GO TO 3
      I1=NSURF(M)
      NSURF(M)=NSURF(M1)
      NSURF(M1)=I1
      3 M1=M+1
      IF (M1.LE.NSURF) GO TO 2
      M=M+1
      IF (M1.LE.M1) GO TO 1

C
      DO 100 M=1,NSURF
      MM=NSURF(M)
      BUFX(M)=XG(MM)
      BUFY(M)=YG(MM)
      DO 120 I=1,INSMNX
      DO 120 J=1,INSMNY
      LL=IL(I,J)
      IF (LL.EQ.MM) GO TO 140
120 CONTINUE
      GO TO 140
140 IL(I,J)=LL
160 DO 180 I=KELIN,MAXELE
      DO 180 J=1,4
      LL=IG(I,J)
      IF (LL.EQ.MM) IG(I,J)=LL
180 CONTINUE
190 CONTINUE

C
      DO 200 M=1,NSURF
      M1=NSURF(M)+1
      IF (M.NE.NSURF) M2=NSURF(M+1)-1
      IF (M.EQ.NSURF) M2=MAXMOD
      MSHFT=M
      IF (M1.GT.M2) GO TO 200
      DO 220 MM=M1,M2
      NEW=MM-MSHFT
      XG(NEW)=XG(MM)
      YG(NEW)=YG(MM)
      DO 240 I=1,INSMNX
      DO 240 J=1,INSMNY
      LL=IL(I,J)
      IF (LL.EQ.MM) GO TO 260
240 CONTINUE
      GO TO 280
260 IL(I,J)=NEW
280 DO 300 I=KELIN,MAXELE
      DO 300 J=1,4
      LL=IG(I,J)
      IF (LL.EQ.MM) IG(I,J)=NEW
300 CONTINUE
320 CONTINUE
340 CONTINUE

C
      MO=MAXMOD-BSURF
      DO 320 M=1,NSURF
      NEW=MO+M
      BUFX(NEW)=BUFX(M)
      YG(NEW)=BUFY(M)
      MM=NSURF(M)
      DO 340 I=1,INSMNX
      DO 340 J=1,INSMNY
      LL=IL(I,J)
      IF (LL.GE.-1) GO TO 340
      IF (IABS(LL).EQ.MM) GO TO 360
340 CONTINUE
      GO TO 380
360 IL(I,J)=NEW
380 DO 400 I=KELIN,MAXELE
      DO 400 J=1,4
      LL=IG(I,J)
      IF (LL.GE.0) GO TO 400
      IF (IABS(LL).EQ.MM) IG(I,J)=NEW
400 CONTINUE
370 CONTINUE
      RETURN
      END
      ENDS

FTM4
SERNAI(AEN1,0)
      PROGRAM MESTR(5,150)

C THIS S/P GENERATES A MESH OF RECTANGULAR FINITE ELEMENTS
C OUTSIDE THE HOST ONE AND DEFINE THE NUMBERS OF THE FOUR NODES
C OF EACH ELEMENT.

      COMMON/AEN1/XG(2540),YG(2540),IG(2540,4),IL(53,53),
      ICH(5,53),ICK(52,52)
      COMMON/CHBSM/INSHN,INSHN1,INSMNX,INSMNY,IHO,JHO,BX,BY
      COMMON/CMST1/MEST(10),NM1(10),NMJ(10),NOUTER(10),KS(10),
      IRE(10),KAR(10),KAMA(10),NMU(10),NMA(10)
      COMMON/CMST2/NEMAX,MAXMOD,MAXELE,NODOUT,NODIN,KELOUT,
      IREL,IN,MODINS
      COMMON/CONV/MCONV(10,4,4)
      COMMON/IDATA/LUN,LU,ITRACS
      COMMON/PSOLV/ISYH,IPDIS,IPBOT,RDEBY,CPOIS
      COMMON/BLR4/IBUF1(25),IBUF2(25),IBUF3(25),IBUF4(25)
      DIMENSION BMTX(10,2),BMTF(10,2),BUF(44),IBUF(44),NAME(3)
      DIMENSION JBUF(254),MCONV(4,40),MINNER(200)
      EQUIVALENCE (JBUF,BUF,IBUF),ICK,MINNER
      DATA NAME/2HME,2HMA,2H1 /

C
      WRITE(LUN,999)
      999 FORMAT('//20','5X','MESTR' STARTS,'5X,20',')
      NS=0
      I=NS-NESMAX-1
      XPT=XT/I/(INSMNX,INSMNY)
      YPT=Y/I/(INSMNX,INSMNY)
      BMTX(1,1)=XPT
      BMTX(1,2)=XPT
      BMTF(1,1)=YPT
      BMTF(1,2)=YPT
      NM=7
      IF (I*YPT+1,1,MM,1

```

```

DO 40 J=1,NMESJ
XB=XB1
Y=YB1
DO 60 J=2,J1
XB=XB+DX$FLOAT(288(J-1)*NMEST(J))
YB=YB+DY$FLOAT(288(J-1)*NMEST(J))
60 CONTINUE
NMSTX(J,1)=XB
NMSTX(J,2)=XB
NMSTY(J,1)=-YB
NMSTY(J,2)=YB
NI=MI(J)
NJ=MN(J)

C
IF(J1.LT.NESMAX) GO TO 75
IF(ISYN.EQ.1) GO TO 72
MOUTER(1)=I
MOUTER(2)=MI
MOUTER(3)=NI+NJ-1
MOUTER(4)=NI+2*NJ-2
MOUTER(5)=(NI+NJ)*2-4
DO 45 J=1,5
MOUTER(J+5)=MOUTER(J)+J-1
45 CONTINUE
GO TO 75
72 MOUTER(2)=I
MOUTER(3)=MJ
MOUTER(4)=NI+NJ-1
MOUTER(5)=MOUTER(4)

C
75 JZ=NMEST(J)
HX=DY$FLOAT(288(J1-1))
HY=DY$FLOAT(288(J1-1))
AS(J)=WB+1
DO 50 J=1,J2
XI=XB-HX$FLOAT(J-1)
YI=YB-HY$FLOAT(J-1)
NN=2
IF(ISYN.EQ.1) NN=1
NI=N1-NNB(J-1)
N2=N1-NNB(J-1)
IF(ISYN.EQ.1) N1=N1+1
IF(ISYN.EQ.1) GO TO 85
DO 80 N=1,N1
NS=NB+1
XS(NS)=XI+NX$FLOAT(N-1)
YS(NS)=-YI
80 CONTINUE
85 DO 90 N=1,N2
NS=NB+1
XS(NS)=XI
YS(NS)=-YI+$FLOAT(ISYN/3)+NY$FLOAT(N-1)
90 CONTINUE
DO 100 N=1,N1
NS=NB+1
XS(NS)=XI-HX$FLOAT(N-1)
YS(NS)=YI
100 CONTINUE
IF(ISYN.EQ.1) GO TO 50
DO 110 N=1,N2
NS=NB+1
XS(NS)=-XI
YS(NS)=YI-HY$FLOAT(N-1)
110 CONTINUE
120 CONTINUE
KE(J)=NB
KAM(J)=KE(J)-KB(J)+1
40 CONTINUE

C
WRITE(LUN,125) (N,XO(N),YO(N),N=1,NAXNO)
C 125 FORMAT(7(I5,2F6.2))
WRITE(LUN,127) ((KS(I),KE(I),KAM(I),I=1,NESMAX)
127 FORMAT('8=IBX'//KS KE KAM'/14X,'NEST 0 ='//I2,5X,3IS))
WRITE(LUN,128) (MOUTER(I),I=1,5)
128 FORMAT('88 MOUTER/SX,SIS)

C
N=0
DO 600 I=1,10
DO 600 J=1,2
N=N+1
BUF(N)=BMSTX(I,J)
BUF(N+32)=BMSTY(I,J)
600 CONTINUE
CALL EXEC(2,LU,BUF,128,ITRACS+4,64)
CALL EXEC(1,LU,BUF,64,ITRACS+2,55)
DO 610 I=1,10
IBUF(I+30)=MOUTER(I)
610 CONTINUE
CALL EXEC(2,LU,BUF,64,ITRACS+2,55)
DO 620 I=1,NESMAX
IBUF(I)=KS(I)
IBUF(I+10)=KE(I)
IBUF(I+20)=KAM(I)
620 CONTINUE
CALL EXEC(2,LU,BUF,64,ITRACS+4,64)

C
N=0
NI=0
IF(ISYN.EQ.1) GO TO 142
DO 140 I=1,INSMIX-2
N=N+1
MINNER(N)=IL(I+1)
IF(IL.EQ.INSMIX) GO TO 140
NI=N1+1
NCONA(1,N1)=IL(I+1,1)
140 CONTINUE
GO TO 145
142 N=N+1
MINNER(N)=IL(INSMIX,1)
145 NI=0
DO 150 J=3,INSMIX-2
N=N+1
NI=N1+1
MINNER(N)=IL(INSMIX,J)
NCONA(2,N1)=IL(INSMIX,J-1)
150 CONTINUE
NI=0
DO 160 I=3,INSMIX-2
N=N+1
NI=N1+1
I1=INSMIX+1-I
MINNER(N)=IL(I1,INSMIX)
NCONA(3,N1)=IL(I1,I1,INSMIX)
160 CONTINUE
IF(ISYN.EQ.1) GO TO 172
JI=INSMIX-2
NI=0
DO 170 J=3,JI-2
N=N+1
NI=N1+1
I1=INSMIX+1-I

```

```

MINN=MAX(1,1-IL*(1.2))
MCN=MAX(4,M1*(1+1.2*(1-IL)))
110 CONTINUE
M1=M1+1
MCN=MAX(4,M1*(1+1.2*(1-IL)))
112 MINN=MAX(1,MINN*(1-1/2*(JMSH+1)))
WRITE(LUN,*)M1,MINN,MCN
VMS=JMSH*(1-1.8*MINN*(2015))
WRITE(LUN,*)M1,MCN,(1+1.2*(1-MINN)*(1-1.4*
FMSH*(1-1.8*MCN*(2015)))

```

```

N=0
MS=1
IF (ISYN.EQ.1) MS=0
DO 200 I=1,INES
  I1=MS*2*I-1
  N1=NN1(I1)
  N1=NNJ(I1)
  IF (ISYN.EQ.1) GO TO 240
  N=N+1
  IG(N,1)=MS
  IG(N,2)=MS+1
  IG(N,3)=MS*(N1+NJ)*2
  IG(N,4)=IG(N,3)-1
240  J1=NNST(I1)
  DO 250 J=1,J1
    NN=2
    IF (ISYN.EQ.1) NN=1
    N1=N1-NN*J
    M2=M1-NN*J
    IF (I.EQ.INES.AND.J.EQ.J1) GO TO 340
    IF (J.EQ.J1) GO TO 270
    JUMP=1
    GO TO 280
270  JUMP=2
280  IF (J.EQ.J1) GO TO 290

```

```

K=K+1
IF (ISYM.EQ.1) GO TO 292
IG(K,1)=IG(K-1,1)+1
IG(K,2)=IG(K-1,1)+1
IG(K,3)=IG(K-1,3)+1
IG(K,4)=IG(K-1,3)+1
GO TO 290
292 IG(K,1)=IG(K-1,1)+1
IG(K,2)=IG(K-1,4)+1
IG(K,3)=IG(K-2)+1
IG(K,4)=IG(K-1)+JUMP
IF (J.NE.J1) GO TO 307
MCONM(I1,2,1)=K
MCONM(I1,2,3)=IG(K,1)+1
GO TO 307
290 IF (ISYM.EQ.1) GO TO 306
IF (J.NE.J1) GO TO 295
MCONM(I1,1,1)=K+1
MCONM(I1,1,3)=IG(K,3)+1

```

```

295 DO 300 M=1,M1
      K=M+1
      IG(K,1)=IG(K-1,1)+1
      IG(K,2)=IG(K-1,2)+1
      IG(K,3)=IG(K-1,3)+JUMP
      IG(K,4)=IG(K,3)-JUMP
300 CONTINUE
      IF(J,NE,J1) GO TO 305
      NCCMH(I1,1,2)=K
      NCCMH(I1,1,4)=IG(K,4)+1
305 K=M+1
      IG(K,1)=IG(K-1,1)+1
      IG(K,2)=IG(K-1,1)+1
      IG(K,3)=IG(K,2)+1
      IG(K,4)=IG(K-1,3)
      IF(J,NE,J1) GO TO 308
      NCCMH(I1,2,1)=M+1
      NCCMH(I1,2,3)=IG(K,4)+1
      GO TO 308

```

```

306 K=K+1
    IG(K,1)=MS+2*MI+NJ
    IG(K,2)=MS+1
    IG(K,3)=MS+2
    IG(K,4)=IG(K,1)+JUMP
    IF(J,ME,J1) GO TO 307
    MCONN(I1,2,1)=K
    MCONN(I1,2,3)=IG(K,1)+1
307 N2=N2+1

```

```

308 DO 310 N=1,M2
      K=N
      I0(N,1)=I0(N-1,4)
      I0(N,2)=I0(K-1,2)+1
      I0(N,3)=I0(K-1,3)+1
      I0(N,4)=I0(K-1,4)+JUMP
310 CONTINUE
      IF(J,NE,J1) GO TO 315
      NCONH(1,2,4)=K
      NCONH(1,2,4)=I0(K,1)+1
315 N=N+1
      I0(K,1)=I0(K-1,4)
      I0(K,2)=I0(K-1,2)+1
      I0(K,3)=I0(K-1,3)+1
      I0(K,4)=I0(K-1,4)+1
      IF(J,NE,J1) GO TO 310
      NCONH(1,1,3)=N+1
      NCONH(1,1,3)=I0(K,1)+1

```

```

310 GO 320 N=1,M1
    A=K*1
    IGR(1)=IGR(1,1)+JUMP
    IGR(2)=IGR(1,1)+JUMP
    IGR(3)=IGR(1,1)+1
    IGR(4)=IGR(3,1)
320 CONTINUE
    IF (J,M1,J1) GO TO 325
    MCONN(1,3,2)=A
    MCONN(1,3,4)=IGR(2,1)
325 IF (ISYR,EQ,1) GO TO 250
    A=K*1
    IGR(1)=IGR(1,4)+2
    IGR(2)=IGR(1,2)+JUMP
    IGR(3)=IGR(1,3)+1
    IGR(4)=IGR(3,1)
    IF (J,M1,J1) GO TO 320
    MCONN(1,4,1)=K*1
    MCONN(1,4,2)=IGR(2,1)

```

```

120 M2=M2-1
    DO 330 M=1,M2
        N=N+1
        IGA(1,1)=IGA(1,1)+1
        IGA(1,2)=IGA(1,2)+N*N
        IGA(1,3)=IGA(1,3)
        IGA(1,4)=IGA(1,4)
    
```

```

001 CONTINUE
      I=K+1; IG(K-1,I)+1
      IG(K,2)=IG(K-1,I)
      IG(K,3)=IG(K-1,2)
      IG(K,4)=IG(K-1,4)+1
      IF (J.EQ.J1) GO TO 250
      NCONM(I,I,4)=2*K
      NCONM(I,I,4)=IG(K-3,I)
250 CONTINUE
      MS=IG(K,2)
      IF (ISTAT.EQ.1) MS=IG(K,4)
200 CONTINUE

340 M=0
      DO 630 I=1,4
        DO 630 J=1,48
          JBUFF(I)=NCONM(I,J)
630 CONTINUE
      CALL EXEC2(LU,BUFF,256,ITRACS+54)

```

```

IF (ISYM.EQ.1) GO TO 352
MS=IG(K+2)
K=K+1
IG(K+1)=MS
IG(K+2)=MS+1
IG(K+3)=NIMMER(1)
IG(K+4)=IG(K+3)+1
NCONM(11,1,1)=K+1
DO 350 N=1,M1
K=K+1
IG(K+1)=IG(K+1-2)
IG(K+2)=IG(K+1-2)
IG(K+3)=NIMMER(M+1)
IG(K+4)=IG(K+1-3)
350 CONTINUE
NCONM(11,1,2)=K
K=K+1
IG(K+1)=IG(K+1-2)
IG(K+2)=IG(K+1-2)
IG(K+3)=IG(K+2)+1
IG(K+4)=IG(K+3)+1
NCONM(11,2,1)=K+1

```

```

352 M4=M1+1
    IF (ISYN.EQ.4) GO TO 355
    K=K+1
    IG(K,1)=WINNER(1)
    IG(K,2)=IG(K-1,4)+1
    IG(K,3)=IG(K,2)+1
    IG(K,4)=WINNER(2)
    CONNM=(1,2,1)=R
    M4=2
    M2=M2-1
355 DO 360 M=1,M2
    K=K+1
    M3=M4+M
    IG(K,1)=IG(K-1,4)
    IG(K,2)=IG(K-1,3)
    IG(K,3)=IG(K,2)+1
    IG(K,4)=WINNER(M3)

```

```

360 CONTINUE
NCONM(I1,2,2)=K
K=K+1
IG(K,1)=IG(K-1,4)
IG(K,2)=IG(K-1,3)
IG(K,3)=IG(K-2,4)
IG(K,4)=IG(K-3,4)
NCONM(I1,3,1)=K+1

```

```

M4=M1+M2+1
IF(18YM.EQ.1) M4=M2+2
DO 370 N=1,M1
K=K+1
M3=M4+M
IG(K,1)=MINNER(M3)
IG(K,2)=IG(K-1,4)
IG(K,3)=IG(K-1,4)
IG(K,4)=IG(K-1,4)

```

```

370 CONTINUE
      NCONV(I1,3,2)=K
      IF(ISHM.EQ.1) GO TO 382
      K=K+1
      IO(K,1)=IO(K-1,4)+2
      IO(K,2)=IO(K-1,1)
      IO(K,3)=IO(K-1,4)
      IO(A,4)=IO(K,3)+1
      NCONV(I1,4,1)=K+1

```

```

M4=M102+M2+1
M2=M2-1
DO 300 M=1,M2
K=K+1
M3=M4+M
IG(K,1)=IG(K-1,1)+1
IG(K,2)=NIMMER(M3)
IG(K,3)=IG(K-1,2)
IG(K,4)=IG(K-1,1)
300 CONTINUE
N=N+1
IG(K,1)=IG(K-1,1)+1
IG(K,2)=NIMMER(1)
IG(K,3)=IG(K-1,2)
IG(K,4)=IG(K-1,1)
MCNMM(1,4,2)=N

```

```

382 KLEOUT=K
      WRITE(LUN,385) ((I8(R,M),M=1,4),R=1,KLEOUT)
385 FORMAT(2015)
      WRITE(LUN,387) ((I,J,(NCONV(I,J,R),R=1,4),J=1,4),I=2,NESMAX)
387 FORMAT('00 NCONV'/2X,' I J A=1 A=2 A=3 A=4'/
          A(215,4))

```

```

      KI=KEOUT+1
      WRITE(LUN,395) ((IG(K,M),M=1,4),K=KI,MAXELE)
395  FORMAT(20I5)
      RETURN

```

```

M=0
DO 440 J=1,10
DO 440 J=1,4
DO 440 A=1,4
M=M+1
      JBUF(M)=NCOWN(J,J,K)
440 CONTINUE
      CALL EXECIO(4U,JBUF,256,1TRACS+4,58

```

```
CALL EXEC(B-NAME)

STOP
END
ENDS
```

```

BT HNA4
PROGRAM MENAI(5,150)

THIS S F WRITES LMA PARAMETERS ON DISCS.

(CUNNAM AFMAI=IG,25601,IG,25601+IG,2560,4+IL,53,53)+
ICMAY,5,53,ICMAY,5,53)
CUNNAM CUNSH ICMNH, JCMNH, ICMNMX, JCMNMX, IMO, JMO, DX, DY
COMMON IOBAT LUM=0,ITRACS
DIMENSION(LU,IBUF1,256,IBUF2,256),BUF1(128),BUF2(128)
EQUivalence (IBUF1,BUF1),(IBUF2,BUF2)

WRITE(LUN,999)
999 FORMAT('01',5X,'MENAI' STARTS '+5X,20')
NSTOP=3072-128
ISTART=0
ISECT=0
DO 100 M=1,NSTOP
DO 110 I=1,128
II=ISTART+I
BUF1(I)=A(G,II)
BUF2(I)=A(G,II)
110 CONTINUE
CALL EXEC(2,LU,BUF1,256,ITRACS+8,ISECT)
CALL EXEC(3,LU,BUF2,256,ITRACS+9,ISECT)
ISECT=ISECT+4
ISTART=ISTART+128
100 CONTINUE

NSTOP=2560/256
ISECT=0
DO 200 J=1,2
M=J*2
DO 210 N=1,NSTOP
DO 220 I=1,I,256
II=ISTART+I
IBUF1(I)=IG(I,F,J)
IBUF2(I)=IG(I,F,M)
220 CONTINUE
CALL EXEC(2,LU,IBUF1,256,ITRACS+10,ISECT)
CALL EXEC(2,LU,IBUF2,256,ITRACS+11,ISECT)
ISECT=ISECT+4
ISTART=ISTART+256
210 CONTINUE
200 CONTINUE

DO 250 I=1,INSMNX
IBUF1(I)=IL(I,1)
IBUF1(I+64)=IL(I,JMSNMX)
250 CONTINUE
DO 260 J=1,JMSNMX
IBUF1(J+128)=IL(1,J)
IBUF1(J+192)=IL(1,INSMNX,J)
260 CONTINUE
CALL EXEC(2,LU,IBUF1,256,ITRACS+2,81)
IPRO=INSMNX*JMSNMX
II=0
M=0
ISECT=0
DO 300 I=1,INSMNX
DO 310 J=1,JMSNMX
II=II+1
M=M+1
IBUF1(M)=IL(I,J)
IBUF2(M)=ICM(I,J)
IF((II.EQ.IPRO) GO TO 320
IF(N.LT.256) GO TO 310
320 CALL EXEC(2,LU,IBUF1,256,ITRACS+12,ISECT)
CALL EXEC(2,LU,IBUF2,256,ITRACS+13,ISECT)
ISECT=ISECT+4
M=0
310 CONTINUE
300 CONTINUE

WRITE(LUN,781)
781 FORMAT('///')
STOP
END
ENDB

```

[illegible][illegible]

```
C CONTINUE,X=J,I,K+L-1 DO TO .001  
190 CONTINUE  
GO TO 710  
C MTYPE=MCONV(1)  
CALL FELMT  
GO TO 170  
  
710 MTYPE=O  
CALL FELMT  
GO TO 170  
  
C  
220 NMD=I  
IGA(I)=IG1  
IGA(J)=IG1  
IGA(K)=IG3  
MA=(XG(IG1)+YGG(IG3)+(XG(IG1)*YG(IG2)+  
YGA(IG3)*YG(IG1)))/(XG(IG2)+YG(IG1)+XG(IG3))+  
YG(IG2)+YAG(IG1)+YG(IG3))  
K1=YG(IG1)-YA(IG3)  
B=YU(IG1)-YU(IG1)  
B3=YG(IG1)-YG(IG2)  
A=XU(IG1)-XU(IG2)  
A2=XG(IG1)-XG(IG3)  
A3=XG(IG2)-YG(IG1)  
C1=HABP*(Z-.08)FOIS  
C2=HAB2*O  
DENOM=C2  
ELMAT(1,1)=(B*BIB2+A*IIB2-2,.08C1)  
ELMAT(1,2)=(B2BB1+A2BA1-C1)  
ELMAT(1,3)=(B3BB1+A3BA1-C1)  
ELMAT(2,2)=(B2+B2*A2BB2-2,.08C1)  
ELMAT(2,3)=(B3BB2+A3BA2-C1)  
ELMAT(3,3)=(B3BB2+A3BB2-2,.08C1)  
  
C  
230 CALL FILE  
170 CONTINUE  
  
C  
235 CONTINUE  
WRITE(LUN,973) KK  
973 FORMAT('      KK=',I2)  
IF(KK.EQ.1) GO TO 160  
DO 240 J=1,4  
K1=NCONM(KK,J,1)  
K2=NCONM(KK,J,2)  
N=J+2-J/384  
IZ(KK,N), K3=NCONM(KK,J,3)  
N=O  
DO 250 K=R1,K2  
N=N+1  
IF(KK.NE.2) IGG(S)=K3+(N-1)/2  
IF(KK.EQ.2) IGG(S)=NCONM(A,J,M)  
NCTYP=-1  
CALL FELMT  
  
250 CONTINUE  
IF(J,EQ.4) GO TO 240  
K=K+1  
NCTYP=O  
CALL FELMT  
240 CONTINUE  
160 CONTINUE  
  
C  
IA(NUAR+1)=JPMAX+1  
  
DO 270 M=1,NUAR  
II=IA(M)  
I2=IA(N+1)-1  
NO=MODINS*M-1  
DO 280 I=I1,I2  
I2=I  
IF((KA(I).EQ.NO) GO TO 290  
280 CONTINUE  
WRITE(LUN,980)  
980 FORMAT('ERROR IS DETECTED')  
STOP  
290 IF((II.EQ.I1) GO TO 270  
NN=JA(II)  
AA=AN(II)  
I3=I1+1  
DO 300 E=I3,I1  
IO=I3-II-1  
JA(IO)=JA(IO-1)  
AN(IO)=AN(IO-1)  
300 CONTINUE  
JA(II)=NN  
AN(II)=A  
270 CONTINUE  
  
C  
C=====APPLY THE BOUNDARY CONDITIONS  
C IBPOT IS THE FLAG INDICATING THE TYPE OF BOUNDARY CONDITIONS  
C IMPOSED ON THE OUTERMOST EDGES.  
C IBPOT=1: PHI=0.O  
C IBPOT=2: PHI=h/R  
C IBPOT=3: PHI=hEXP(-R/RDEBY)  
C IBPOT=4: PHI=hEXP(-R/RDEBY)/R  
  
C  
WRITE(LUN,546) R,(AM(IA(I)),I=1,64)  
333 IF(IBPOT.EQ.1) GO TO 510  
NMDB=O  
DEBA=RDEBY*.2  
NND=4  
DENON=1.O  
DO 330 M=1,4  
DO 330 N=1,2  
K1=NOUTER(M)  
K2=NINNER(M+1)  
IF(R.NE.4) K2=K2-1  
WRITE(LUN,547) A,R,K1,K2  
C 547 FORMAT('N= ',I3,'X','K1=' ,I3,'X','K2=' ,I3)  
L=O  
DO 340 K=R1,K2  
L=L+1  
NZ=N  
DO 350 I=1,4  
IGA(I)=IG(O,K,I)  
DO 350 J=1,4  
ELMAT(I,J)=O.O  
350 CONTINUE  
IG1=IGA(1)  
IG2=IGA(2)  
IG3=IGA(3)  
IG4=IGA(4)  
MX=XU(IG2)-XU(IG1)  
MY=YU(IG3)-YU(IG2)
```

```

000 R1=YG(IG)
R1=NT
R3=ABS(XG(IG))
GO TO 410
100 R1=XG(IG)
R1=NZ
R3=ABS(YG(IG))
GO TO 410
400 R1=YG(IG)
R1=NT
R3=ABS(XG(IG))
410 F1=B2*B2
IF (IMPT.EQ.1) GO TO 430
D1=(AMT-B1*B1)/(B1*B1-1)*B2*(1+B2)
D2=(MGT-B1*B1)/(B1*B1-1)*B2*(1+B2)
F2=((1+B2)/B2+3)*B2-D1*D2*((1+B2)/B2)
F3=((1+B2)/B2+3)*B2-D1*D2*((1+B2)/B2)
IF (IMPT.EQ.2) GO TO 440
IF (IMPT.EQ.3) GO TO 430
430 P1=0.0
P2=0.0
P3=0.0
84=SORT(1,(J-1)*(B1+B2)/B3)+B2
85=SORT(1,(J-1)*(B1+B2)/B3)
B6=B2/(B4+B5)*(B2+2.0*B1/B3)
B7=B2*B3*B6
D3=MGT-1.0*(B2+B6)/(B1+B5*B3)
P1=P1+(7-(3.0*B1+4.0*B2)*B6)/(2.0*(B1-B2)+B2-33*B2*B3)
I=DEBA
P2=P2+(3.0*B1+2.0*B2)*B6-B7/(2.0*B1*(B1-B2)-33*B2*B3)
P3=P3+(7-(3.0*B1+B6)/(2.0*B1+B2-33*B2*B3))/DEBA
440 P1=P1/E1
P2=P2/E1
P3=P3/E1
N1=NZ
N2=NZ+1-NZ/404
IF (NZ.LE.2) GO TO 450
N1=NZ
N2=NZ
450 ELMAT(N1,M1)=ELMAT(N1,M1)+P1
ELMAT(N1,N2)=ELMAT(N1,N2)+P2
ELMAT(N2,M1)=ELMAT(N2,M1)+P3
IF (NZ.EQ.3) ELMAT(3,4)=ELMAT(4,3)
WRITE(LUN,98B) I,P1,P2,P3
98B FORMAT('L=',I3,X,'P1=',IPE12.5,X,'P2=',IPE12.5,X,'P3=',IPE12.5)
IF (NF.EQ.0) GO TO 500
NFL=0
IF (K.EQ.K1) NZ=(NZ+1)+(5-NZ)/404
IF (K.EQ.K2) NZ=(NZ+1)-NZ/404
GO TO 360
500 CONTINUE
IF (K.NE.K1) BDIA(M,L)=BDIA(M,L)+ELMAT(N,M)
IF (K.NE.K1) BDIA(M,L)=ELMAT(N,M)
IF (K.NE.K2) BDIA(M,L)=BDIA(M,L+1)+ELMAT(N+1,M+1)
IF (K.NE.K2) BDIA(M,L+1)=ELMAT(N+1,M+1)
DOFF(M,L)=ELMAT(N,M+1)
WRITE(LUN,507) K,I,(IGA(I),I=1,4)
507 FORMAT('SX='X,'I3,X,'IGA'4I6)
WRITE(LUN,509) ((ELMAT(I,J),J=1,4),I=1,4)
509 FORMAT(IPAE13.5)
CALL FILE
WRITE(LUN,56B) K,(AN(IA(I)),I=1,64)
56B FORMAT('BK'=I3/'IP1OE13.5')
340 CONTINUE
330 CONTINUE
WRITE(LUN,732)
732 FORMAT('88 BDIA')
WRITE(LUN,733) ((BDIA(M,L),L=1,20),M=1,2)
733 FORMAT(IP1OE13.5)
WRITE(LUN,777)
777 FORMAT('88 DOFF')
WRITE(LUN,734) ((DOFF(M,L),L=1,20),M=1,2)
734 FORMAT(IP1OE13.5)
DO 1000 I=1,NNUM
I1=IA(I)
I2=IA(I+1)-1
WRITE(LUN,1001) I,(JA(J),J=1,12)
1001 FORMAT(I3,X,'I29')
WRITE(LUN,1002) (AN(J),J=1,12)
1002 FORMAT(6X,I2F9.4)
1000 CONTINUE
CALL EXEC(2,LU,BDIA,I2B,ITRACS+6,B1)
CALL EXEC(2,LU,DOFF,I2B,ITRACS+6,B3)
GO TO 800
510 NOMB=ROUTER(S)
NA=NOMB+1
DO 600 N=NA,NOMBS
IP1=IA(N)
IP2=IA(N+1)-1
DO 610 I=IP1,IP2
JP=JA(I)
IF (JP.GT.NOMB) GO TO 610
JA(I)=-1
LAST=N
410 CONTINUE
600 CONTINUE
NC=1
IA(I)=1
NUM=0
DO 650 N=NA,LAST
IP1=IA(N)
IP2=IA(N+1)-1
DO 660 I=IP1,IP2
JP=JA(I)
IF (JP.EQ.-1) GO TO 660
NUM=NUM+1
JA(NUM)=JP
AN(NUM)=AN(I)
660 CONTINUE
NC=NC+1
IA(NC)=NUM+1
650 CONTINUE
NB=IP2+1
NB=LAST+1
NSUB=IA(NB)-IA(NC)
NB=NB+1
DO 700 N=NB,NOMBS
NC=NC+1
IA(NC)=IA(N)-NSUB
700 CONTINUE
NUAB=NC
DO 10 I=N,NB,NMAX
I=N-NUAB
AN(I)=AN(N)
IA(I)=IA(N)

```

```

CONTINUE
      IF (M.EQ.1) N=MAX
      GO TO 100
    10 CONTINUE
      CALL ELEM(1,N,M)
      STOP
    END
  ENDA(MA2,0)
SUBROUTINE FELMT
COMMON/NEPA2/AH(4096),JA(4096),IA(512),XG(2560),YG(2560),
1IG(2560*4),YBC(512),JBC(512),IBC(512),MCOMU(128),
2NCOMU(128),NCONH(128),NCONK(256)
COMMON/COMM/MCOMU(128),NCOMA(4*48),NCONH(10*4),
COMMON/ELEL/SXA(10),SYA(10),SNA(10),SKB(10),SYB(10),
ISNR(10),SYC(12),SYC(12),SMC(12),SKC(10),SYD(10),
3SMC(10),SKC(15),SYC(15),SMC(15),SKB(10),SYD(10),
4SKB(10),SYE(15),SYE(15),SME(15),SKE(12),SYE(12),
4SNC(12),SAF(36),SYF(36),SRF(36)
COMMON/IDAT/LUM,LU,ITRACS
COMMON/BLK1/ELMAT(9*9)
COMMON/BLK4/BUF(125),IGA(25),IGG(25)
COMMON/BLK6/AI,AZ,A3,BENOR,AAL,A2
COMMON/BLK7/NOMB,MUAR,JPMAX,MPC,K,ID6,ID7,ID8,ID9,ID10,
1ID11,ID12
COMMON/BLAB/NMB,NZ,NZ1,NZ2,NZ3,NCTYP
DO 100 I=1,4
  IGG(I)=IG(A,I)
100 CONTINUE
  IF(NCTYP.EQ.0) GO TO 470
  IF(NCTYP.GE.1) GO TO 110
  NTYP=1
  GO TO 130
110 IF(NCTYP.LE.4) NTYP=1
  IF(NCTYP.GE.5.AND.NCTYP.LE.10) NTYP=2
  IF(NCTYP.GE.11.AND.NCTYP.LE.14) NTYP=3
  IF(NCTYP.GE.15) NTYP=4
  NN=NCONH(N)
  DO 170 J=1,NTYP
    I1=NN+J-1
    IGG(I+J)=NCONH(I1)
120 CONTINUE
    IF(NCTYP.EQ.9.OR.NCTYP.EQ.10) GO TO 300
    IF(NTYP.EQ.4) GO TO 410
    NZ=NCTYP-(NTYP-2)*8(NTYP-1)
130 NZ1=NZ+1-NZ/488
    NZ2=NZ+2-NZ/384
    NZ3=NZ+3-NZ/488
    IF(NZ.EQ.2.OR.NZ.EQ.4) GO TO 140
    AA1=A1
    AA2=A2
    GO TO 150
140 AA1=A2
    AA2=A1
    GO TO (160,190,350,300,410,470),NTYP
150 NMD=4
160 DENOM=144.0
    DO 170 M=1,2
      N=0
      DO 180 I=1,4
        DO 180 J=1,4
          N=N+1
          ELMAT(I,J)=(AA1$XBI(N)+AA2$BYB(N)+6.0-A3$SHB(N))
180 CONTINUE
          IF(M.EQ.1) NZ4=NZ
          IF(M.EQ.2) NZ4=NZ1
          IGA(1)=IGG(NZ4)
          IGA(2)=IGG(NZ)
          IGA(3)=IGG(NZ2)
          IGA(4)=IGG(NZ3)
          IGA(5)=IGG(NZ1)
          IGA(6)=IGG(NZ3)
          CALL FILE
170 CONTINUE
          RETURN
C
190 DENOM=576.0
    NZ4=5
    IF(NZ.EQ.2.OR.NZ.EQ.3) NZ4=6
    DO 200 M=1,4
      N=0
      GO TO (210,230,250,260),M
C
210 DO 220 I=1,4
      DO 220 J=1,4
        N=N+1
        ELMAT(I,J)=(AA1$XCI(N)+AA2$BYC(N))+12.0-A3$SHC(N)
220 CONTINUE
        NMD=4
        IGA(1)=IGG(NZ)
        IGA(2)=IGG(NZ1)
        IGA(3)=IGG(NZ2)
        IGA(4)=IGG(NZ3)
        IGA(5)=IGG(S)
        IGA(6)=IGG(6)
        GO TO 290
230 DO 240 I=1,4
      DO 240 J=1,4
        N=N+1
        ELMAT(I,J)=(AA1$XC2(N)+AA2$BYC2(N))+12.0-A3$SHC2(N)
240 CONTINUE
        NMD=4
        IGA(1)=IGG(NZ)
        IGA(2)=IGG(S)
        IGA(3)=IGG(NZ2)
        IGA(4)=IGG(6)
        GO TO 290
C
250 AA1=A1
    AA2=A2
    GO TO 270
260 AA1=A2
    AA2=A1
270 DO 280 I=1,5
      DO 280 J=1,5
        N=N+1
        ELMAT(I,J)=(AA1$XCI(N)+AA2$BYC(N))+12.0-A3$SHC(N)
280 CONTINUE
        NMD=5
        IGA(1)=IGG(NZ)
        IGA(2)=IGG(NZ2)
        IF(M.EQ.1) NZ5=NZ
        IF(M.EQ.2) NZ5=NZ1
        IGA(4)=IGG(NZ5)
        IGA(10)=IGG(11) NZ4
        IGA(14)=IGG(NZ4)
        CALL FILE
290 DO 300 I=1,4
      DO 300 J=1,4
        N=N+1
        ELMAT(I,J)=ELMAT(I,J)/DENOM
        IF(M.EQ.M) GO TO 30
        ELMAT(I,J)=ELMAT(I,J)
30 CONTINUE
C
310 DO 320 M=1,NMD
      MO=IGA(M)
      IF(MO.LT.MOD(NS,MO).GT.MOD(S) GO TO 100
      MOD=MAT-MINTMC

```

1 104
 2 104
 3 104

```

C THIS S/P WRITES THE VARIABLES ON DISK.
      COMMON/AFACZ/ARI(4096), JRI(4096), IRI(512), JIRI(512), MCONTR(256)
      IIG(2560+4), ITR(512+4), IBU(512), BCU(512), MCONM(128)
      NCONDM(128), NCONMM(128), MCONTR(256)
      COMMON/IDDATA/LUN/LU,ITRACKS
      COMMON/PSDQ/ISTN,IPDIS,IBPDT,NDBY,LPOIS
      COMMON/ALTA7/NOMB,NVAR,JPMAX,NBC,IJS,IDB,IDI,IMDI,IDO,
      IDUI,IDI2
      DIMENSION BUFR(128),IBUF(1:8),IBUF2(128),JBUF(4),NAME(1)
      DIMENSION AYO(256)
      EQUIVALENCE (IBUF2,JBUF),(XG,AYO)
      DATA NAME/'NBC','NMR','HP' /

C
      WRITE(LUN,999)
999 FORMAT('//20 ','5X','MEAN2' STARS,'5X','20 ','')
      CALL EXEC(2,LU,JBUF,44,ITRACS+2,55)
      JBUFF(22)=NVAR
      JBUFF(23)=JPMAX
      JBUFF(24)=NBC
      JBUFF(25)=NOMB
      CALL EXEC(2,LU,JBUF,44,ITRACS+2,55)
      WRITE(LUN,971) NVAR,JPMAX,NBC,NOMB
971 FORMAT('88 NVAR='//14,5X,'JPMAX='//5,5X,'NBC='//14,5X,
      'I NOMB='//14)

C
      ISECT=0
      ISTART=0
      ITRACK=ITRAC-30
      NSTOP=JPMAX/128+1
      DO 150 N=1,NSTOP
        DO 140 I=1,128
          IBUF(I)=JA(ISTART+I)
140 CONTINUE
          CALL EXEC(2,LU,IBUF,128,ITRACK,ISECT)
          ISECT=ISECT+2
          ISTART=ISTART+128
          IF(NDB(N+48),NE.O) GO TO 150
          ITRACK=ITRACK+1
          ISECT=0
150 CONTINUE

C
      ISECT=0
      ISTART=0
      ITRACK=ITRACS+14
      DO 170 N=1,NSTOP
        DO 160 I=1,128
          BUFR(I)=AN(ISTART+I)
160 CONTINUE
          CALL EXEC(2,LU,BUFR,256,ITRACK,ISECT)
          ISECT=ISECT+4
          ISTART=ISTART+128
          IF(NDB(N+24),NE.O) GO TO 170
          ITRACK=ITRACK+1
          ISECT=0
170 CONTINUE

C
      NSTOP=(NVAR+1)/128+1
      ISTART=0
      ISECT=0
      DO 200 N=1,NSTOP
        DO 210 I=1,128
          IBUF1(I)=JA(ISTART+I)
210 CONTINUE
          CALL EXEC(2,LU,IBUF1,128,ITRACS+34,ISECT)
          ISECT=ISECT+2
          ISTART=ISTART+128
200 CONTINUE

C
      NSTOP=NBC/128+1
      ISECT=0
      ISTART=0
      ITRACK=ITRACS+35
      DO 250 N=1,NSTOP
        DO 240 I=1,128
          IBUF1(I)=IBC(ISTART+I)
          IBUF2(I)=JBC(ISTART+I)
          BUFR(I)=IDC(ISTART+I)
240 CONTINUE
          CALL EXEC(2,LU,IBUF1,128,ITRACK,ISECT)
          CALL EXEC(2,LU,IBUF2,128,ITRACK,ISECT+24)
          CALL EXEC(2,LU,BUFR,256,ITRACK,ISECT+48)
          ISECT=ISECT+2
          ISTART=ISTART+128
250 CONTINUE

C
      WRITE(LUN,972) (IBC(I),I=1,NBC)
972 FORMAT('/IBC'//25IS)
      WRITE(LUN,974) (JBC(I),I=1,NBC)
974 FORMAT('/JBC'//25IS)

C
      NSTOP=NVAR/128+1
      ISTART=0
      ISECT=0
      DO 350 N=1,NSTOP
        DO 340 I=1,128
          BUFR(I)=AYO(ISTART+I)
340 CONTINUE
          CALL EXEC(2,LU,BUFR,256,ITRACS+36,ISECT)
          ISECT=ISECT+4
          ISTART=ISTART+128
350 CONTINUE
          IF(IPDIS.EQ.0) STOP 0001
          IF(IPDIS.LT.0) CALL EXEC(S,NAME)
      STOP 0002
      END
      ENDP

```


[illegible]

[illegible]

```

10  DO 300 J=1,4
11  I=MAX(K-1,1)-N+1
12  I=MAX(K-1,1)-N+1
13  CONTINUE
14  DO 200 K=1,1000000
15  IF (MOD(K,1000000) .EQ. 1000000)
16  FOR THE INTERIOR SPACE OF GRID.
17  DO 250 J=1,4
18  AMAX=I*MAX(J)
19  N=N+1
20  IF (J.NE.1) GO TO 250
21  K=START+1
22  SUM=A(12)+8*(POT(L+1)+POT(L-1)+POT(N+1)+POT(N-1))+
23  1A(13)+8*(POT(L)+POT(N)+POT(N+1)+POT(N-1))
24  GO TO 270
250 K=270
26  L=L+1
27  SUM=A(12)+8*(POT(L+1)+POT(L-1)+POT(N)+POT(L-3))+
28  1A(13)+8*(POT(L)+POT(L-2)+POT(N+1)+POT(N-1))
29  RES=SUM-POT(N)
30  POT(N)=POT(N)+ONEGA*RES
31  EPS=EPS+ABS(RES)
32  N=N+1
33  L=L+1
34  SUM=A(12)+8*(POT(L+1)+POT(L-1)+POT(N+1)+POT(N-2))+
35  1A(13)+8*(POT(L)+POT(N)+POT(N+1)+POT(N-1))
36  RES=SUM-POT(N)
37  POT(N)=POT(N)+ONEGA*RES
38  EPS=EPS+ABS(RES)
39  DO 280 K=A*START+AMAX
40  N=N+1
41  N=N+1
42  L=L+1
43  NS=N+1
44  IF (J.EQ.4.AND.(K.EQ.AMAX)) NS=N+2
45  SUM=A(12)+8*(POT(L+1)+POT(L-1)+POT(NS)+POT(N-1))+
46  1A(13)+8*(POT(L)+POT(N)+POT(N+1)+POT(N-1))
47  RES=SUM-POT(N)
48  POT(N)=POT(N)+ONEGA*RES
49  EPS=EPS+ABS(RES)
50  CONTINUE
51  N=N+1
52  N=N+1
53  L=L+1
54  IF (J.EQ.4) GO TO 285
55  SUM=A(12)+8*(POT(L+1)+POT(L-1)+POT(N+2)+POT(N-1))+
56  1A(13)+8*(POT(L)+POT(N)+POT(N+1)+POT(N-1))
57  GO TO 290
58 285 SUM=A(12)+8*(POT(L+1)+POT(L-1)+POT(L+3)+POT(N-1))+
59  1A(13)+8*(POT(L)+POT(N+1)+POT(L+2)+POT(N-1))
60  RES=SUM-POT(N)
61  POT(N)=POT(N)+ONEGA*RES
62  EPS=EPS+ABS(RES)
63  CONTINUE
64 290 GO TO 230
65  FOR THE INNER EDGE OF GRID.
66 300 CONTINUE
67  IF (I.EQ.1) GO TO 345
68  DO 310 J=1,4
69  AMAX=I*MAX(J)
70  N=N+1
71  IF (J.NE.1) GO TO 320
72  SUM=A(12)+8*(POT(L+1)+POT(L-1)+POT(N+1)+POT(N-2))+A(13)+
73  1*(POT(L)+POT(N)+POT(N+1)+POT(N-1))
74  RES=SUM-POT(N)
75  POT(N)=POT(N)+ONEGA*RES
76  EPS=EPS+ABS(RES)
77  N=N+1
78  N=N+1
79  L=L+1
80  SUM=A(12)+8*(POT(L+1)+POT(L-1)+POT(N-1))+A(13)+
81  1*(POT(L)+POT(N)+POT(N-1))+A(14)+8*(POT(N)+A(15)+8*(POT(N+1)+
82  1A(16)+8*(POT(N+2)
83 20 GO TO 330
84  L=L+1
85  SUM=A(12)+8*(POT(L+1)+POT(L-1)+POT(N)+POT(L-3))+A(13)+
86  1*(POT(L)+POT(L-2)+POT(N+1)+POT(N-1))
87  RES=SUM-POT(N)
88  POT(N)=POT(N)+ONEGA*RES
89  EPS=EPS+ABS(RES)
90  N=N+1
91  L=L+1
92  SUM=A(12)+8*(POT(L+1)+POT(L-1)+POT(N-2))+A(13)+
93  1*(POT(L)+POT(N+1)+POT(N-1))+A(14)+8*(POT(N)+A(15)+8*(POT(N+1)+
94  1A(16)+8*(POT(N+2)
95 30 GO TO 340
96  RES=SUM-POT(N)
97  POT(N)=POT(N)+ONEGA*RES
98  EPS=EPS+ABS(RES)
99  DO 340 K=3+AMAX
100 N=N+1
101 N=N+2
102 L=L+1
103 NS=N+2
104 IF (J.EQ.4.AND.(K.EQ.AMAX)) NS=N+2
105 SUM=A(12)+8*(POT(L+1)+POT(L-1))+A(13)+
106 1*(POT(L)+POT(N+1)+POT(N-1))+A(14)+8*(POT(N)+A(15)+8*(POT(N+1)+
107 1A(16)+8*(POT(N+2)
108 GO TO 344
109 SUM=A(12)+8*(POT(L+1)+POT(L-1)+POT(L+3))+A(13)+
110 1*(POT(L)+POT(L+2)+POT(N-1))+A(14)+8*(POT(N+1)+
111 1A(15)+8*(POT(N-1))+A(16)+8*(POT(NS)+POT(N-2))
112 RES=SUM-POT(N)
113 POT(N)=POT(N)+ONEGA*RES
114 EPS=EPS+ABS(RES)
115 CONTINUE
116 CONTINUE
117 FOR THE INNERMOST GRID.
118 145 CONTINUE
119 AMAX=MOD(M,1)
120 IF (MOD(M,1000000) .EQ. 1000000)
121 FOR THE INTERIOR OF GRID.
122 DO 150 N=MOD(M)-AMAX
123 L=1
124 NS=1
125 IF (N .EQ. 0)
126 CONTINUE
127 IF (N .EQ. 1)
128 CONTINUE
129 IF (N .EQ. 2)
130 CONTINUE
131 IF (N .EQ. 3)
132 CONTINUE
133 IF (N .EQ. 4)
134 CONTINUE
135 IF (N .EQ. 5)
136 CONTINUE
137 IF (N .EQ. 6)
138 CONTINUE
139 IF (N .EQ. 7)
140 CONTINUE
141 IF (N .EQ. 8)
142 CONTINUE
143 IF (N .EQ. 9)
144 CONTINUE
145 IF (N .EQ. 10)
146 CONTINUE
147 IF (N .EQ. 11)
148 CONTINUE
149 IF (N .EQ. 12)
150 CONTINUE
151 IF (N .EQ. 13)
152 CONTINUE
153 IF (N .EQ. 14)
154 CONTINUE
155 IF (N .EQ. 15)
156 CONTINUE
157 IF (N .EQ. 16)
158 CONTINUE
159 IF (N .EQ. 17)
160 CONTINUE
161 IF (N .EQ. 18)
162 CONTINUE
163 IF (N .EQ. 19)
164 CONTINUE
165 IF (N .EQ. 20)
166 CONTINUE
167 IF (N .EQ. 21)
168 CONTINUE
169 IF (N .EQ. 22)
170 CONTINUE
171 IF (N .EQ. 23)
172 CONTINUE
173 IF (N .EQ. 24)
174 CONTINUE
175 IF (N .EQ. 25)
176 CONTINUE
177 IF (N .EQ. 26)
178 CONTINUE
179 IF (N .EQ. 27)
180 CONTINUE
181 IF (N .EQ. 28)
182 CONTINUE
183 IF (N .EQ. 29)
184 CONTINUE
185 IF (N .EQ. 30)
186 CONTINUE
187 IF (N .EQ. 31)
188 CONTINUE
189 IF (N .EQ. 32)
190 CONTINUE
191 IF (N .EQ. 33)
192 CONTINUE
193 IF (N .EQ. 34)
194 CONTINUE
195 IF (N .EQ. 35)
196 CONTINUE
197 IF (N .EQ. 36)
198 CONTINUE
199 IF (N .EQ. 37)
200 CONTINUE
201 IF (N .EQ. 38)
202 CONTINUE
203 IF (N .EQ. 39)
204 CONTINUE
205 IF (N .EQ. 40)
206 CONTINUE
207 IF (N .EQ. 41)
208 CONTINUE
209 IF (N .EQ. 42)
210 CONTINUE
211 IF (N .EQ. 43)
212 CONTINUE
213 IF (N .EQ. 44)
214 CONTINUE
215 IF (N .EQ. 45)
216 CONTINUE
217 IF (N .EQ. 46)
218 CONTINUE
219 IF (N .EQ. 47)
220 CONTINUE
221 IF (N .EQ. 48)
222 CONTINUE
223 IF (N .EQ. 49)
224 CONTINUE
225 IF (N .EQ. 50)
226 CONTINUE
227 IF (N .EQ. 51)
228 CONTINUE
229 IF (N .EQ. 52)
230 CONTINUE
231 IF (N .EQ. 53)
232 CONTINUE
233 IF (N .EQ. 54)
234 CONTINUE
235 IF (N .EQ. 55)
236 CONTINUE
237 IF (N .EQ. 56)
238 CONTINUE
239 IF (N .EQ. 57)
240 CONTINUE
241 IF (N .EQ. 58)
242 CONTINUE
243 IF (N .EQ. 59)
244 CONTINUE
245 IF (N .EQ. 60)
246 CONTINUE
247 IF (N .EQ. 61)
248 CONTINUE
249 IF (N .EQ. 62)
250 CONTINUE
251 IF (N .EQ. 63)
252 CONTINUE
253 IF (N .EQ. 64)
254 CONTINUE
255 IF (N .EQ. 65)
256 CONTINUE
257 IF (N .EQ. 66)
258 CONTINUE
259 IF (N .EQ. 67)
260 CONTINUE
261 IF (N .EQ. 68)
262 CONTINUE
263 IF (N .EQ. 69)
264 CONTINUE
265 IF (N .EQ. 70)
266 CONTINUE
267 IF (N .EQ. 71)
268 CONTINUE
269 IF (N .EQ. 72)
270 CONTINUE
271 IF (N .EQ. 73)
272 CONTINUE
273 IF (N .EQ. 74)
274 CONTINUE
275 IF (N .EQ. 75)
276 CONTINUE
277 IF (N .EQ. 76)
278 CONTINUE
279 IF (N .EQ. 77)
280 CONTINUE
281 IF (N .EQ. 78)
282 CONTINUE
283 IF (N .EQ. 79)
284 CONTINUE
285 IF (N .EQ. 80)
286 CONTINUE
287 IF (N .EQ. 81)
288 CONTINUE
289 IF (N .EQ. 82)
290 CONTINUE
291 IF (N .EQ. 83)
292 CONTINUE
293 IF (N .EQ. 84)
294 CONTINUE
295 IF (N .EQ. 85)
296 CONTINUE
297 IF (N .EQ. 86)
298 CONTINUE
299 IF (N .EQ. 87)
300 CONTINUE
301 IF (N .EQ. 88)
302 CONTINUE
303 IF (N .EQ. 89)
304 CONTINUE
305 IF (N .EQ. 90)
306 CONTINUE
307 IF (N .EQ. 91)
308 CONTINUE
309 IF (N .EQ. 92)
310 CONTINUE
311 IF (N .EQ. 93)
312 CONTINUE
313 IF (N .EQ. 94)
314 CONTINUE
315 IF (N .EQ. 95)
316 CONTINUE
317 IF (N .EQ. 96)
318 CONTINUE
319 IF (N .EQ. 97)
320 CONTINUE
321 IF (N .EQ. 98)
322 CONTINUE
323 IF (N .EQ. 99)
324 CONTINUE
325 IF (N .EQ. 100)
326 CONTINUE
327 IF (N .EQ. 101)
328 CONTINUE
329 IF (N .EQ. 102)
330 CONTINUE
331 IF (N .EQ. 103)
332 CONTINUE
333 IF (N .EQ. 104)
334 CONTINUE
335 IF (N .EQ. 105)
3
```

```

100 CONTINUE
      SUM1=SUM1+POT*(N1-I+1)
      SUM2=SUM2+POT*(N1-I+1)
150 CONTINUE
      IF (N1-I+1) 100,100,100
      A6=SUM1/IOT(N)
      FOT(N)=BIT-N*HIRE(LABRES)
      EPS=EPS+ABS(E6)
150 CONTINUE
L
      DO 370 N=1,NMAX
      I0=I+IN
      I1=I+I1
      I2=I+I+I1-1
      NO=MOD(I0-1,N)
      SUM=0
      DO 530 I=I1,I2
      SUM=SUM+AM(I)*POT(I+I1)
180 CONTINUE
      SUM=AM(I+IN)-SUM/AM(I0)
      A6=SUM-FOT(N0)
      FOT(N0)=SUM
      EPS=EPS+ABS(E6)
170 CONTINUE
C
C 980 WRITE(LUN1,980) ITER,EPS
C 980 FORMAT('ITER=',I3,'X',EPS=' ',IPE13.5)
      IF (ITER,GE,ITERAX) GO TO 510
      IF (EPS,LT,EPSTAX) GO TO 510
      GO TO *2000
500 CALL EXEC(B,NAME,10,ITER)
C
510 CONTINUE
      CALL EXEC(B,NAME,20,ITER)
      STOP
      END
      ENDS

```

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WRITE(UNIT=11, I=1, J=1)
C ***** CONVERGENCE HAS NOT BEEN REACHED AFTER 111
C ITERATIONS *****
ITERATION 1
CALL EXECUTE(MAIN)
C *****
END
END

114
PROGRAM PLUT(15,150)
C *****
C THIS PROGRAM GENERATES POTENTIAL CONTOUR PLOTS. THE SATELLITE
C TRAJECTORY IS ALSO PLOTTED WITH THE CONTOURS.
C *****
COMMON ALBA4/POT(2560),YD(2560),YD(2560),IG(2560,4),
  IZ(50,50),IP(50),YF(50),INUP(50),IL(50,50),
  CUNUM/BLK1/NNI(10),NNJ(10),FLOUT,ANAX,DX,DY,
  COMMON BLAS/ROUTER(10),NNEST(10),S(4,4),NCONM(10,4,4),
  INCUNA(10),IGAL(4),
  COMMON BLAS15/BUF1(1),BUF2(25),
  COMMON FILE2/INAX,NP,II,MESHAX,MAXMOD,MAXELE,NODOUT,
  COMMON FLOT1/PLOT(1),MAX,INAX1,NS,NA,ISYN,IFLAG,
  DIMENSION XPP(4),YPP(4),CNP(30)
C *****
IEND=57
IEND=MESHAX-3
C *****
NN=2
NNM=1
C *****
ZM=-1.0E+28
SEP=0.1
IF(1SYN.EQ.1) GO TO 10
AA=0.5
AA1=0.5
SC=1.0
GO TO 20
10 AA=2.0
AA1=0
SC=0.5
20 SX=SCBDY
SY=SCBDY
SCZ=1.0
C *****
CALL PAPLT(MCN,CNP)
C *****
IF(MN.EQ.1) GO TO 47
CALL START
CALL SYMBOL(0.0,0.0,0.14,'PLEASE MOUNT BLACK LIG-IMP PENS'
  IBROAD IN POSITION 1 AND EXTRA FINE IN POSITION 2',90.0,80)
C *****
CALL PLOT(0.0,0.0,-3)
CALL NEWPEN(1)
CALL PLOT(ANAX,AY,-3)
C *****
DO 40 I=1,IFLAG
  NI=I+I-1)8NS
  NZ=NS(I-1)8NS
  XI=FLOAT(1BUF1(N2))8SX
  YI=FLOAT(1BUF2(N2))8SY
  CALL PLOT(XI,YI,3)
  DO 40 M=NI,N2
    XI=FLOAT(1BUF1(M))8SX
    YI=FLOAT(1BUF2(M))8SY
    CALL PLOT(XI,YI,2)
40 CONTINUE
CALL PLOT(0.0,0.0,3)
IF(1SYN.EQ.1) GO TO 45
CALL PLOT(10.0,0.0,2)
CALL PLOT(0.0,0.0,3)
CALL PLOT(0.0,10.0,2)
CALL PLOT(0.0,0.0,3)
45 CALL NEWPEN(2)
C *****
47 DO 50 I=1,IEND
  II=IEND+I-I
  NI=NNI(II)
  NJ=NNJ(II)
  IF(II.EQ.1) GO TO 70
  NN=2
  IF(1SYN.EQ.1) NN=1
  INI=NI82
  JNJ=NJ82
  INAX=INI+1
  JMAX=JNJ+1
  GO TO 80
70 INAX=NI+1
  JMAX=NJ+1
80 DO 90 L=1,INAX
  DO 90 M=1,JMAX
  ZP(L,M)=ZN
90 CONTINUE
IP=4
IF(1SYN.EQ.1) IP=3
IF(II.EQ.1) GO TO 280
IF(II.EQ.MESHAX) GO TO 100
NI=NCONM(II+1,IP,2)+1
GO TO 110
100 NI=1
110 A2=NCONM(II,IP,2)
II=IG(NI,1)
I2=IG(NI,2)
I4=IG(NI,4)
XO=XG(II)
YO=YG(II)
DDX=XG(I2)-XG(1)/2.0
DDY=YG(I2)-YG(1)/2.0
IF(1SYN.EQ.1) GO TO 115
XO=0.0
YO=0.0
115 DO 120 K=1,A2
  IF(1SYN.EQ.1) GO TO 124
  II=1
  J2=4
  GO TO 128
124 II=2
  J2=1
128 DO 130 J=II,J2
  II=J
  IF(A2,NCONM(II,J+1),AND(A2,NCONM(II,J+2))) GO TO 140
130 CONTINUE
  II=5
  GO TO 130
140 II=4
  GO TO 130
150 II=3
  GO TO 130
160 II=2
  GO TO 130
170 II=1
  GO TO 130
180 N=NCONM(II,J+1)+NCONM(II,J+2)
  L=IFIX((XG(N)-XO)/DDX*10.1)+1
  M=IFIX((YG(N)-YO)/DDY*10.1)+1
  ZP(L,M)=FOT(N)
160 CONTINUE
  IF(JJ.EQ.5) GO TO 120
  GO TO (190,200,210,220)+JJ
190 LI=0
  NI=-2
  GO TO 230
200 LI=2
  NI=0
  GO TO 230
210 LI=0
  NI=2
  GO TO 230
220 LI=-2
  NI=0
230 NI=JJ
  N2=JJ+1-JJ/484
  NI=IG(N,N1)
  N2=IG(N,N2)
  L2=L+LI
  N2=N+NI
  ZP(L2,N2)=(POT(N1)+POT(N2))/2.0
  L3=L+LI/2
  N3=N+NI/2
  ZP(L3,N3)=(ZP(L2,N2)+POT(N))/2.0
120 CONTINUE
  DO 240 L=1,INAX+2
  DO 240 M=1,JM1+2
  Z1=ZP(L,M)
  Z2=ZP(L,M+1)
  Z3=ZP(L,M-1)
  IF(Z1,ME,ZN) GO TO 240
  IF(Z2,ME,ZN,OR,Z3,ME,ZN) GO TO 240
  ZP(L,M)=(Z2+Z3)/2.0
240 CONTINUE
  DO 250 M=1,JMAX
  DO 250 L=2,IM1+2
  Z1=ZP(L,M)
  Z2=ZP(L+1,M)
  Z3=ZP(L-1,M)
  IF(Z1,ME,ZN) GO TO 250
  IF(Z2,ME,ZN,OR,Z3,ME,ZN) GO TO 250
  ZP(L,M)=(Z2+Z3)/2.0
250 CONTINUE
  DO 260 L=1,INAX
  YP(L)=XO+DDX*FLOAT(L-1)
260 CONTINUE
  DO 270 L=1,JMAX
  YP(L)=YO+DDY*FLOAT(L-1)
270 CONTINUE
  GO TO 320
C *****
280 DO 290 L=1,INAX
  NI=IL(L,JMAX)
  XI=IL(L,N)
290 CONTINUE
  DO 300 L=1,JMAX
  NI=IL(INAX,L)
  YP(L)=YG(N)
300 CONTINUE
  DO 310 L=1,INAX
  DO 310 M=1,JMAX
  NI=IL(L,M)
  IF(NI.EQ.-1) GO TO 310
  IF(MAX.EQ.0) GO TO 306
  DO 305 LL=1,MAX
  LI=(LL-1)*2+1
  IF(NI.EQ.1) GO TO 310
  ZP(L,M)=POT(N)
305 CONTINUE
  ZP(L,M)=POT(N)
310 CONTINUE
C *****
320 IF(SC.EQ.1.0) GO TO 345
  DO 330 L=1,INAX
  XI=IL(L,1)8SC
  YP(L)=YP(L)8SC
330 CONTINUE
  DO 340 L=1,JMAX
  YP(L)=YP(L)8SC
340 CONTINUE
  IF(SCZ.EQ.1.0) GO TO 355
  DO 350 L=1,INAX
  DO 350 M=1,JMAX
  ZP(L,M)=ZP(L,M)8SCZ
350 CONTINUE
  IF(MN.EQ.1) GO TO 370
  DO 360 L=1,MEN
  CN=CNP(L)
  CALL CHTOUR(XP,INAX,YP,JMAX,ZP,1DINX,CN,SEP,CN)
  CONTINUE
360 IF(MN.EQ.1) GO TO 475
  WRITE(6,380) (XP(L),L=1,INAX)
  WRITE(6,380) (YP(L),L=1,JMAX)
380 FORMAT(15F9.3)
  DO 390 M=1,JMAX
  MASA=JMAX+1-M
  WRITE(6,380) (ZP(L,MASA),L=1,INAX)
390 CONTINUE
C *****
395 NI=0
  NI=ALLOUT+1
  DO 400 K=1,ANAX
  IF(IG(K,4),ME,0) GO TO 400
  NI=NI+1
  IF(NI=1) NI=0
400 CONTINUE
  IF(NI.EQ.0) GO TO 475
  DO 410 M=1,MEN

```

[illegible]

FILM

7-