Summary Report

COMPUTER PROGRAM FOR PLANETARY SOLAR ARRAY DEVELOPMENT

Prepared for
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91103

Attention: Mr. M. H. Beckstrom, Senior Contract Negotiator
Technical Monitor: Mr. L. Schmidt

Contract 952606

EOS Report 4042-SR

10 November 1969

ELECTRO-OPTICAL SYSTEMS
A XEROX COMPANY
PASADENA, CALIFORNIA 91107 • 213/351-2351


EOS

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ABSTRACT

This summary report, submitted under the terms of contract 952606 (subcontract under NASA Contract NAS7-100, Task Order No. RD-26), describes a computer program that will print the power output of a solar panel located arbitrarily on the surface of Mars. The original program was developed under Contract 952035 between the Jet Propulsion Laboratory and Electro-Optical Systems, and is detailed in EOS Report 7254-Final, dated 28 February 1969.

The modifications made under the present contract were to:

a. Provide for solar cell model input in terms of 200 (or fewer) points describing the room-temperature I-V characteristics, and up to 25 points for each temperature coefficient.

b. Add a subroutine to define the attenuation and scattering as a result of atmospheric dust, including layering on the panel.

c. Print out important cell I-V values during three periods of the Martian day.

d. Perform a brief study of the sand dune height pected on Mars.

Theoretical calculations of Rayleigh and Mie scattering are derived in the report.

The program is included; it is written in Fortran IV for an XDS Sigma VII computer. Instructions are given to prepare the set of necessary input parameters; an explanation and sample printout are included.

CONTENTS

SECTION 1

INTRODUCTION

Included in this report are the following major items:

a. A theoretical derivation treating the Mie and Rayleigh scattering due to the molecules and particles present in the Martian atmosphere.

b. A theoretical derivation of the expected dust layer buildup on a solar panel, by means of the Stokes-Cunningham equation, and a calculation of light attenuation through this layer.

c. A theoretical study of the parameters of the sand dunes expected on the Martian surface, based upon the Bagnold equations, and other physical characteristics of the surface environment.

d. A discussion of a solar cell model and description of its computer implementation.

e. The computer program, typical printouts, and a set of recommendations.

SECTION 2

THEORETICAL SCATTERING AND DUST LAYERING

2.1 GENERAL

In order to determine the output of a solar cell on the Martian surface, it is necessary to know the intensity of the sunlight at the location of the solar cell on the planet's surface. Sunlight which enters the Martian atmosphere is both absorbed and scattered by atmospheric molecules. Dust particles suspended in the atmosphere will also absorb and scatter the sunlight, but, for the sake of simplicity, we shall consider the dust particles to be perfect dielectrics (i.e., nonconducting), so that they do not absorb the solar energy. The intensity of the sunlight at the solar panel depends on the absorption coefficient of the molecular atmosphere and the scattering coefficient of both the atmospheric molecules and the dust particles. These coefficients are discussed in the following subsections.

2.2 ABSORPTION COEFFICIENT OF MARTIAN ATMOSPHERE

Let z denote the altitude (vertical distance above the Martian surface) of a point in the Martian atmosphere, and let $\mu(z)$ denote the absorption coefficient of the atmosphere at this point. Then, if I_o is the intensity of sunlight in free space at Mars' distance from the sun, the intensity of light at a point on the Martian surface directly beneath the sun, resulting only from the loss of energy due to absorption by the atmosphere, is given by

$$I_a = I_o \exp\left[-\int_o^H \mu(z)dz\right],$$

where H = height of effective atmosphere. Now, the absorption coefficient, $\mu(z)$, is directly proportional to the density, $\rho(z)$, of the atmosphere. Thus,

$$\mu(z) = k\,\rho(z),$$

where

$$\rho(z) = \rho_o \exp\left[\frac{-\alpha z}{R(R+z)}\right].$$

Here, ρ_o = density of atmosphere at the surface of Mars = 1.465×10^{-5} gm/cm^3, R = radius of Mars = 3332 km, and

$$\alpha = \frac{K\rho_o}{p_o}$$

where p_o = atmospheric pressure at the surface of Mars = 7.0×10^3 dynes/cm^2 and K = gravitational constant of Mars = 4.255×10^{19} cm^3/sec^2. Here, $\alpha = 8.9 \times 10^5$ km. Combining the first three equations gives

$$\frac{I_a}{I_o} = \exp\left\{-k\rho_o \int_o^H \exp\left[\frac{-\alpha z}{R(R+z)}\right] dz\right\},$$

for which

$$k = \frac{\ln(I_o/I_a)}{\rho_o \int_o^H \exp\left[\frac{-\alpha z}{R(R+z)}\right] dz}.$$

Therefore we finally have

$$\mu(z) = k\rho(z) = \frac{\ln(I_o/I_a)}{\int_o^H \exp\left[\frac{-\alpha z}{R(R+z)}\right] dz} \cdot \exp\left[\frac{-\alpha z}{R(R+z)}\right]. \qquad (1)$$

The values of ρ_o, p_o given above are taken from Ref. 1. For the purpose of our problem, we shall let $I_a/I_o = 0.95$, so that $\ell n(I_o/I_a) = 0.05126$. Also, the height of the effective Martian atmosphere is taken as $H = 200$ km. A computer calculation yields

$$\int_o^H \exp\left[\frac{-\alpha z}{R(R+z)}\right] dz = 12.57 \text{ km.}$$

2.3 RAYLEIGH SCATTERING COEFFICIENT

According to Ref. 1 (Fig. 4-25), the maximum solar irradiance on the Martian surface occurs at a wavelength $\lambda = 0.5\mu$ (μ = 1 micron = 10^{-4} cm). Since the diameter of an atmospheric molecule is considerably less than 0.1λ, the scattering of the sunlight by the atmospheric molecules will be Rayleigh-type scattering. The Rayleigh scattering coefficient, s_R, is given by

$$s_R = n_R \sigma_R,$$

where n_R = molecular number density of the Martian atmosphere and σ_R = Rayleigh scattering cross section. Here, $n_R = \rho/m$, where m = mass of an atmospheric molecule. From Ref. 1, we deduce that $m = 6.3 \times 10^{-23}$ gram. Therefore,

$$n_R = n_o \exp\left[\frac{-\alpha z}{R(R+z)}\right],$$

where n_o = molecular number density at the surface of Mars = 2.32×10^{17} cm^{-3}.

According to Ref. 2, p.3, the Rayleigh scattering cross section is given by

$$\sigma_R(\lambda) = \frac{8\,\pi^3 (m_s^2 - 1)^2}{3\,\lambda^4 n_o^2} \cdot \frac{6 + 3\delta}{6 - 7\delta},$$

where m_s = index of refraction of Mars' atmosphere at the surface of Mars and δ = depolarization factor. It can be shown that $m_s = 1.000004$ and $\delta = 0.075$. Then, since $\lambda = 0.5\mu$, we have $\sigma_R = 1.79 \times 10^{-26}\ cm^2$.

Consequently,

$$s_R = n_o \sigma_R \exp\left[\frac{-\alpha z}{R(R + z)}\right], \tag{2}$$

where $n_o \sigma_R = 4.15 \times 10^{-4}\ km^{-1}$.

2.4 MIE SCATTERING COEFFICIENT

The diameters of the dust particles in the Martian atmosphere being considered for this problem lie in the range 1.0μ, 100.0μ. Since these diameters are the same order of magnitude as $\lambda = 0.5\mu$, and greater, the scattering of the sunlight by the dust particles will be Mie-type scattering. The classical theory which describes this type of scattering assumes that the scattering particles are spherical. Also as mentioned in the introduction, we shall assume, for simplicity, that the dust particles are nonconducting. The Mie scattering coefficient, s, is given by

$$s = n\sigma, \tag{3}$$

where n = number density (constant) of dust particles in the atmosphere, and σ is the Mie scattering cross section. According to Ref. 3,

$$\sigma(\lambda, N, \rho) = \frac{\lambda^2}{2\pi} \sum_{i=1}^{\infty} (2i + 1)(|a_i|^2 + |b_i|^2), \tag{4}$$

where N = index of refraction of a dust particle, and

$$\rho = \frac{2\pi a}{\lambda},$$

where a = radius of dust particle. Here,

$$a_i = \frac{N\psi_i(\rho)\psi_i'(N\rho) - \psi_i'(\rho)\psi_i(N\rho)}{\psi_i(N\rho)\zeta_i'(\rho) - N\psi_i'(N\rho)\zeta_i(\rho)}$$

and

$$b_i = \frac{N\psi_i'(\rho)\psi_i(N\rho) - \psi_i(\rho)\psi_i'(N\rho)}{\psi_i'(N\rho)\zeta_i(\rho) - N\psi_i(N\rho)\zeta_i'(\rho)},$$

where the primes denote differentiation with respect to the argument of the respective function. Further,

$$\psi_i(x) = \left(\frac{\pi x}{2}\right)^{1/2} J_{i+1/2}(x)$$

and

$$\zeta_i(x) = \psi_i(x) - j(-1)^i\left(\frac{\pi x}{2}\right)^{1/2} J_{-(i+1/2)}(x),$$

where $j = (-1)^{1/2}$.

Also,

$$J_{i+1/2}(x) = \left(\frac{2}{\pi x}\right)^{1/2}\left[P_i(x)\ \sin\left(x - \frac{i\pi}{2}\right) + Q_i(x)\ \cos\left(x - \frac{i\pi}{2}\right)\right] ;$$

$$J_{-(i+1/2)}(x) = \left(\frac{2}{\pi x}\right)^{1/2}\left[P_i(x)\ \cos\left(x + \frac{i\pi}{2}\right) - Q_i(x)\ \sin\left(x + \frac{i\pi}{2}\right)\right] .$$

Here,

$$P_i(x) = \sum_{p=0}^{\leq \frac{i}{2}} \frac{(-1)^p (i + 2p)!}{(2p)!(i - 2p)!} \frac{1}{(2x)^{2p}}$$

and

$$Q_i(x) = \sum_{p=0}^{\leq \frac{1}{2}(i-1)} \frac{(-1)^p (i + 2p + 1)!}{(2p + 1)!(i - 2p - 1)!} \frac{1}{(2x)^{2p + 1}} ,$$

where the upper limit that ultimately belongs on each summation sign is the nearest integer to the value indicated. The quantities $J_{i+1/2}$ and $J_{-(i+1/2)}$ are the Bessel Functions of half-integral order.

2.5 INTENSITY OF SUNLIGHT AT THE SOLAR PANEL

The total intensity of sunlight at the solar panel on the Martian surface consists of three parts: (1) the intensity, I_1, resulting from the attenuation of solar energy due to absorption (by the atmospheric molecules) and scattering (by the molecules and dust particles); (2) the intensity, I_{sm}, due to energy scattered by the molecules; (3) the intensity, I_{sd}, due to energy scattered by the dust particles. Thus, the total intensity of sunlight at the solar panel is

$$I_T = I_1 + I_{sm} + I_{sd} \tag{5}$$

2.5.1 INTENSITY, I_1, DUE TO ATTENUATION

Consider the rays of light from the sun to be incident on the solar panel at an arbitrary angle, γ, relative to the local vertical, as shown in Fig. 1. When $\gamma = 0^o$, the sun is directly over the panel, and when $\gamma = 90^o$, the sun is on the horizon. The intensity I_1, for arbitrary γ, is given by

$$I_1 = I_o \exp\left\{- \int_0^L [\mu(\xi) + s_R(\xi) + s(\xi)]\, d\xi \right\}, \tag{6}$$

where

$$\int_0^L [\mu(\xi) + s_R(\xi) + s(\xi)]\, d\xi$$

$$\approx \left[\frac{\ell n(I_o/I_a)}{\int_0^H \exp\left[\frac{-\alpha z}{R(R+z)}\right] dz} + n_o \sigma_R \right]$$

$$\cdot \int_0^L \exp\left[- \frac{\alpha}{R}\left(\frac{1}{2}\ \frac{\xi^2}{R^2} + \frac{\xi \cos\gamma}{R}\right)\right] d\xi + sL, \tag{7}$$

and

$$L = -R \cos\gamma + (H + R)\left[1 - \left(\frac{R \sin\gamma}{H + R}\right)^2\right]^{1/2}.$$

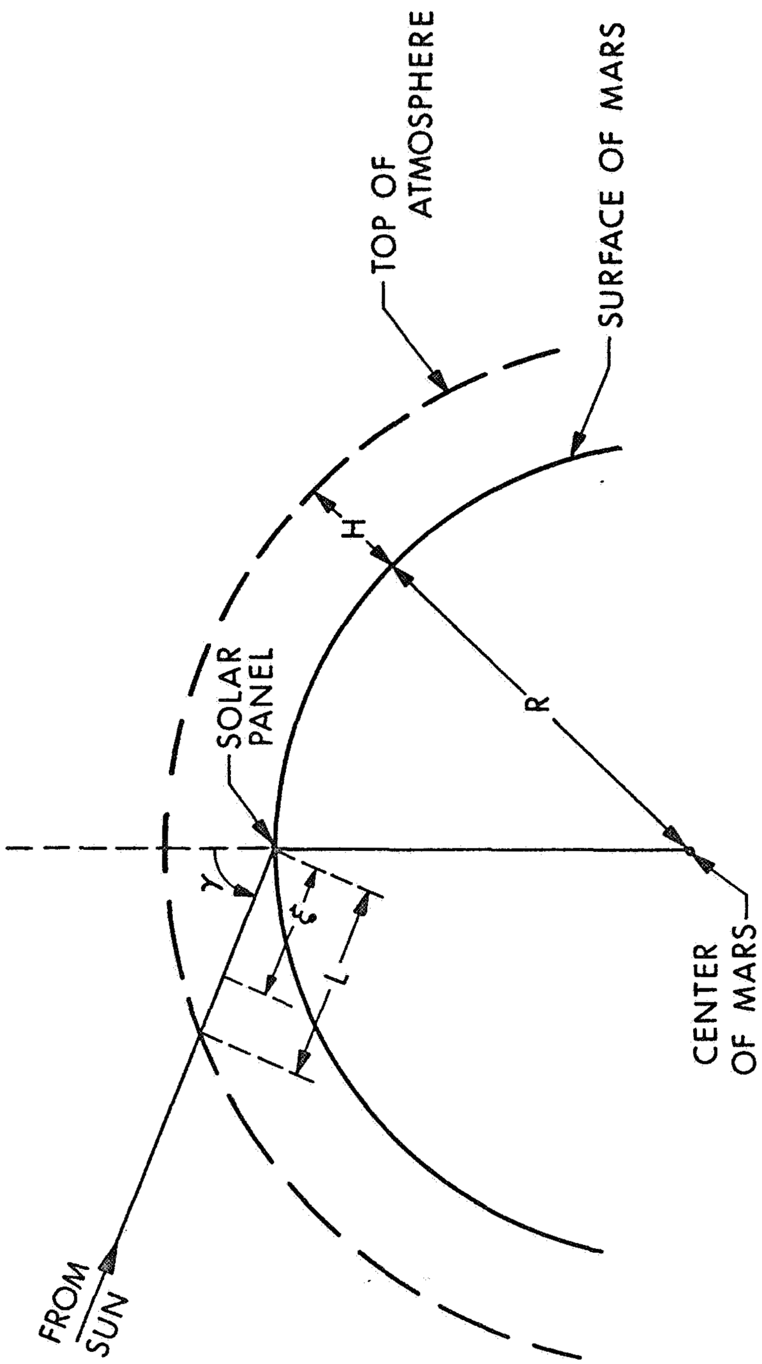

Figure 1. Definition of γ

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A digital computer is needed to evaluate the above integral. However, in the special cases when $\gamma = 0^o$ or 90^o, the integration may be performed analytically. Thus, when $\gamma = 0^o$,

$$\int_0^L \exp\left[-\frac{\alpha}{R}\left(\frac{1}{2}\frac{\xi^2}{R^2} + \frac{\xi \cos\gamma}{R}\right)\right] d\xi = \int_0^H \exp\left[-\frac{\alpha}{R}\left(\frac{1}{2}\frac{\xi^2}{R^2} + \frac{\xi}{R}\right)\right] d\xi$$

$$\approx \int_0^H \exp\left(-\frac{\alpha}{R}\cdot\frac{\xi}{R}\right) d\xi \approx \frac{R^2}{\alpha} = 12.48 \text{ km}, \qquad (8)$$

and when $\gamma = 90^o$,

$$\int_0^L \exp\left[-\frac{\alpha}{R}\left(\frac{1}{2}\frac{\xi^2}{R^2} + \frac{\xi \cos\gamma}{R}\right)\right] d\xi = \int_0^L \exp\left(-\frac{\alpha}{R}\cdot\frac{1}{2}\frac{\xi^2}{R^2}\right) d\xi$$

$$\approx \int_0^\infty \exp\left(-\frac{\alpha}{R}\cdot\frac{1}{2}\frac{\xi^2}{R^2}\right) d\xi = \left(\frac{\pi R^3}{2\alpha}\right)^{1/2} = 256 \text{ km},$$

where $L = (H^2 + 2HR)^{1/2} = 1170$ km.

2.5.2 INTENSITY, I_{sm}, DUE TO SCATTERING BY MOLECULES

In the derivation of I_{sm}, and also I_{sd}, it is assumed that the scattered sunlight reaching the solar panel has been scattered only once, i.e., multiple scattering is not taken into account. For this reason, and because of the limited region of space in which the scattered light is assumed to originate (explained below and in Fig. 2), the intensity of the scattered sunlight at the solar panel will represent a conservative value.

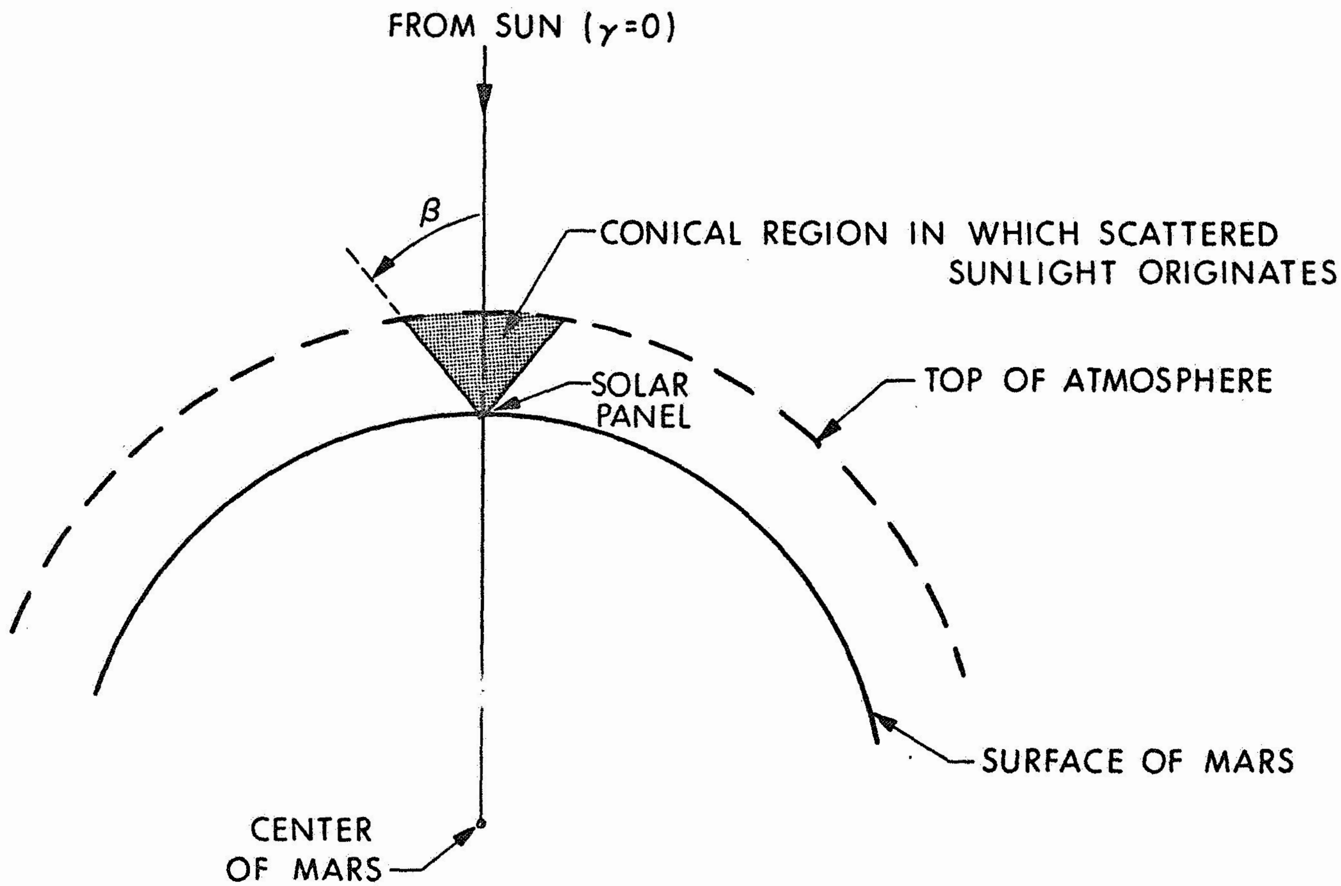

Figure 2. Definition of β

The derivation of I_{sm} for arbitrary γ is rather difficult. For the purpose of this study, only the I_{sm} corresponding to $\gamma = 0^o$ will be derived. Preliminary calculations of I_{sm}, in which it is assumed that the scattered light reaching the solar panel originates in a long cylindrical column whose axis coincides with the panel-sun direction and whose cross section is the projected area of the solar panel surface, show that the ratio, I_{sm}/I_1, is the same for $\gamma = 0^o$ and $\gamma = 90^o$. We shall assume that the ratio I_{sm}/I_1 remains constant for all values of $\gamma(0^o \leq \gamma \leq 90^o)$. Hence, the value of I_{sm} for an arbitrary γ can be obtained from,

$$I_{sm} = \frac{(I_{sm})_{\gamma=0}}{(I_1)_{\gamma=0}} \cdot I_1, \tag{10}$$

where $(I_1)_{\gamma=0}$ is obtained from Eqs. 6, 7, 8 and I_1 is determined from Eqs. 6 and 7. In order to reduce the mathematical complexity in the derivation of $(I_{sm})_{\gamma=0}$, it is assumed that the scattered (by the atmospheric molecules) sunlight incident on the solar panel comes only from that part of the atmosphere contained in a cone of half-angle β, with vertex at the solar panel and central axis coincident with the local vertical. The shaded area in Fig. 2 denotes this conical region. Here, $\beta \leq 45^o$. The intensity is given by

$$(I_{sm})_{\gamma=0} = \frac{3}{8} I_o n_o \sigma_R e^{-sH} \int_0^\beta \frac{(1 - \eta \sec\theta)(1 + \cos^2\theta)\sin\theta}{\frac{\alpha}{R^2}\cos\theta + s(1 - \cos\theta)} d\theta$$

$$+ \frac{3}{8} I_o \eta n_o \sigma_R e^{-sH} \int_0^\beta \frac{(1 + \cos^2\theta)\tan\theta}{2\frac{\alpha}{R^2}\cos\theta + s(1 - \cos\theta)} d\theta, \tag{11}$$

where

$$\eta = \frac{R^2}{\alpha}\left[\frac{\ln(I_o/I_a)}{\int_0^H \exp\left[\frac{-\alpha z}{R(R+z)}\right] dz} + n_o\sigma_R\right] = 0.0560.$$

The smaller the value of β, the more accurate is Eq. 11. The value of β should not exceed 45^o.

2.5.3 INTENSITY, I_{sd}, DUE TO SCATTERING BY DUST PARTICLES

The derivation of I_{sd} for arbitrary γ is also rather difficult, and so, for the purpose of this study, only the I_{sd} corresponding to $\gamma = 0^o$ will be derived. Preliminary calculations of I_{sd}, in which it is assumed that the scattered light reaching the solar panel originates in the same cylindrical column as previously described for I_{sm}, show that the ratio I_{sd}/I_1 is the same for $\gamma = 0^o$ and $\gamma = 90^o$. We shall assume that this ratio is constant for all values of $\gamma(0^o \le \gamma \le 90^o)$, so that the value of I_{sd} for an arbitrary γ can therefore be obtained from

$$I_{sd} = \frac{(I_{sd})_{\gamma=0}}{(I_1)_{\gamma=0}} \cdot I_1 \,. \qquad (12)$$

In order to reduce the mathematical complexity in the derivation of $(I_{sd})_{\gamma=0}$, it is assumed that the scattered (by the dust particles suspended in the atmosphere) sunlight incident on the solar panel comes only from the conical region shown in Fig. 2. The intensity is given by

$$(I_{sd})_{\gamma = 0} = \frac{\lambda^2}{4\pi} \frac{I_o}{\sigma} e^{-sH} \int_0^{\beta} (1 - \eta \sec\theta)$$

$$\cdot \left[\frac{1 - \exp\left[-s(1 - \cos\theta)\left(\frac{2RH + H^2}{2R \cos\theta}\right)\right]}{1 - \cos\theta} \right]$$

$$\cdot \left[i_1(\theta) + i_2(\theta) \right] \sin\theta \, d\theta$$

$$+ \frac{\lambda^2}{4\pi} I_o \, \eta \, n \, e^{-sH} \int_0^{\beta} \frac{\tan\theta}{\frac{\alpha}{R^2} \cos\theta + s(1 - \cos\theta)}$$

$$\cdot \left[i_1(\theta) + i_2(\theta) \right] d\theta \, , \tag{13}$$

where

$$i_1(\theta) = |S_1|^2, \qquad i_2(\theta = |S_2|^2 \, , \tag{14}$$

$$S_1 = \sum_{i=1}^{\infty} \frac{2i + 1}{i(i+1)} \left[a_i \frac{dP_i^1 (\cos\theta)}{d\theta} + b_i \frac{P_i^1 (\cos\theta)}{\sin\theta} \right],$$

and

$$S_2 = \sum_{i=1}^{\infty} \frac{2i + 1}{i(i+1)} \left[a_i \frac{P_i^1 (\cos\theta)}{\sin\theta} + b_i \frac{dP_i^1 (\cos\theta)}{d\theta} \right].$$

Here, $P_i^1(\cos\theta)$ are the Associated Legendre Functions, and a_i, b_i are given in subsection 2.4. The dimensionless quantities $i_1(\theta)$, $i_2(\theta)$ are called the intensity functions, or angular distribution functions, of the scattered radiation. Again, the angle β should not exceed 45^o. Of course, the same value of β should be used in equations 11 and 13.

It should be noted that a singularity does not exist in the first integral of equation 13. Thus, when $\theta = 0$,

$$\frac{1 - \exp\left[- s(1 - \cos\theta) \left(\frac{2\ RH + H^2}{2\ R\ \cos\theta}\right)\right]}{1 - \cos\theta} = s(1 + \frac{H}{2R})\ H\ .$$

2.6 EFFECTIVE LIGHT INTENSITY AT THE SOLAR PANEL

The power generated by a solar panel due to a particular ray of light incident on the panel is proportional to the intensity of this ray (at the panel) multiplied by the cosine of the angle between the normal to the panel and the direction of the ray. Since the scattered light reaching the panel arrives from several directions in space (angular variation = 2β), not all of this intensity, I_T, given by equation 5 will be equally effective in generating power. Since the rays of light contributing to the nonscattered intensity, I_1, come directly from the sun, this intensity should be multiplied by $\cos\chi$, where χ = angle between the normal to the panel and the panel-sun direction. Also, each of the several rays of light contributing to the scattered intensity, $I_{sm} + I_{sd}$, should be multiplied by the appropriate quantity. This latter task is very complicated mathematically. Since the rays of light having the highest intensity are generally those coming directly from the sun, little accuracy will be lost if we multiply the total intensity, I_T, by $\cos\chi$ in order to obtain the power output of the solar panel.

The quantity, $\cos\chi$, is obtained from the computer program described on pages 56 - 68 of EOS Report 7254-Final, "Planetary Solar Array Development," dated 28 February 1969.

Multiplying $I_{sm} + I_{sd}$ by $\cos\chi$ (as recommended above) will give a slightly higher intensity than the product of the scattered intensity constituents and their associated cosines. Some of this additional intensity will be supplied, realistically, by the intensity resulting from multiple scattering and from the intensity due to scattered light originating outside of the conical region defined in Fig. 2.

2.7 ATTENUATION OF SUNLIGHT BY DUST LAYER ON SOLAR PANEL SURFACE

In addition to being attenuated by absorption and scattering in the Martian atmosphere, the incident sunlight will also be attenuated by the layer of dust which is expected to collect on the solar panel surface. Evidence obtained from close-up photographs of Mars suggests the existence of dust storms in the Martian atmosphere. After a dust storm has passed over an area, it is reasonable to expect that the dust particles suspended in the atmosphere will fall to the surface, thereby forming a layer of dust on the solar panel. Of course, a minimal dust layer will probably exist on the solar panel surface while the wind is blowing, but the thickness of this layer will depend largely on the electrostatic forces between the dust particles and the panel surface, and this phenomenon is too complex to be analyzed in this report.

For simplicity, we assume that the dust particles are spherically shaped. According to the Stokes-Cunningham equation (Ref. 4, pp. 592, 593), a small spherical particle falling under gravitation through an atmosphere will reach a constant terminal velocity, v, given by

$$v = \frac{2\,ga^2}{9\eta}\,(\rho - \rho_o)\,\left(1 + \frac{B}{ap_o}\right), \tag{15}$$

where ρ = density of particle, g = gravitational acceleration, a = radius of particle, η = coefficient of viscosity of Martian atmosphere, B = 0.004632, and ρ_o, p_o are the density and pressure, respectively, of the Martian atmosphere at the surface of Mars. In equation 15, a is expressed in centimeters and p_o is given in millimeters of mercury. Here, p_o = 13.5 mm Hg.

The thickest dust layer will form on the solar panel if it is lying flat on the Martian surface, i.e., if the normal to the panel lies along the local vertical. If n denotes the number density of dust particles in the Martian atmosphere, then the number of dust particles which will fall on unit area of the solar panel in unit time, i.e., the deposition or settling rate, υ, is

$$\upsilon = nv , \tag{16}$$

where v is given by equation 15. If A denotes the area of the solar panel surface, then the number of dust particles which are required to completely cover the surface and thereby form a single layer on the solar panel is approximately $A/\pi a^2$. If Δt denotes the time taken for a single layer to form on the surface, then $A/\pi a^2 = \upsilon A \Delta t$, or

$$\Delta t = \frac{1}{\pi a^2 \upsilon} .$$

We assume that the dust layer thickness increases continuously and uniformly with time. Let h denote the thickness of the layer and let t denote time. Then, since the thickness of a single layer equals 2a, the general thickness will be $h = (2a/\Delta t)t$, or

$$h = 2\pi a^3 \upsilon t , \tag{17}$$

where $t > \Delta t$ and υ is given by equation 16.

Values must be assigned to ρ, g, and η before h can be computed. According to Ref. 5, the density of the top few centimeters of the Martian surface is estimated to lie between 0.6 and 2.9 gm/cm^3. We shall assume that the density, ρ, of a dust particle in the Martian atmosphere is $\rho = 2.0\ gm/cm^3$. The gravitational acceleration at the surface of Mars is $g = 382\ cm/sec^2$. An approximate value of η can be determined from information contained in chapter 4 of Ref. 6. We assume that the Martian atmosphere is 100% carbon dioxide and that the temperature of the atmosphere near the Martian surface is $220^{\circ}K$ (Ref. 1). The resulting coefficient of viscosity is, from Ref. 6,

$$\eta = 1.11 \times 10^{-4}\ gm\ cm^{-1}\ sec^{-1} .$$

Combining equations 15, 16, and 17 and employing the above values of ρ, g, and η, we obtain

$$h = 0.96 \times 10^{7} \left(1 + \frac{0.343 \times 10^{-3}}{a}\right) a^{5}\ nt , \qquad (18)$$

where $t \le \tau$, $[a] = cm$, $[n] = cm^{-3}$, $[t] = sec$, $[h] = cm$, and τ denotes the length of time between dust storms. For given values of a and n, the maximum h occurs when $t = \tau$. (It is assumed that, while the wind is blowing, no dust exists on the solar panel, but as soon as the wind stops, dust begins to fall on the panel surface and continues to do so until the next storm at which time all the dust is blown off the panel.) Since the minimum values of a and n considered in our problem are 5×10^{-5} cm and 1 cm^{-3}, respectively, the minimum h, as a function of time, is

$$h_{min} = 2.36 \times 10^{-14}\ t ,$$

and since the maximum values of a and n considered in our problem are 5×10^{-3} cm and $10^{2}\ cm^{-3}$, respectively, the maximum h, as a function of time, is

$$h_{max} = 3.2 \times 10^{-3} \; t.$$

Note that for the minimum values of a and n, it would take approximately 10^5 years to accumulate a 1 mm thick dust layer, whereas, for the maximum values of a and n, this same thickness would be generated in only 31.2 seconds.

Sunlight incident on the solar panel will be reflected, absorbed, and transmitted by the dust layer on the panel surface. If we let ζ denote the absorption coefficient of the dust layer and let ν denote its reflectivity, then the transmitted intensity, I_2, which ultimately determines the output power of the solar panel is given by

$$I_2 = I_T \cos\chi \,(1 - \nu)\, e^{-\zeta (h \sec\chi)} , \tag{19}$$

where I_T is given by equation 5, h is given by equation 18, and χ is discussed in subsection 2.6. The reflectivity, ν, of the dust layer will not be constant but will depend on the layer thickness, h. A realistic functional dependency is

$$\nu = \nu_o \,(1 - e^{-kh}) ,$$

where ν_o = reflectivity of dust layer for large values of h. We assume that when h = 4a (a = radius of dust particle), then $\nu/\nu_o = 0.99$. Hence, $k = 1.15/a \approx 1/a$, so that

$$\nu = \nu_o \,(1 - e^{-h/a}) , \tag{20}$$

where h is given by equation 18.

Values must be assigned to the parameters ζ and ν_o. An approximate range of values for ζ is $1\ cm^{-1} \leq \zeta \leq 100\ cm^{-1}$. Also, $0 \leq \nu_o \leq 1$. As reliable estimates of ζ and ν_o (and k) are obtained from the Mariner missions, they can be substituted in equations 19 and 20 and a correspondingly realistic value of I_2 can then be determined.

SECTION 3

DUNE MOVEMENT STUDY

The existence of sand dunes on the Martian surface can be dangerous to an unmanned Martian mission in two ways: (1) the spacecraft may land on the side of a dune and then sink in the sand and/or topple over; (2) the spacecraft may land near a sand dune and eventually be covered by the dune as the dune is slowly "pushed" along the ground by a steady Martian wind. Neither of these mishaps can be prevented in the case of an unmanned landing, unless the spacecraft lands on a part of Mars which is free of strong winds and dust storms, and hence, free of sand dunes. According to Ref. 5, most of the dust storms on Mars occur in the $0^{o} \pm 35^{o}$ latitude belt.

If the height of the sand dunes is small compared with the vertical dimension of the landing spacecraft, then either of the above two mishaps will be less likely to occur. It is desirable, therefore, to know the height of sand dunes on the Martian surface. According to Ref. 7, it is not possible to divorce the height of a sand dune from the rate at which the sand is transported across the dune, since the dune would not exist without the surface winds which create it by moving sand particles over the Martian surface. Hence, in order to predict the dune height, one must also make some assumptions regarding the rate of sand movement.

The motion of sand from one side of the dune to the other side has the net effect of displacing the sand dune (very slowly) along the ground in the direction of the wind. According to Ref. 7, the speed, c, at which the sand dune moves along the ground, and the rate, q, at which sand is carried over the dune along a path of unit width, are related to the sand dune height, H, by

$$H = \frac{q}{\gamma c}, \tag{1}$$

where γ = bulk density of the sand dune. Here, $[q]$ = mass/(time x distance). Also according to Ref. 7, the quantity q is given by

$$q = C\left[\frac{0.174}{\log_{10}\frac{z}{k'}}\right]^3 \left(\frac{d}{D}\right)^{1/2} \frac{\rho_o}{g} (v-V_t)^3. \tag{2}$$

Here, C = dimensionless constant which depends on the type of sand, z = height above ground that the wind velocity, v, is measured, k' = height of ripples of sand on ground, d = diameter of sand particles, D = diameter of typical (earth) sand particle = 0.25 mm, ρ_o = density of Martian atmosphere near the surface, g - gravitational acceleration at Mars' surface, v = velocity of wind at a height z, V_t = threshold velocity, i.e., the velocity of wind at height k' at which sand particles on the ground first begin to move. By combining Eqs. 1 and 2 and assigning values to γ, C, z, k' d, ρ_o, g, and V_t, we will obtain H as a function of c and v. Treating c as a parameter, we can therefore obtain graphs of H versus v, for selected values of c.

According to Ref. 5, the density of the top few centimeters of the Martian surface brackets the value 2.0 gm/cm^3, which we take for γ. From Ref. 7, C = 1.8. Reasonable values to assume for the Martian surface are: z = 1 meter, k' = 10^{-2} meters, d = D. Also, ρ_o = 14.65 x 10^{-6} gm/cm^3, g = 382 cm/sec^2. Approximate values of V_t as a function of the particle radius, d/2, are given in the graph on page 6 of Ref. 8, for two surface pressures of the Martian atmosphere. We consider a 7-millibar air pressure (p_o = 7.0 x 10^3 dynes/cm^2) near the surface of Mars. Then, for d/2 = 0.25 mm/2 = 125 microns and p = 7 mb, the graph gives $V_t \approx 3.6 \times 10^2$ cm/sec. Combining Eqs. 1 and 2 and substituting the above values finally gives

$$H = \frac{2.275 \times 10^{-11}}{c} (v-360)^3, \qquad (3)$$

where $[c]$ = cm/sec, $[v]$ = cm/sec, $[H]$ = cm, and $v \geq 360$ cm/sec. Figure 3 shows a graph of H versus v for the five values, c = 0.1, 0.5, 1.0, 5.0, and 10 cm/sec.

It is interesting to note that, according to Ref. 7, sand dunes on the earth may reach a height of 30 meters and move along the ground at speeds ranging from 0.1 to 0.2 cm/hr.

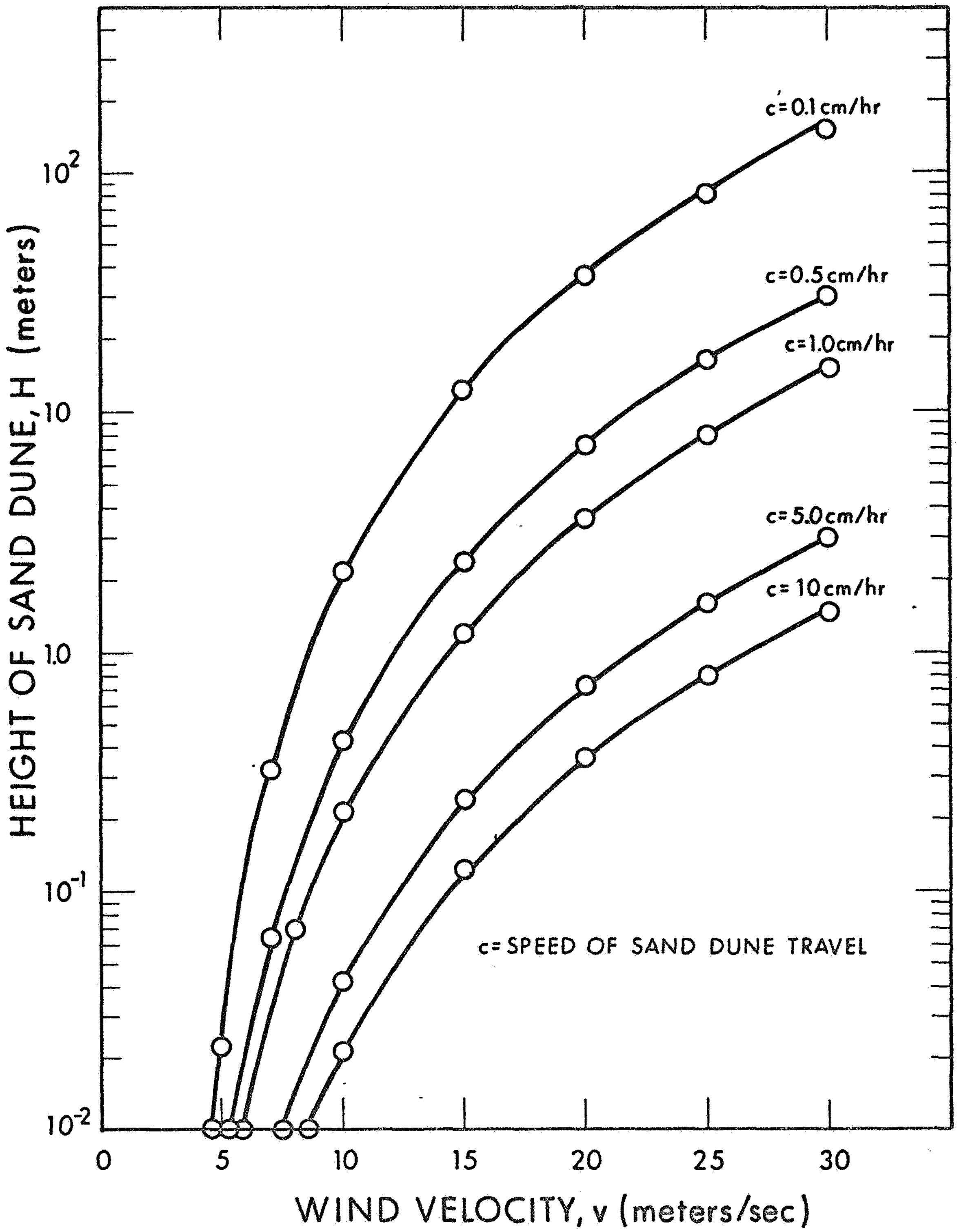

Figure 3. Sand Dune Height versus Wind Velocity

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SECTION 4

COMPUTER CELL MODEL PROGRAM ADDITIONS AND CHANGES

Tasks I and II of the present contract were essentially concerned with modifying the solar cell model used. That is, it was desired to incorporate arbitrary solar cell characteristic I-V curves, temperature coefficients, and cell resistances. The method of expressing cell characteristics in closed equation form was abandoned, and point-by-point descriptors were substituted.

4.1 SOLAR CELL MODEL

The previously developed computer program used an equation of the form

$$I = \alpha - \beta e^{\gamma V} \quad \text{(where I = current, V = voltage)}$$

as a model for the solar cell I-V curve. The constants α, β, and γ were manually computed for a given cell, temperature, and solar intensity. At a different temperature the origin of coordinates was assumed to undergo a translation proportional to the temperature change, ΔT. The translation equations were of the form

$$\Delta I = -T_c (\Delta T) ;$$

$$\Delta V = T_v (\Delta T) + (\Delta I) R_s ,$$

where T_c, the short-circuit temperature coefficient, and T_v, the open-circuit voltage coefficient, were each expressed as piecewise linear functions of solar intensity. The cell resistance is R_s.

Thus, for an arbitrary temperature, the current was

$$I = \alpha + \Delta I - \beta e^{\gamma(v-\Delta V)},$$

while the power became

$$\rho = IV = V [\alpha + \Delta I - \beta e^{\gamma(V-\Delta V)}].$$

Using the Newton-Raphson method, the maximum power point could be easily calculated from the above power equation.

Finally, for solar intensities differing from the initially specified intensity, the solar cell power was assumed to be a linear function of intensity.

The present computer program does not use any specific equation to represent the initial I-V curve. Instead, the curve is defined by reading into the computer up to 200 I-V points. Linear interpolations and extrapolations are then used to evaluate the curve at unspecified points.

The linear shift of the curve with change in temperature, which was assumed in the previous program, is still incorporated in the present version. However the calculation of T_c and T_v is now performed by inputting up to 25 values of each quantity and then linearly interpolating.

Up to this point the only differences between the previous program and the present program were implementational (i.e., instead of an equation for the I-V curve, data points were read in, etc.). Now, the first procedural difference: Instead of linearly scaling the maximum power of a cell (with solar intensity), the vertical axis of the I-V curve is linearly shifted proportional to intensity. (Thus the short-circuit current is assumed to vary linearly with intensity.) With the input data points shifted, the maximum power point is calculated by means of a binary search for the maximum of the expression P = IV, where P is the power output of the cell.

Finally, the open-circuit voltage is computed from the intersection of the abscissa with the input data points. This procedure results in a solar cell model whose short-circuit current is proportional to light intensity, at constant temperature, and whose open-circuit voltage changes logarithmically with intensity, provided a curve is specified having the normal exponential solar cell I-V curve. Temperature changes cause the origin of coordinates to undergo an effective translation along a curve whose slope depends upon the temperature coefficients used. The temperature coefficients may be arbitrary functions of solar intensity. All data points for the solar cell room temperature curve and the temperature coefficients may be spaced nonuniformly for input.

4.2 INPUT/OUTPUT LISTS

Several data cards are read by the program. The following subsections describe their order, contents, and format.

4.2.1 INPUT CARDS

The first input card specifies the cell resistance, R_s. It may be punched anywhere in the first ten columns, with a decimal point.

The second card contains the first value of the short-circuit temperature coefficient, T_c, and the value of the solar intensity associated with it. The units are milliamps $^{o}C^{-1}$ and milliwatts cm^{-2}. The next card contains the second value, etc. Up to 25 points may be thus specified. The values of T_c and brightness are read from anywhere in columns 1 to 10 and 11 to 20, respectively. The final card of this set must have a 7 punched in column 80 as a delimiter for this data set.

The next set of cards defines values of the open-circuit voltage temperature coefficient, T_v, as a function of solar intensity. Units are millivolts $^oC^{-1}$ and milliwatts cm^{-2}. The input format is identical to that of T_c, including the 7 punched in column 80 of the last card of the set.

Finally, the set of points (up to 200) defining the I-V curve is read. The current (in mA) is punched anywhere in columns 1 through 10, while the corresponding voltage (in volts) is punched anywhere in columns 11 through 20. Again, the final card of the set must contain a 7 punched in column 80.

In addition to the previously mentioned inputs, three additional cards are required for each run and must be read in order:

Card 1 - Title Card

Column 1 - Must contain a 1, which identifies it as the title card.

Columns 2 to 71 - Can be filled with any alphanumeric characters to identify the run.

Columns 72 to 80 - Not used

Card 2 - Input Data

Column 1 - Must contain a 2, which identifies it as the data card.

Columns 5 to 12 - Contains date the run is to start. The format is Mo/Da/Yr. (earth time)

Columns 15 to 22 - Contains date run is to be terminated. Same format as above.

Columns 25 to 32 - Contains date payload landed on surface of Mars. Same format as above.

Column 34 - Not used.

Column 35 - Cloud model flag. Presently not implemented.

Column 37 - Dust storm flag: 1, if storm is in progress; 0, if no storm is in progress.

NOTE: When "no storm" is specified, the program assumes that a storm has just ended and dust particles are just starting to fall on the panel.

Column 39 - Radiation model flag. If 1, use no attenuation model. If 2, use worst-case attenuation model (21%/year).

Columns 40 to 44 - Latitude of solar panel. Zero is at the equator; $+90^{\circ}$ is north pole; -90° is south pole.

Columns 45 to 48 - Angle of solar panel relative to the ground; 90° is a vertical panel.

Columns 50 to 54 - This is the azimuth angle of the panel defined as follows: Let a vector normal to the panel (pointing out) be projected on the local horizontal plane. The direction of this projection measured clockwise from north is the azimuth angle. Thus, for a panel tilted so as to receive the morning sun at any point above the eastern horizon, the azimuth angle would be 90°.

Columns 56 to 60 - Active area of solar panel in square feet.

Columns 61 to 65 - Desired power output in watts. For each instantaneous power point, the program calculates and prints the panel area required to generate this power.

Columns 66 to 70 - Defines the horizon below which the sun will not be able to shine on the solar panel. Can be used to indicate the blockage of sunlight, e.g., by a hill that rises 15^{o} above the horizon.

Columns 72 to 74 - Days print interval. If 1, prints daily summary every day; if 3, prints daily summary every third day, etc.

Columns 76 to 78 - Daily frequency print interval. Specifies the number of times within any Mars day (that a summary is printed) to print the instantaneous value of parameters. If 0, no instantaneous power points are printed (only the summary is printed). If 1, only the maximum power point is printed. If 2 or greater, the points in time for dawn, sun on panel, maximum power, sun off panel, and dusk are printed. In addition, this number is divided into the period of one Mars revolution and, starting from midnight, instantaneous power points are printed at this interval.

Card 3 - Input Data (continued)

Column 1 - Must contain a 3, which identifies it as the last data card.

Columns 2 to 10 - Value of ρ, the ratio of dust particle circumference to light wavelength. It can range from 2π to 200π.

Columns 11 to 20 - Value of N, the index of refraction of the dust particle. It can range from 1.4 to 1.8.

Columns 21 to 30 - Value of n, the number density of the dust particles in the atmosphere. It can range from 10^{15} to 10^{17} km^{-3}. (E format with the E to be punched in column 27)

Columns 31 to 40 - Value of a, the radius of the dust particles. It can range from 5×10^{-10} to 5×10^{-8} km. (E format with the E to be punched in column 37)

Columns 41 to 50 - Value of ζ, the absorption coefficient of the dust. It can range from 10^5 to 10^7 km^{-1}. (E format with the E to be punched in column 47)

Columns 51 to 60 - Value of ν, the reflection coefficient of the dust layer. It ranges from 0 to 1.

4.2.2 OUTPUT DATA

Column 1 - Time of Martian day in hours past midnight. (Martian midnight = 0.0000.)

Column 2 - The power output of one 4 cm^2 solar cell in milliwatts.

Column 3 - The power output, in watts, of a panel of 4 cm^2 solar cells whose area is specified in ft^2 as an input parameter.

Column 4 - The panel area required, in ft^2, to provide a power output specified as an input parameter.

Column 5 - The accumulated energy, in watt-hours, generated by the panel since the start of the computer run.

Column 6 - Solar intensity at the upper atmosphere of Mars in milliwatts/cm^2.

Columns 7, 8, 9 - Solar intensity transmission coefficients for the Mars atmosphere, cloud cover, and dust environment, respectively.

Column 10 - Magnitude of solar intensity, in mW/cm^2, after passing through the Mars atmosphere, cloud covers, and dust environment.

Column 11 - Solar intensity normal to panel surface in mW/cm^2.

Column 12 - Temperature of solar panel in ^oC.

Column 13 - Power output, in mW, of 4 cm^2 solar cell before radiation degradation is applied.

Column 14 - Percentage of column 13 actually generated due to radiation degradation.

Column 15 - Elevation of sun in degrees as measured from the local geographic vertical.

Column 16 - Azimuth of sun in degrees. That is, the angle measured in the local geographic horizontal plane between the projection of the sun-Mars line in that plane and Mars North (measured in the clockwise direction).

Column 17 - Elevation of the sun relative to the solar panel surface vertical.

Line preceding detail printout:

"Mars day" - The number of Martian days that have elapsed since start of computer program.

"Earth time" - The number of Earth days that have elapsed since midnight (GMT) of April 20, 1967 to midnight of this Mars day. Adding column 1 time to this time gives Earth GMT of that particular point.

Printed at the bottom of the page are the quantities:

(a) Short-circuit current (in mA),
(b) Maximum power point voltage (in volts), and
(c) Open circuit voltage (in volts),

for the three periods of the day:

(a) Near dawn,
(b) At the time of maximum power, and
(c) Near dusk.

The sun elevation angle for the "near dawn" and "near dusk" periods is also presented.

4.3 PROGRAM LISTING

The following is a literal copy of the cards comprising the computer program. Language used is Fortran IV, and no compilation or other messages are included. These data cards were used to run the sample problem.

```
RJOB 5411.BISHOP,F
RASSIGN M951,)DEVICE,SI*,)FBCD*
RASSIGN F960,)DEVICE,SI*,)FBCD*
RASSIGN F961,)DEVICE,LO*
RFORTRAN LS,GO,NS,ADP
      REAL MAAEP,MOECC,MICRO,LAT,LOSS
      INTEGER AIFG,CLDFG,DSTFG,CARID,CFG,DFG,ELEFG
      INTEGER RADFG,DSI,IPI,OUT,SMO,SDAY,SYR,EMO,EDAY,EYR
      INTEGER TITLE, START, END
      COMMON SMO,SDAY,SYR,EMO,EDAY,EYR,LMO,LDAY,LYR,AIFG,CLDFG,DSTFG
      COMMON RADFG,LAT,SLOPE,AZIMH,AREA,POUT,HORIZ,DSI,IPI,DELPT
      COMMON MICRO,IN,TRUEV,SEGIN,CEGIN,DECDY,TITLE,ADOMU,LPAGE,RADEG
      COMMON OUT,IMPFG,DELTI,MAAEP,EDPMR,MOECC,EPSIL,ERATI,EARTB,SEMIM
      COMMON START,END,LANDT,LOSS
      COMMON CORENT (200), VOLTAG (200), NIVPTS, SCTEMP (25), BSCT (25),
     *   NSCPTS, OCTEMP (25), BOCT (25), NOCPTS, RESIST
      COMMON /BERNIE/ BKRHO, BKENN, BKSN
      COMMON /DUSTY/ PARAMA, PARAML, PARAMV
      DIMENSION TITLE (35)
      IN = 60
      OUT = 61
      READ (IN, 2) RESIST
      NSCPTS = 0
   11 NSCPTS = NSCPTS + 1
      READ (IN, 2) SCTEMP (NSCPTS), BSCT (NSCPTS), NO MORE
      IF (NO MORE) 12, 11, 12
   12 NOCPTS = 0
   13 NOCPTS = NOCPTS + 1
      READ (IN, 2) OCTEMP (NOCPTS), BOCT (NOCPTS), NO MORE
      IF (NO MORE) 4, 13, 4
    4 NIVPTS = 0
    3 NIVPTS = NIVPTS + 1
      READ (IN, 2) CORENT (NIVPTS),VOLTAG (NIVPTS), NO MORE
    2 FORMAT (2F10.0,59XI1)
C     * * * * *
      CORENT (NIVPTS) = 1.18 * CORENT (NIVPTS) * 1000.0
C     * * * * *
      IF (NO MORE) 1, 3, 1
    1 LOSS = .95
      TMPFG=0.                                                          7254CCC2
      DELTI = 0.0208333333                                              7254CON1
      MAAEP = 240.222/57.29577951
      EDPMR = 687.4588                                                  7254CONO
      MOECC = 0.093379                                                  7254CONO
      EPSIL = 0.00001                                                   7254CONO
      ERATI = SQRT((1.0 + MOECC)/(1.0 - MOECC))                         7254CONO
      EARTB = 140.0                                                     7254CONO
      SEMIM = 1.523691                                                  7254CONO
      MICRO=0.0007
      RADEG=57.29577951
      TRUEV=115.450963/57.29577951
      EQINC = 23.99/57.29577951
      SEGIN = SIN(EQINC)                                                7254CONO
```

```
      CEQIN = COS(EGINC)                                                7254CONO
      DELDY=1.027486426
    9 READ(IN,8) CARID,TITLE                                            7254ELE1
    8 FORMAT(I1,35A2)                                                   7254ELE1
      IF(CARID-1)7,6,7
    7 WRITE(OUT,21)
   21 FORMAT (48H1TITLE CARD NOT WHERE IT SHOULD BE - JOB ABORTED)
      GO TO 9                                                           7254ELE3
C         READ  SET-UP  INFORMATION                                     7254ELE1
    6 READ(IN,10) CARID,SMO,SDAY,SYR,EMO,EDAY,EYR,LMO,LDAY,LYR,ATFG,CLDF7254ELE1
     1G,CFG,DSTFG,DFG,RADFG,LAT,SLOPE,AZIMH,AREA,POUT,ELEFG,HORIZ,DSI,  7254ELE1
     2IPI                                                               7254ELE1
   10 FORMAT(I1,1X,3(2X,I2,1X,I2,1X,I2),1X,6I1,F5.1,F4.1,1X,F5.1,1X,
     1F5.2,F5.1,I1,F5.1,1X,I3,1X,I5)
      AGOM1=0.0
      IF(CARID - 2)5,15,5                                               7254ELE1
    5 WRITE(OUT,20)                                                     7254ELE1
   20 FORMAT (58H1INPUT PARAMETER CARD NOT WHERE IT SHOULD BE - JOB ABOR7254ELE2
     *TED)
      GO TO 9                                                           7254ELE3
   15 READ (IN, 68) CARID,BKRHO, BKENN, BKSN, PARAMA, PARAML, PARAMV
   68 FORMAT(I1,F9.0,F10.0,3E10.2,F10.0)
      IF(CARID - 3) 69, 67, 69
   69 WRITE (OUT, 70)
   70 FORMAT (33H1THIRD CARD MISSING - JOB ABORTED)
      GO TO 9
   67 LPAGE = 1
   14 FORMAT(1H1,20X,72HM A R S   S O L A R   P O W E R   A N A L Y S I S  7254ELE1
     1P R O G R A M       REV 012X4HPAGEI4/25X12HRUN TITLE...35A2)
      IF(IPI)40,50,40                                                   7254EL
   50 DELPT=1.028
      GO TO 41                                                          7254EL
   40 DELPT=DELDY/IPI                                                   7254EL
   41 WRITE(OUT,14)LPAGE,TITLE                                          7254ELE1
      WRITE(OUT,16)SMO,SDAY,SYR,EMO,EDAY,EYR,LMO,LDAY,LYR               7254ELE2
   16 FORMAT (21H ANALYSIS PERIOD FROMI3,1H/,I2,1H/,I2,6H  TO  I2,1H/,I
     *2,1H/,I2/25H SPACECRAFT LANDING DATE I2,1H/I2,1H/I2//26H ATTENUATI
     *ON FACTORS USED-)
      WRITE (OUT, 17) PARAMA, BKRHO, BKENN, BKSN, PARAML, PARAMV
   17 FORMAT (/@ SMALL A =@E10.2@ KM@/@ RHO =@F8.2/@ LARGE N =@F6.2/@ SM
     *ALL N =@E10.2@ KM(-3)@/@ ZETA =@E10.2@ KM(-1)@/@ NU =@F6.3)
      WRITE (OUT,18) RADFG
   18 FORMAT (/@ RADIATION MODEL FLAG =@I2)
      IF (DSTFG) 25, 24, 25
   25 WRITE (OUT, 19)
   19 FORMAT (/@ DUST STORM IN PROGRESS@)
      GO TO 32
   24 WRITE (OUT, 28)
   28 FORMAT (/@ NO DUST STORM@)
   32 WRITE(OUT,37)LAT,SLOPE,AZIMH,AREA,POUT,HORIZ,DSI                  7254ELE1
   37 FORMAT (//21H SPACECRAFT POSITION-/1 H  LATITUDEF20.1,4H DEG/ 21H
     * PANEL INCLINED FROM/16H   HORIZONTAL BYF14.1,4H DEG/22H  DIRECTIO
     *N OF INCLINE/12H   (AZIMUTH)F18.1,4H DEG//17H SOLAR PANEL AREAF13.
```

```
     *1,7H SQ.FT./22H REQUIRED POWER OUTPUTF8.1,5HWATTS//16H DEFINED HOR
     *IZONF14.1,4H DEG//17H PRINTER CONTROL-/22H   PRINT,SUMMARY EVERY14
     *,7H DAY(S))                                                     7254ELE2
      IF(IPI-3)53,39,39                                               7254ELE1
   53 IF(IPI)42,43,42                                                 7254ELE1
   43 WRITE(OUT,44)
   44 FORMAT (22H   NO DETAIL PRINT-OUT)                              7254ELE1
      GO TO 52                                                        7254ELE1
   42 IF(IPI-1)46,47,46                                               7254ELE1
   47 WRITE(OUT,48)
   48 FORMAT (34H   PRINT MAXIMUM POWER DETAIL ONLY)                  7254ELE1
      GO TO 49                                                        7254ELE1
   46 WRITE(OUT,51)
   51 FORMAT (44H   PRINT MAX. POWER, DAWN, DUSK DETAILS ONLY)        7254ELE1
      GO TO 49                                                        7254ELE1
   39 ELEVS=DELPT*24.                                                 7254ELE1
      WRITE(OUT,56) ELEVS
   56 FORMAT (22H   PRINT DETAIL EVERY F8.3,20H HRS DURING DAYLIGHT)  7254ELE1
   49 WRITE(OUT,57)
   57 FORMAT (26H     (ONLY ON SUMMARY DAYS))                         7254ELE1
   52 HORIZ=HORIZ/RADEG                                               7254ELE3
      DEGRA = (1. - LOSS)*100. + .005                                 7254ELE2
      WRITE(OUT,61)DEGRA
   61 FORMAT(/105H SOLAR PANEL OUTPUT BASED ON MARINER 1969 S/N 2, 2X2 C
     *M SOLAR CONVERTER I-V CURVE,N/P .018 IN,2 OHM-CM//28H MISCELLANEOU
     *S POWER LOSSES F5.2,9H PER CENT)
      SYR=SYR+1900
      EYR=EYR+1900
      LYR=LYR+1900
      CALL JTIME(SMO,SDAY,SYR,START)
      CALL JTIME(EMO,EDAY,EYR,END)
      CALL JTIME(LMO,LDAY,LYR,LANDT)
      SYR=SYR-1900
      CALL PART 6
      GO TO 1
      END
```

```
RFORTRAN LS,GO,NS,ADP
      SUBROUTINE PART B
C         TOTWH   -  TOTAL ENERGY GENERATED SINCE START OF RUN            7254DEF2
C         IPI     -  INSTANTEOUS PRINT FREQUENCY )24/IPI== OF TIMES/DAY*  7254DEF2
C         MICRO   -  ALLOWABLE TIME ERROR IN LOCATING MAXIMUMPOWER        7254DEF2
C                 -  POINT IN DAYS ).000M= 1 MINUTE*                      7254DEF2
C         RADEG   -  CONVERSION FACTOR FROM RADIANS TO DEGREES            7254DEF2
C         IN      -  LOGICAL UNIT NUMBER OF DEVICE INPUT DATA IS ON       7254DEF2
C         OUT     -  LOGICAL UNIT NUMBER OF DEVICE RESULTS ARE TO BE      7254DEF2
C                 -  PRINTED ON                                           7254DEF2
C         DELDY   -  LENGTH OF MARTIAN DAY RELATIVL TO EARTH DAY          7254DEF2
C         CARID   -  CONTAINS NUMBER THAT IDENTIFIES THE TYPE OF INPUT    7254DEF2
C                 -  RECORD                                               7254DEF2
C         TITLE   -  CONTAINS ALPHANUMERIC CHARACTERS FROM INPUT RECORD   7254DEF2
C                 -  NUMBER 1                                             7254DEF2
C         EMO     -  MONTH NUMBER OF PROBLEM END TIME                     7254DEF2
C         EDAY    -  DAY OF PROBLEM END TIME                              7254DEF2
C         EYR     -  YEAR OF PROBLEM END TIME                             7254DEF2
C         LMO     -  MONTH NUMBER OF PAYLOAD LANDING DATE                 7254DEF2
C         LDAY    -  DAY OF PAYLOAD LANDING DATE                          7254DEF2
C         LYR     -  YEAR OF PAYLOAD LANDING DATE                         7254DEF2
C         CLDFG   -  CLOUD ATTENUATION MODEL TO USE - NOT IMPLIMENTED     7254DEF2
C         CFG     -  NOT USED                                             7254DEF2
C         DSTFG   -  DUST ATTENUATION MODEL TO USE - NOT IMPLEMENTED      7254DEF2
C         DFG     -  NOT USED                                             7254DEF2
C         RADFG   -  RADIATION ATTENUATION MODEL TO USE.IF 0,NO ATTEN     7254DEF2
C                 -                                       1, 21(/YEAR     7254DEF2
C         AREA    -  AREA OF SOLAR PANEL IN SQ. FT.                       7254DEF2
C         POUT    -  INPUT PARAMETER - DESIRED POWER OUTPUT IN WATTS      7254DEF2
C         ELEFG   -  IF 0 USE REFERENCE I-V CURVE FOR SOLAR CELL          7254DEF2
C                 -     1 READ I-V PARAMETERS OFF OF NEXT INPUT RECORD    7254DEF2
C         DSI     -  DAILY SUMMARY PRINTOUT INTERVAL                      7254DEF2
C         LPAGE   -  OUTPUT PAGE COUNTER                                  7254DEF2
C         DELPT   -  INSTANTEOUS RESULTS PRINT INTERVAL IN MARTIAN DAYS   7254DEF2
C         PTIME   -  NEXT POINT IN TIME TO OUTPUT INSTANTEOUS RESULTS     7254DEF2
C         NOL     -                                                       7254DEF2
C         HOS     -                                                       7254DEF2
C         PUCM1   -  PREVIOUS VALUE OF UNIT CELL POWER                    7254DEF2
C         LANDT   -  LANDING DATE IN DAYS FROM APRIL 20,1967              7254DEF2
C         ENDAY   -  MIDNIGHT OF CURRENT DAY                              7254DEF2
C         PRTDF   -  IF 1, PRINT SUMMARY AT END OF CURRENT DAY            7254DEF2
C         DPTCT   -  COUNT BETWEEN DAYS SUMMARY IS TO BE PRINTED          7254DEF2
C         NOFG    -  IF 0, BYPASS ADVANCING IN TIME IN SETTING UP FOR NX  7254DEF2
C         DAYCT   -  NUMBER OF MARTIAN DAYS SINCE START DAY               7254DEF2
C         PRINT   -                                                       7254DEF2
C         PDONE   -                                                       7254DEF2
C         POWFG   -                                                       7254DEF2
C         LINEC   -  = OF LINES PRINTED ON CURRENT OUTPUT PAGE            7254DEF2
C         AGOIN   -  ANGLE OF INCIDENCE OF SUN ON PANEL                   7254DEF0
C         AGOM1   -  MOST PREVIOUS VALUE OF AGOIN                         7254DEF0
C         AT1     -  ATTENUATION DUE TO ATMOSPHERE                        7254DEF0
C         ATFG    -  IF 0,USE NOMINAL MODEL.IF 1, USE WORST CASE          7254DEF0
C         ATMAT   -  SUB-ROUTINE THAT CALCULATES ATMOSPHERIC ATTENUATION  7254DEF0
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C        AZIMH  -  AZIMUTH ANGLE OF FALL LINE OF HILL S/C SITS ON        7254DEF0
C        BRITE  -  SOLAR INTENSITY AT MARS UPPER ATMOSPHERE              7254DEF0
C        CAZHL  -  COSINE OF AZIMH                                       7254DEF0
C        CEQIN  -  COSINE OF EQINC                                       7254DEF0
C        CLAT   -  COSINE OF LAT                                         7254DEF0
C        CLONG  -  COSINE OF LONG                                        7254DEF0
C        CPMER  -   COSINE OF PMERD                                      7254DEF0
C        CSLOP  -  COSINE OF SLOPE                                       7254DEF0
C        CTRUE  -  COSINE OF TRUE1                                       7254DEF0
C        DAWN   -  TIME OF SUNRISE IN EARTH TIME                         7254DEF0
C        DAWNF  -  IF 1, SUN AT DAWN                                     7254DEF0
C        DAYFG  -  IF 1, SUN ABOVE HORIZ. IF 0, SUN BELOW HORIZ.         7254DEF0
C        DAYWH  -  ENERGY GENERATED BY SOLAR ARRAY FOR CURRENT MARS DAY7254DEF0
C        DELTI  -  CALCULATION INTERVAL (IN EARTH DAYS AND FRACTION OF   7254DEF0
C                   DAYS)                                                7254DEF0
C        DUSK   -  TIME OF SUNSET IN EARTH TIME                          7254DEF0
C        DUSKF  -  IF 1, SUN AT DUSK                                     7254DEF0
C        EARTB  -  SOLAR INTENSITY AT 1 ASTRONOMICAL UNIT (AU)           7254DEF0
C        EDPMR  -  NUMBER OF EARTH DAYS PER MARS REVOLUTION              7254DEF0
C        EK1    -  TRIAL VALUE OF ECCENTRIC ANOMALY                      7254DEF0
C        EK2    -  NEW TRIAL VALUE OF ECCENTRIC ANOMALY                  7254DEF0
C        ELEMI  -  PREVIOUS VALUE OF ELEVS                               7254DEF0
C        ELEVS  -  SUN ELEVATION ANGLE AS MEASURED FROM LOCAL HORIZON    7254DEF0
C        EPSIL  -  ALLOWABLE TRUNCATION ERROR IN CALCULATING             7254DEF0
C                  ECCENTRIC ANOMALY                                     7254DEF0
C        EQINC  -  INCLINATION OF EQUATORIAL PLANE TO ORBIT              7254DEF0
C        ERATI  -  RATIO USED TO CALCULATE TRUE1 (SEE CONSTANTS LIST)    7254DEF0
C        HORIZ  -  HORIZON ANGLE. ELEVATION ANGLE OF DAY-NIGHT LINE      7254DEF0
C        JTIME  -  SUBROUTINE TO CONVERT FROM DAY-MONTH-YEAR TIME        7254DEF0
C                   FORMAT TO NUMBER OF DAYS FROM A REFERENCE DATE       7254DEF0
C        LAT    -  MARS LATITUDE OF SPACECRAFT                           7254DEF0
C        LITEF  -  IF 1, SUN ABOVE PANEL. IF 0,SUN BELOW PANEL           7254DEF0
C        LONG   -  LONGITUDE, NUMBER OF DEGREES FROM MERIDIAN THAT IS    7254DEF1
C                   AT MIDNIGHT AT START TIME                            7254DEF1
C        MAAEP  -  MEAN ANOMALY OF MARS AT EPOCH (APRIL 20,1967)         7254DEF0
C        MEANI  -  CURRENT MEAN ANOMALY                                  7254DEF0
C        MOECC  -  MARS ORBITAL ECCENTRICITY                             7254DEF0
C        MXPOC  -  MAXIMUM POWER OUTPUT OF UNIT CELL DURING DAY          7254DEF0
C        OFFFG  -  IF 1, SUN JUST OFF SOLAR PANEL                        7254DEF0
C        ONFG   -  IF 1, SUN JUST ON SOLAR PANEL                         7254DEF0
C        PASS1  -  FLAG TO INDICATE FIRST PASS THROUGH CALCULATIONS      7254DEF0
C        PMERD  -  ANGLE BETWEEN VERNAL EQUINOX AND PRIME MERIDIAN       7254DEF0
C        SAZHL  -  SINE OF AZIMH                                         7254DEF0
C        SDAY   -  DAY OF PROBLEM START TIME                             7254DEF0
C        SEMIM  -  SEMI-MAJOR AXIS OF MARS ORBIT                         7254DEF0
C        SEQIN  -  SINE OF EQINC                                         7254DEF0
C        SLAT   -  SINE OF LAT                                           7254DEF0
C        SLONG  -  SINE OF LONG                                          7254DEF0
C        SLOPE  -  VERTICAL SLOPE ANGLE OF HILL S/C SITS ON              7254DEF0
C        SMO    -  MONTH NUMBER OF PROBLEM START TIME                    7254DEF0
C        SPMER  -  SINE OF PMERD                                         7254DEF0
C        SSLOP  -  SINE OF SLOPE                                         7254DEF0
C        START  -  TI AT START OF PROBLEM                                7254DEF0
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C          STRUE   -  SINE OF TRUE1                                            7254DEF0
C          SYR     -  YEAR OF PROBLEM START TIME                               7254DEF0
C          TI      -  CURRENT TIME (IN EARTH DAYS AND FRACTION OF DAYS)        7254DEF0
C          THOLD   -  TEMPORARY STORAGE FOR TI WHILE SPECIAL POINTS ARE        7254DEF0
C                      CALCULATED (SUCH AS DAWN)                               7254DEF0
C          TRUE1   -  CURRENT TRUE ANOMALY                                     7254DEF0
C          TRUEV   -  TRUE ANOMALY OF MARS VERNAL EQUINOX                      7254DEF0
C          XG      -  SUN X COMPONENT VECTOR IN LOCAL GEOCENTRIC FRAME         7254DEF0
C          XHILL   -  SUN X COMPONENT VECTOR IN LOCAL GEOCENTRIC FRAME         7254DEF0
C          YG      -  SUN Y COMPONENT VECTOR IN LOCAL GEOCENTRIC FRAME         7254DEF0
C          YHILL   -  SUN Y COMPONENT VECTOR IN LOCAL GEOCENTRIC FRAME         7254DEF0
C          ZG      -  SUN Z COMPONENT VECTOR IN LOCAL GEOCENTRIC FRAME         7254DEF0
C          ZHILL   -  SUN Z COMPONENT VECTOR IN LOCAL GEOCENTRIC FRAME         7254DEF0
      REAL MAAEP,         MOECC,LONGM
      REAL                LONGH,MAXPW,MICRO
      REAL LAT,LOSS
      INTEGER ATFG,CLDFG,DSTFG                                                 7254ELE3
      INTEGER DAWNF,RADFG
      INTEGER POWFG,PDONE,DUSKF,DAWNF,ONFG,OFFFG,LITEF ,PRTDF,DPTCT,DSI 7254EL
      INTEGER IPI,PRINT,OUT                                                    7254EL
      INTEGER PASS1                                                            7254T+D0
      INTEGER SMO,SDAY,SYR,EMO,EDAY,LYR,START,END
      INTEGER DAYFG,DAYCT
      INTEGER TITLE
      COMMON SMO,SDAY,SYR,EMO,EDAY,EYR,LMO,LDAY,LYR,ATFG,CLDFG,DSTFG
      COMMON RADFG,LAT,SLOPE,AZIMH,AREA,POUT,HORIZ,DSI,IPI,DELPT
      COMMON MICRO,IN,TRUEV,SEGIN,CEGIN,DELDY,TITLE,AGOMO,LPAGE,RADEG
      COMMON OUT,TMPFG,DELTI,MAAEP,EOPMR,MOECC,EPSIL,ERATI,EARTB,SEMIM
      COMMON START,END,LANDT,LOSS
      COMMON CROD (400), KROD, BARF (50), NORD, TRASH (50), JUNK, GOOF
      DIMENSION M (17), TITLE (35)
      DIMENSION SUNANG (2), SCCEND (3), VMPEND (3), OCVEND (3)
   14 FORMAT(1H1,20X,72HM A R S   S O L A R   P O W E R   A N A L Y S I S  7254ELE1
     1P R O G R A M       REV 012X4HPAGEI4/25X12HRUN TITLE...35A2)
      NOL=45                                                                   7254ELE1
      HOS=24.                                                                  7254ELE1
      PJCM1=0.
      DAYWH=0.
      TOTWH=0.
      CSLOP=COS(SLOPE/RADEG)
      SSLOP=SIN(SLOPE/RADEG)
      CAZHL=COS(AZIMH/RADEG)
      SAZHL=SIN(AZIMH/RADEG)
      PTIME=START+DELPT                                                        7254ELE2
      ENDAY=START+DELDY                                                        7254EL
      PRTDF=1                                                                  7254EL
      DPTCT=DSI                                                                7254ELE1
      NOFG=0
      DAYCT=1
      TOTWH=0.
      PRINT=0                                                                  7254EL
      PDONE=0                                                                  7254EL
      POWFG=0                                                                  7254EL
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      DUSKF=0                                                           7254EL
      DAWNF=0                                                           7254EL
      ONFG=0                                                            7254EL
      OFFFG=0                                                           7254EL
      LITEF =0
      DAYFG = 0
      FLEM1 =0.0
      LONG=0.0                                                          7254ELE2
      SLONG = SIN(LONG)                                                 7254ICNO
      CLONG = COS(LONG)                                                 7254ICNO
      PASS1 = 1                                                         7254ICNO
      SLAT = SIN(LAT/ 57.29577951)
      CLAT = COS(LAT/ 57.29577951)
      TI = START
      KSTAGE = 1
      GO TO 1022
  180 CALL SUN UP (TI, PMERD, ELEVS,
     *   ER1, ER2, EPSIL, TRUE1, PASS1, XG, YG, ZG, SLAT, CLONG, CLAT,
     *   SLONG, MAAEP, EDPMK, MOECC, ERATI, TRUEV, CEGIN, SEGIN)
      IF(POWFG-1)60,310,60
C       TEST ELEVATION ANGLE FOR BEING ABOVE DEFINED HORIZON           7254ELE0
   60 IF(ELEVS - HORIZ)265,275,275                                      7254ELE2
C       SUN BELOW HORIZON  -  IS IT ALMOST DAWN                         7254ELE1
  265 IF(DAWNF -1)300,310,300                                           7254ELE1
C       IT IS NOT NEAR DAWN. DID WE JUST PAST DUSK                      7254ELE1
  300 IF(DAYFG -1)320,330,320                                           7254ELE1
C       NO,WE DID NOT PAST DUSK IS THIS DUSK                            7254ELE1
  320 IF(DUSKF-1)510,310,510
C       YES,DUSK WAS PASTED. FIND TIME OF DUSK AND RE-CALCULATE THERE 7254ELE1
  330 IF(ONFG-1)331,310,331                                             7254ELE2
  331 DAYFG = 0                                                         7254ELE2
      DUSK = TI - DELTI + ELEM1*DELTI/(ELEM1 - ELEVS)                   7254ELE1
      DUSKF = 1                                                         7254ELE1
      HOLDL= PMERD                                                      7254ELE1
      PMERD = PMERD + 6.12421108*(DUSK - TI)                            7254ELE1
      THOLD = TI                                                        7254ELE1
      TI = DUSK                                                         7254ELE1
      GO TO 180                                                         7254ELE1
C       SUN ABOVE HORIZON - IS IT ABOUT AT DUSK                         7254ELE1
  275 IF(DUSKF - 1)350,310,350
C       NOT AT DUSK. DID WE JUST PASS THRU DAWN                         7254ELE1
  350 IF(DAYFG)310,360,310                                              7254ELE1
C       JUST PASSED THRU DAWN. FIND TIME OF DAWN AND RE-CALCULATE       7254ELE1
  360 DAWN = TI -DELTI + ELEM1*DELTI/(ELEM1 - ELEVS)                    7254ELE1
      HOLDL= PMERD                                                      7254ELE1
      PMERD = PMERD + 6.12421108*(DAWN - TI)                            7254ELE1
      THOLD = TI                                                        7254ELE1
      TI=DAWN
      DAWNF = 1                                                         7254ELE1
      MAXPW=0.
      DAYWH = 0.0                                                       7254ELE1
      DAYFG = 1                                                         7254ELE1
      GO TO 180                                                         7254ELE1
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  310 CALL INC ANG (XG, YG, ZG, SSLOP, CSLOP, CAZHL, SAZHL, AGOIN)
C         IS SUN ABOVE OR BELOW PANEL                                   7254ELE1
      IF(AGOIN) 370,380,380                                             7254ELE1
C         IF AT DAWN, GO PRINT IT
C         IF AT DAWN + SUN ALMOST ON PANEL, ASSUME IT IS ON PANEL
  370 IF(DAWNF-1)371,372,371
  372 IF(AGOIN-ELEVS+.002)340,430,430                                   7254ELE2
C         SUN BELOW PANEL. IS IT ALMOST ON                              7254ELE1
  371 IF(ONFG-1)390,340,390
C         NOT JUST ON. DID SUN JUST GO OFF OF PANEL                     7254ELE1
  390 IF(LITEF - 1)400,410,400                                          7254ELE1
C         IS THIS THE CALCULATION OF THE OFF POINT                      7254ELE1
  400 IF(OFFFG - 1)401,340,401                                          7254ELE3
  401 IF(DUSKF-1)660,340,660                                            7254ELE3
C         SUN JUST PASSED OFF POINT                                     7254ELE1
  410 OFFFG=1
      LITEF = 0                                                         7254ELE1
      IF(DUSKF-1)411,340,411
  411 THOLD = TI
      HOLDL=PMERD
      TI = TI - DELTI + AGOMI*DELTI/(AGOMI   AGOIN)                     7254ELE1
      PMERD = PMERD + 6.12421108*(TI-THOLD)                             7254ELE1
      GO TO 180                                                         7254ELE1
C         SUN IS ON PANEL. IS IT JUST ON                                7254ELE1
  380 IF(DUSKF-1)381,410,381
  381 IF(OFFFG-1)420,340,420
C         SUN IS ON PANEL. DID IT JUST GET ON                           7254ELE1
  420 IF(LITEF - 1)430,340,430
C         SUN JUST GOT ON PANEL.                                        7254ELE1
  430 ONFG = 1                                                          7254ELE1
      LITEF = 1                                                         7254ELE1
C         IS THIS DAWN                                                  7254ELE1
      IF(DAWNF - 1)440,340,440                                          7254ELE1
C         SUN IS ON PANEL AFTER DAWN                                    7254ELE1
  440 THOLD = TI                                                        7254ELE1
      HOLDL = PMERD                                                     7254ELE1
      TI = TI + DELTI*(-1.0 + AGOMI/(AGOMI   AGOIN))                    7254ELE1
      PMERD = PMERD + 6.12421108*(TI-THOLD)                             7254ELE1
      GO TO 180                                                         7254ELE1
C         CALCULATE INTENSITY OF SUN AT UPPER ATMOSPHERE                7254ELE1
  340 BRITE = EARTB/((SEMIM*(1.0 - HOECC*COS(ER2)))**2)                 7254ELE1
C         CALCULATE ATTENUATION OF SUN BETWEEN UPPER ATMOSPHERE AND     7254ELE1
C          PANEL FACE.                                                  7254ELE1
      CALL ATMAT(ELEVS,ATFG,AT1)                                        7254ELE1
      CALL CLDAT(TRULI,LAT,CLDFG,AT2)                                   7254ELE1
      RUNTYM = (TI - START) * 86400.0
      CALL DSTAT (AGOIN, RUNTYM, DSTFG, AT3)
      SUNRY = BRITE * AT1 * AT2 * AT3
      SNPOW = SUNRY * SIN (AGOIN)
C         CALCULATE SOLAR PANEL TEMPERATURE                             7254ELE1
      TFDWN=(TI-DAWN)*24.                                               7254ELE2
      PHI=90./RADEG-AGOIN                                               7254ELE2
      IF(SNPOW)450,460,460                                              7254ELE1
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  450 SNPOW = 0.0                                                   7254ELE1
  460 AINDG=SNPOW
      CALL TEMP(LAT,IFDWN,AINDG,PHI,TMPFG,PTEMP)                    7254ELE5
      KALGL8 = 0
      GO TO (15, 17, 98), KSTAGE
   15 IF (ELEVS) 98, 98, 25
   25 IF (ELEVS - 0.262) 98, 19, 19
   19 KALGL8 = 1
      CALL POWER (PTEMP, SNPOW, RWPOW, VMPEND (1), SCCEND (1), OCVEND
     *    (1), KALGL8)
      SUNANG (1) =  ELEVS * 57.29578
      KSTAGE = 2
      GO TO 99
   17 IF (ELEVS - 0.262) 21, 21, 98
   21 KALGL8 = 1
      CALL POWER (PTEMP, SNPOW, RWPOW, VMPEND (3), SCCEND (3),
     *    OCVEND (3), KALGL8)
      SUNANG (2) = ELEVS * 57.29578
      KSTAGE = 3
      GO TO 99
   98 CALL POWER(PTEMP,SNPOW,RWPOW,VRWPOW,SCURNT,OCVOLT,KALGL8)
   99 CALL RADAT(TI,LANDT,RADFG,AT4)                                 7254ELE1
      POWUC = RWPOW *AT4 * LOSS                                      7254ELE1
      IF(ONFG - 1)470,480,470                                        7254ELE1
C         RECORD TIME SUN CAME ONTO PANEL                            7254ELE1
  480 ONTIM = TI                                                     7254ELE1
  470 IF(POWFG-1)490,610,490                                         7254ELE1
  490 IF(LITEF - 1)511,520,511                                       7254ELE1
  520 IF(ONFG - 1)530,540,530                                        7254ELE1
  540 DELPW  = THOLD - TI                                            7254ELE1
  545 IF(PDONE - 1)560,550,560                                       7254ELE1
  511 IF(OFFFG - 1)570,580,570                                       7254ELE1
  570 IF(DUSKF - 1)550,580,550
  580 DELPW = TI - THOLD + DELTI                                     7254ELE1
  550 DELWH = 0.5*DELPW*(POCMI+POWUC)
      DAYWH = DAYWH + DELWH                                          7254ELE1
      TOTWH = TOTWH + DELWH                                          7254ELE1
      DELPW=DELTI
      GO TO 545                                                      7254ELE1
  560 IF(POWFG - 1)600,610,600                                       7254ELE1
  600 IF(POWUC - POCMI)620,550,550
  620 POWFG = 1                                                      7254ELE1
      MAXPW = POWUC                                                  7254ELE5
      DAYWH=DAYWH-DELWH
      TOTWH=TOTWH-DELWH
      PHOLD = TI                                                     7254ELE1
      LONGH = PMERD                                                  7254ELE1
  650 TI = TI - MICRO                                                7254ELE1
      POCMI = POWUC                                                  7254ELE1
      PMERD = PMERD - 0.12421108* MICRO                              7254ELE1
      GO TO 180                                                      7254ELE1
  610 IF(POWUC - POCMI)630,640,640                                   7254ELE1
  640 IF(TI - ONTIM)630,650,650                                      7254ELE1
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630 PDONE = 1                                                          7254ELE1
    MAXPW = 5.574*AREA*(TOTWH+.5*(TI-PHOLD+DELTI)*(POCM1+MAXPW))       7254ELE3
    IF(PRTDF - 1)660,670,660                                           7254ELE1
670 IF(IPI-1)660,700,700                                               7254ELE2
550 POCM1 = POWOC                                                      7254ELE1
    IF(PRTDF - 1)660,690,660                                           7254ELE1
690 IF(IPI - 2)665,710,710                                             7254ELE1
750 IF(DAWNF - 1)720,730,720                                           7254ELE1
730 WRITE(OUT,731)                                                     7254ELE1
731 FORMAT(17H      *** DAWN *** )                                     7254ELE1
    GO TO 700                                                          7254ELE1
720 IF(ONFG - 1)770,740,770                                            7254ELE1
740 WRITE(OUT,741)                                                     7254ELE1
741 FORMAT(25H      *** SUN ON PANEL ***)                              7254ELE1
    GO TO 700                                                          7254ELE1
710 IF(DAWNF + ONFG - 2)750,760,750                                    7254ELE1
760 WRITE(OUT,761)                                                     7254ELE1
761 FORMAT(26H      *** DAWN - SUN ON PANEL )                          7254ELE1
    GO TO 700                                                          7254ELE1
770 IF(DUSKF + OFFFG - 2)780,790,780                                   7254ELE1
790 WRITE(OUT,791)                                                     7254ELE1
791 FORMAT(40H      *** DUSK - SUN CUT OFF OF PANEL *** )              7254ELE1
    GO TO 700                                                          7254ELE1
780 IF(OFFFG - 1)800,810,800                                           7254ELE1
810 WRITE(OUT,811)                                                     7254ELE1
811 FORMAT(34H      *** SUN BELOW SOLAR PANEL ***)                     7254ELE1
    GO TO 700                                                          7254ELE1
800 IF(DUSKF - 1)820,830,820                                           7254ELE
830 WRITE(OUT,831)                                                     7254ELE1
831 FORMAT(17H      *** DUSK ***)                                      7254ELE1
    GO TO 700                                                          7254ELE1
820 IF(PRINT - 1)660,700,660                                           7254ELE1
700 TODAY =(TI - ENDAY + DELDY) *24.0 +0.005                           7254ELE2
    APOWR = AREA * POWOC*0.922/4.0
    ASIMS=RADEG*ATAN((-YG)/(-XG))
    IF(-XG)840,850,850                                                 7254ELE1
840 ASIMS=ASIMS+180.                                                   7254ELE1
    GO TO 855                                                          7254ELE1
850 IF(ASIMS)845,855,855                                               7254ELE1
845 ASIMS=360.+ASIMS                                                   7254ELE1
855 AINDG = PHI*RADEG                                                  7254ELE3
    PHI= 90. - ELEVS*RADEG                                             7254ELE
    RTWH=TOTWH*AREA*5.574                                              7254ELE3
    REQAR=(4.0*POUT)/(POWOC*0.922)
    IF(POWFG-1)856,857,856                                             7254ELE3
857 M(1)=TODAY                                                         7254ELE3
    M(2)=POWOC                                                         7254ELE3
    M(3)=APOWR                                                         7254ELE3
    M(4)=REQAR                                                         7254ELE3
    M(5) = MAXPW                                                       7254ELE3
    M(6)=BRITE                                                         7254ELE3
    M(7)=AT1                                                           7254ELE3
    M(8)=AT2                                                           7254ELE3
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                                                                   7254ELE3
      M(9)=AT3                                                     7254ELE3
      M(10)=SUNNY                                                  7254ELE3
      M(11)=SNPOW                                                  7254ELE3
      M(12)=PTEMP                                                  7254ELE3
      M(13)=RWPOW                                                  7254ELE3
      M(14)=AT4                                                    7254ELE3
      M(15)=PHI                                                    7254ELE3
      M(16)=ASIMS                                                  7254ELE3
      M(17)=AINDG
      CALL POWER (PTEMP, SNPOW, RWPOW, VMPEND (2), SCCEND (2), OCVEND
     *   (2), 1)
      GO TO 665                                                    7254ELE3
  856 WRITE(OUT,860)TODAY,POWOC,APOWR,RCOAR,RTWH ,BRITE,AT1,AT2,AT3,  7254ELE2
     1SUNNY,SNPOW,PTEMP,RWPOW,AT4,PHI   ,ASIMS,AINDG
  860 FORMAT(1H ,F6.2, 2F7.2,F7.1,F9.1,F6.2,5F7.2 ,F7.1,2F7.2,F5.1,2F6.17254ELE3
     1)                                                            7254ELE3
  665 IF(DUSKF-1)660,870,660                                       7254ELE1
C        PRINT SUMMARY IF AT DUSK                                  7254ELE1
  870 IF(PDONE-1)890,871,890                                       7254ELE3
  871 IF(PRTDF-1)890,872,890                                       7254ELE3
  872 IF(IPI-1)890,873,873                                         7254ELE3
  873 WRITE(OUT,681)                                               7254ELE3
  681 FORMAT(32H      *** MAXIMUM POWER POINT *** )                7254ELE1
      WRITE(OUT,860)M(1),M(2),M(3),M(4),M(5),M(6),M(7),M(8),M(9),M(10), 7254ELE3
     1M(11),M(12),M(13),M(14),M(15),M(16),M(17)
  890 HOS =(DUSK - DAWN)* 24.0                                     7254ELE1
      DAWN =(DAWN - ENDAY + DELDY)*24. + .  5                      7254ELE1
      RTWH=TOTWH*AREA*5.574                                        7254ELE3
      DAYWH=DAYWH*AREA*5.574                                       7254ELE3
      WRITE(OUT,900)DAWN,HOS,M(3) ,DAYWH,RTWH                      7254ELE3
  900 FORMAT (10H SUMMARY -/9H    DAWN =F6.2,20H HRS, HOURS OF SUN =F6.2,
     *14H, MAX OUTPUT =F7.2,19HW, ENERGY FOR DAY =F7.1,20HWH, ENERGY TO
     *DATE =F8.1,2HWH)
      WRITE (OUT, 31)
   31 FORMAT (//56X29H SHORT        MAXIMUM       OPEN/56X31HCIRCUIT       P
     *OWER       CIRCUIT/56X31HCURRENT       VOLTAGE      VOLTAGE)
      WRITE (OUT, 32) SUNANG (1), SCCEND (1), VMPEND (1), OCVEND (1)
   32 FORMAT (/30X11HNEAR DAWN (F4.1,6H DEG.)F11.1,2F12.3)
      WRITE (OUT, 33) SCCEND (2), VMPEND (2), OCVEND (2)
   33 FORMAT (/30X20HPERIOD OF MAX. POWERF12.1,2F12.3)
      WRITE (OUT, 34) SUNANG (2), SCCEND (3), VMPEND (3), OCVEND (3)
   34 FORMAT (/30X11HNEAR DUSK (F4.1,6H DEG.)F11.1,2F12.3)
      KSTAGE = 1                                                   7254ELE1
  660 IF(DAWNF+ONFG+OFFFG+DUSKF-1)910,920,920                      7254ELE1
  920 TI = THOLD                                                   7254ELE1
      PMERD = HOLDL                                                7254ELE1
      DAWNF = 0                                                    7254ELE1
      ONFG  = 0                                                    7254ELE1
      OFFFG = 0
      NOFG=0
  910 IF(POWFG-1)930,940,930                                       7254ELE1
  940 TI = PHOLD
      PMERD=LONGH
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      POWFG =0                                                          7254ELE1
      NOFG=0
C        IF SPECIAL CONDITION EXIST DON T UPDATE PRINT COUNTER
  930 IF(NOFG)931,950,931
  931 PRINT=0
      IF(TI - PTIME)950,960,960                                         7254ELE1
  960 PTIME = TI + DELPT                                                7254ELE1
      PRINT = 1                                                         7254ELE1
  950 IF(TI - ENDAY)970,980,900                                         7254ELE1
  980 TI = ENDAY                                                        7254ELE1
      GO TO 990                                                         7254ELE1
  970 IF(DUSKF - 1)510,1000,510                                         7254ELE1
 1000 DUSKF = 0                                                         7254ELE1
      PDCMI=0.
      PMERD = PMERD + 6.12421108*(ENDAY - TI)                           7254ELE1
      TI = ENDAY                                                        7254ELE1
      LITEF=0
  990 ENDAY = ENDAY + DELDY                                             7254ELE1
      PDONE=0
      DAYCT = DAYCT + 1                                                 7254ELE1
      PTIME = TI + DELPT                                                7254ELE1
      DPTCT  = DPTCT - 1                                                7254ELE1
      IF(DPTCT)1010,1020,1010                                           7254ELE1
 1010 PRTDF = 0                                                         7254ELE1
      GO TO 510                                                         7254ELE1
 1020 DPTCT = DSI                                                       7254ELE1
      PRTDF = 1                                                         7254ELE1
 1021 NODL=HOS/DELPT
      IF(NODL-(NOL-LINEC))1025,1022,1022
 1022 LINEC=0
      LPAGE=1+LPAGE                                                     7254ELE1
      WRITE(OUT,14)LPAGE,TITLE                                          7254ELE1
      WRITE(OUT,1029) LAT                                               7254ELE2
 1029 FORMAT (12H LATITUDE = F5.1,4H DEG)
      WRITE(OUT,1023)                                                   7254ELE1
 1023 FORMAT(//119H  TIME   UNIT     MAX  REQUIRED ACCUM  SI AT      TRANSM
     *ISSION       S.I. AT PANEL  PANEL  CELL  RADIAT SUN  SUN  INCIDENCE
     2/56H OF DAY CELL    PANEL    AREA   ENERGY UPPER        FACTORS20X,40
     3H    TEMP  POWER  DEGRAD ELEV AZIM- ANGLE)
      WRITE(OUT,1026)
 1026 FORMAT (20H (HOUR) POWER  POWER10X12H(WATT- ATMOS24X12HMAG   NORMA
     *L8X13HBEFORE FACTOR6X8HOUTH   ON/9X27H(MW)  (WATT)(SQ.FT.) HOURS)9X
     *47HATMO   CLOUD  DUST   (MW/SQ. CM)   (CLN) RADIAT8X16H(DG) (DEG)
     *PANEL/)
      DPAST=TI-START                                                    7254ELE2
 1025 WRITE(OUT,1030)DAYCT,DPAST,SMO,SDAY,SYR                           7254ELE2
 1030 FORMAT(/11H MARS DAY =,I3 ,14H, EARTH TIME =,F9.4,23H DAYS PAST HO
     *UR 0.0 OF I2,1H/I2,1H/I2,4H GMT)
  510 IF(NOFG)512,515,512
  512 ELEM1=ELEVS
      AGOM1=AGOIN
      TI = TI + DELTI
      PMERD = PMERD + 6.12421108*DELTI
```

```
513 NOFG=1
    IF(II-END)180,180,280
280 WRITE(OUT,281)
281 FORMAT(14H ** END OF RUN)                                  7254ELE2
    RETURN
    END
```

```
RFORTRAN LS,GO,NS,ADP                                               7254EL
      SUBROUTINE ATMAT(X,LY,Z)
      COMMON /BERNIE/ A, B; C
      E = 1.57079632 - X
      CALL KAPPA (A, B, C, E, Z)
      IF (Z) 1, 9, 2
    1 WRITE (61, 3)
    3 FORMAT (30H SET ATTENUATION EQUAL TO ZERO)
      WRITE (61, 99) Z
   99 FORMAT (8 ATTENUATION COEFFICIENT =@E10.2)
      Z = 0.0
      RETURN
    2 IF (Z - 1.0) 9, 9, 4
    4 WRITE (61, 5)
    5 FORMAT (29H SET ATTENUATION EQUAL TO ONE)
      WRITE (61, 99) Z
      Z = 1.0
    9 RETURN                                                        7254EL
      END
```

```
RFORTRAN LS,GO,NS,AOP
      SUBROUTINE SUN UP (TI, PMERD, ELEVS,
     *   EK1, EK2, EPSIL, TRUEI, PASS1, XG, YG, ZG, SLAT, CLONG, CLAT,
     *   SLONG, MAAEP, EDPMK, MOECC, ERATI, TRUEV, CEGIN, SEGIN)
      REAL MAAEP, MEANI, MOECC
      INTEGER PASS1                                                     7254ELE0
C        MEAN ANOMALY OF START DATE                                     7254ELE0
  180 MEANI= MAAEP + (TI * 6.2831853)/EDPMK                             7254ELE0
C        CALCULATE ECCENTRIC ANOMALY                                    7254ELE0
      EK1 = MEANI
  190 EK2 = (MOECC * (SIN(EK1) - EK1 * COS(EK1)) + MEANI)/(1.0 - MOECC *7254ELE0
     .1 COS(EK1))                                                       7254ELE0
      IF(EPSIL - ABS(EK1-EK2))200,210,210                               7254ELE0
  200 EK1 = EK2                                                         7254ELE0
      GO TO 190                                                         7254ELE0
C        CALCULATE TRUE ANOMALY (FROM PERIHELION)                       7254ELE0
  210 TRUEI = 2.0 * ATAN(ERATI *((SIN(EK2/2.0))/COS(EK2/2.0)))          7254ELE0
C        CALCULATE TRUE ANOMALY (FROM VERNAL EQUINOX)                   7254ELE0
      TRUEI= TRUEI - TRUEV                                              7254ELE0
C        CALCULATE COMPONENTS OF MARS-SUN VECTOR IN LOCAL GEOCENTRIC    7254ELE0
C        FRAME                                                          7254ELE0
      IF(PASS1-1)220,230,220                                            7254ELE0
  230 PMERD = ATAN(CEGIN * SIN(TRUEI)/ COS(TRUEI))                      7254ELE0
      IF(COS(TRUEI))240,250,250                                         7254ELE0
  240 PMERD = PMERD + 3.1415927                                         7254ELE0
  250 PASS1 = 0                                                         7254ELE0
  220 CPMER = COS(PMERD)                                                7254ELE0
      SPMER = SIN(PMERD)                                                7254ELE0
      CTRUE = COS(TRUEI)                                                7254ELE0
      STRUE = SIN(TRUEI)
      XG=-SLAT*(CLONG*(CPMER*CTRUE+SPMER*CEGIN*STRUE)+SLONG*(-SPMER*CTRU
     1E+CPMER*CEGIN*STRUE))-CLAT*SEGIN*STRUE
      YG=-SLONG*(CPMER*CTRUE+SPMER*CEGIN*STRUE)+CLONG*(-SPMER*CTRUE+CPME
     1R*CEGIN*STRUE)
      ZG=-CLAT*(CLONG*(CPMER*CTRUE+SPMER*CEGIN*STRUE)+SLONG*(-SPMER*CTRU
     1E+CPMER*CEGIN*STRUE))+SLAT*SEGIN*STRUE                            7254ELE0
      ELEVS = ATAN( ZG/ SQRT(XG**2 + YG**2))
      RETURN
      END
```

```
RFORTRAN LS,GO,NS,ADP
      SUBROUTINE INC ANG (XG, YG, ZG, SSLOP, CSLOP, CAZHL, SAZHL, AGOIN)
C         CALCULATE SUN ANGLE ON PANEL                                  7254ELE1
  310 XHILL = XG*CSLOP*CAZHL - YG*CSLOP*SAZHL - ZG*SSLOP                7254ELE1
      YHILL = XG*SAZHL + YG*CAZHL                                       7254ELE1
      ZHILL = XG*SSLOP*CAZHL - YG*SSLOP*SAZHL + ZG*CSLOP                7254ELE1
      AGOIN = ATAN(ZHILL/SQRT(XHILL**2 + YHILL**2))                     7254ELE1
      RETURN
      END
```

```
RFORTRAN LS,GO,NS,ADP
      SUBROUTINE POWER (I, B, PL, VP, SCI, OCV, KFLAG)
      IF (B) 8, 8, 7
    7 VMIN = 0.0
      VMAX = 1.0
      KF = 1
    1 VP = (VMIN + VMAX)/2.0
      CALL JUICE (A, VP, I, B, SCI, DI, DV, KF)
      PL = A * VP
      IF (VMAX - VMIN - 0.0001) 5, 5, 4
    4 VPLUS = VP + 0.000025
      CALL JUICE (A, VPLUS, I, B, SCI, DI, DV, KF)
      PR = A * VPLUS
      IF (PR - PL) 2, 5, 3
    2 VMAX = VP
      GO TO 1
    3 VMIN = VP
      GO TO 1
    5 IF (PL) 8, 8, 10
   10 IF (VP) 8, 8, 6
    8 PL = 0.0
      VP = 0.0
      SCI = 0.0
      OCV = 0.0
      RETURN
    6 IF (KFLAG) 12, 13, 12
   12 CALL GETOCV (DI, DV, OCV)
   13 IF (0.52 * B - PL) 9, 11, 11
    9 SCI = SCI * 0.52 * B/PL
      PL = 0.52 * B
   11 RETURN
      END
```

```
RFORTRAN LS,GO,NS,ADP
      SUBROUTINE JUICE (I, V, T, B, SCI, DI, DV, KFLAG)
      REAL I
      COMMON K7A (13), Q7A (6), K7B (2), Q7B (2), K7C, Q7C (4),
     *   K7D (35), Q7D, K7E, Q7E, K7F, Q7F (9), K7G (3), Q7G
      COMMON AMPS (200), VOLTS (200), NIV, TC (25), BTC (25), NTC,
     *   TV (25), BTV (25), NTV, RS
      IF (KFLAG) 8, 9, 8
    8 KFLAG = 0
      IF (B - BTC (2)) 1, 1, 4
    4 IF (B - BTC (NTC - 1)) 2, 3, 3
    1 NDX = 1
      GO TO 5
    3 NDX = NTC - 1
      GO TO 5
    2 LIMIT = NTC - 1
      DO 6 K = 3, LIMIT
      IF (B - BTC (K)) 7, 7, 6
    6 CONTINUE
      STOP
    7 NDX = K - 1
    5 ALPHA = TC (NDX) + (B - BTC (NDX)) * ((TC (NDX + 1) - TC (NDX))/
     *   (BTC (NDX + 1) - BTC (NDX)))
      IF (B - BTV (2)) 11, 11, 14
   14 IF (B - BTV (NTV - 1)) 12, 13, 13
   11 NDX = 1
      GO TO 15
   13 NDX = NTV - 1
      GO TO 15
   12 LIMIT = NTV - 1
      DO 16 K = 3, LIMIT
      IF (B - BTV (K)) 17, 17, 16
   16 CONTINUE
      STOP
   17 NDX = K - 1
   15 BETA = TV (NDX) + (B - BTV (NDX)) * ((TV (NDX + 1) - TV (NDX))/
     *   (BTV (NDX + 1) - BTV (NDX)))
      DI = ALPHA * (T - 28.0)
      DV = (BETA * (28.0 - T) - DI * RS)/1    .0
      DI = - DI
      DV = - DV
      CALL KURENT (SCI, DV)
      SCI = SCI - DI
      SCTERM = SCI * (1.0 - B/140.0)
      SCI = SCI - SCTERM
      DI = DI + SCTERM
    9 VSHIFT = V + DV
      CALL KURENT (VALI, VSHIFT)
      I = VALI - DI
      RETURN
      END
```

```
RFORTRAN LS,GO,NS,ADP
      SUBROUTINE KURENT (I, VSHIFT)
      REAL I
      COMMON K7A (13), Q7A (6), K7B (2), Q7B (2), K7C, Q7C (4),
     *   K7D (35), Q7D, K7E, Q7E, K7F, Q7F (9), K7G (3), Q7G
      COMMON AMPS (200), VOLTS (200), NIV, TC (25), BTC (25), NTC,
     *   TV (25), BTV (25), NTV, RS
      IF (VSHIFT - VOLTS (2)) 21, 21, 24
   24 IF (VSHIFT - VOLTS (NIV - 1)) 22, 23, 23
   21 NDX = 1
      GO TO 25
   23 NDX = NIV - 1
      GO TO 25
   22 LIMLO = 2
      LIMHI = NIV - 1
   20 LIMID = (LIMHI + LIMLO)/2
      IF (VSHIFT - VOLTS (LIMID)) 27, 28, 26
   26 LIMLO = LIMID
      GO TO 29
   27 LIMHI = LIMID
   29 IF (LIMHI - LIMLO - 1) 30, 30, 20
   28 LIMLO = LIMID
   30 NDX = LIMLO
   25 I = AMPS (NDX) + (VSHIFT - VOLTS (NDX)) * ((AMPS (NDX + 1) -
     *   AMPS (NDX))/(VOLTS (NDX + 1) - VOLTS (NDX)))
      RETURN
      END
```

```
RFORTRAN LS,GO,NS,ADP
      SUBROUTINE GETOCV (DI, DV, OCV)
      COMMON R7A (13), Q7A (6), R7B (2), Q7B (2), R7C, Q7C (4),
     *  R7D (55), Q7D, R7E, Q7E, R7F, Q7F (9), R7G (3), Q7G
      COMMON AMPS (200), VOLTS (200), NIV, CROD (50), NIC, BARF (50),
     *  NIV, RS
      NDX = NIV
      DO 2 K = 2, NIV
      NDX = NIV - K + 1
      IF (AMPS (NDX) - DI) 2, 3, 3
    2 CONTINUE
      OCV = 0.0
      RETURN
    3 OCV = VOLTS (NDX) - DV - (AMPS (NDX)   DI)* (VOLTS (NDX + 1) -
     *  VOLTS (NDX))/(AMPS (NDX + 1) - AMPS (NDX))
      RETURN
      END
```

```
RFORTRAN LS,GO,ADP
      SUBROUTINE KAPPA (RHO,ENN,SN,GAMR,AKAP)
      COMMON/BK1/AK1,AK2,H,AOR,R22,X1,X2,FACX1,FACX2,X12,X22,XL,N,NL1,
     1F,EN,NL2
      DIMENSION F(700)
      DATA AK1,     H,R,AOR/.0802,        20 .,3332.,267./
      DATA ENO,SIGR,XLAM/2.32E+32,1.79E-36,5.E-10/
      DATA SC,ETA/4.49E-03,.056/
      IF(IFLG1-12345)10,100,10
   10 IFLG1=12345
      F(1)=0.
      DO  50 I=2,700
      Y=I
   50 F(I)=ALOG10(Y)+F(I-1)
      R2=R*R
      R22=2.*R2
      HPR2=(H+R)*(H+R)
      A2C=3.*ENO*SIGR/8.
      XL=XLAM*XLAM/6.2831853
      RHOL=1.E+70
      ENL=1.E+70
      SNL=1.E+70
      ULIM=.01745329*45.
  100 IF(RHO.EQ.RHOL.AND.ENN.EQ.ENL) GO TO 150
      EN=ENN
      X1=RHO
      X2=RHO*EN
      FACX1=SQRT(2./(3.1415927*X1))
      FACX2=SQRT(2./(3.1415927*X2))
      X12=2.*X1
      X22=2.*X2
      CALL SIGG(SIGMA)
      AK2=SN*SIGMA
      CALL INTG(1,0.,ULIM,BI1,DUM)
      CALL INTG(2,0.,ULIM,BI2,DUM)
      IF(ABS(SN).LE.1.E-07) GO TO 120
      CALL INTG(3,0.,ULIM,BI3,DUM)
      GO TO 130
  120 BI3=0.
  130 CALL INTG(4,0.,ULIM,BI4,DUM)
      CGAMR=1./R
      CALL INTG(5,0.,200.,BI50,CGAMR)
      RHOL=RHO
      ENL=ENN
      GO TO 160
  150 IF(SN.EQ.SNL) GO TO 200
  160 S=SN*SIGMA
      A10=EXP(-SC*BI50-S*H)
      EX=EXP(-S*H)
      A2=A2C*EX*(BI1+ETA *BI2)
      A3=XL/2.*EX*(BI3/SIGMA+SN*ETA *BI4)
      FAC=1.+(1./A10)*(A2+A3)
      SNL=SN
```

```
200 CGAM=COS(GAMR)
    SGAM=SIN(GAMR)
    EL=-R*CGAM+SQRT(HPR2-R2 *SGAM*SGAM)
    CGAMR=CGAM/R
    CALL INTG(5,0.,EL,BI5,CGAMR)
    A1=EXP(-SC*BI5-S*EL)
    AKAP=A1*FAC
    RETURN
    END
```

```
RFORTRAN LS,GO,ADP
      SUBROUTINE FUNC(ITYPE,X,V,VAR)
      COMMON/BK1/AK1,AK2,H,AOR,R22,X1,X2,FACX1,FACX2,X12,X22,XL,N,NL1,
     1F,EN,NL2
      DIMENSION F(700)
      IF(ITYPE.EQ.5) GO TO 5000
      COX=COS(X)
      GO TO (1000,2000,3000,4000)ITYPE
 1000 XNUM=(1.-.056/COX)*(1.+COX*COX)*SIN(X)
      XDEN=AK1*COX+AK2*(1.-COX)
      V=XNUM/XDEN
      RETURN
 2000 XNUM=(1.+COX*COX)*TAN(X)
      XDEN=2.*AK1*COX+AK2*(1.-COX)
      V=XNUM/XDEN
      RETURN
 3000 F1=(1.-.056/COX)
      CALL SMALLI(X,ANS1,ANS2)
      IF(X)3100,3400,3100
 3100 EX=-AK2*(1.-COX)*(206./COX)
      F2=(1.-EXP(EX))/(1.-COX)
      GO TO 3500
 3400 F2=AK2*H
 3500 V=F1*F2*(ANS1+ANS2)*SIN(X)
      RETURN
 4000 CALL SMALLI(X,ANS1,ANS2)
      XNUM=(ANS1+ANS2)*TAN(X)
      XDEN=AK1*COX+AK2*(1.-COX)
      V=XNUM/XDEN
      RETURN
 5000 V=EXP(-AOR*(X*X/R22+X*VAR))
      RETURN
      END
```

```
RFORTRAN LS,GO,ADP
      SUBROUTINE INTG(ITYPE,A,B,Y,VAR)
  600 CALL FUNC(ITYPE,A,V1,VAR)
      CALL FUNC(ITYPE,B,V2,VAR)
      FAB=V1+V2
      DELX=B-A
      SOLD=0.
      SNEW=0.
      YNEW=.9E+50
      N=3
  900 X=A+DELX/2.
      SOLD=SOLD+SNEW
      SNEW=0.
      YOLD=YNEW
 1000 CALL FUNC(ITYPE,X,V,VAR)
      SNEW=SNEW+V
      X=X+DELX
      IF(X-B)1000,1300,1300
 1300 YNEW=DELX/6.*(FAB+4.*SNEW+2.*SOLD)
 1400 IF(ABSF(YNEW/YOLD-1.)-1.E-04)1800,18  ,1500
 1500 IF(N-300)1600,1700,1700
 1600 DELX=DELX/2.
      N=2*N-1
      GO TO 900
 1700 WRITE(108,1)ITYPE
    1 FORMAT(11H FLAG FOR I,I2)
 1800 Y=YNEW
      RETURN
      END
```

```
RFORTRAN LS,GO,ADP
       SUBROUTINE SIGG(SIGMA)
       COMMON/BK1/AK1,AK2,H,AOR,R22,X1,X2,FACX1,FACX2,X12,X22,XL,N,NL1,
      1F,EN,NL2
       DIMENSION F(700),X(4),RR(4),RRL(4)
       DO 100 I=1,4
   100 RR(I)=0.
       N=0
   125 N=N+1
       IF(N-350)140,140,130
   130 WRITE(61,4)
     4 FORMAT(22H N IS GREATER THAN 350)
       STOP
   140 DO 200 I=1,4
   200 RRL(I)=RR(I)
       CALL VWYZ(V,W,Y,Z,X)
       N2=2*N+1
   220 RR(1)=RRL(1)+N2*V*V
       RR(2)=RRL(2)+N2*W*W
       RR(3)=RRL(3)+N2*Y*Y
       RR(4)=RRL(4)+N2*Z*Z
       DO 230 J=1,4
       IF(ABS(RR(J)-RRL(J))-1.E-04)230,125,125
   230 CONTINUE
       SIGMA=XL*(RR(1)+RR(2)+RR(3)+RR(4))
       RETURN
       END
```

```
RFORTRAN LS,GO,ADP
      SUBROUTINE SMALLI(TH,ANS1,ANS2)
      COMMON/BK1/AK1,AK2,H,AOR,R22,X1,X2,FACX1,FACX2,X12,X22,XL,N,NL1,
     1F,EN,NL2
      DIMENSION F(700),X(4),R(4),RL(4)
      CTH=COS(TH)
      DO 175 I=1,4
  175 R(I)=0.
      ANS1=1.E+50
      ANS2=1.E+50
      A=1.E+50
      B=1.E+50
      C=1.E+50
      D=1.E+50
      IFLA=0
      IFLB=0
      IFLC=0
      IFLD=0
      N=0
  125 N=N+1
      IF(N-350)140,140,130
  130 WRITE(61,4)
    4 FORMAT(22H N IS GREATER THAN 350)
      STOP
  140 AL=A
      BL=B
      CL=C
      DL=D
      DO 200 I=1,4
  200 RL(I)=R(I)
      ANS1L=ANS1
      ANS2L=ANS2
      CALL VWYZ(V,W,Y,Z,X)
  300 IF(N-1)320,310,320
  310 ALF=1.
      BET=CTH
      ALF2=1.
      GO TO 350
  320 IF(N-2)340,330,340
  330 ALF=3.*CTH
      ALF1=ALF
      BET=6.*CTH*CTH-3.
      GO TO 350
  340 ALF=((2.*N-1)*ALF1*CTH-N*ALF2)/(N-1)
      BET=N*ALF*CTH-(N+1)*ALF1
      ALF2=ALF1
      ALF1=ALF
  350 A=V*BET+Y*ALF
      B=W*BET+Z*ALF
      C=V*ALF+Y*BET
      D=W*ALF+Z*BET
      FAC=2*N+1
      FAC=FAC/(N*(N+1))
```

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```
      R(1)=RL(1)+FAC*A
      R(2)=RL(2)+FAC*B
      R(3)=RL(3)+FAC*C
      R(4)=RL(4)+FAC*D
      ANS1=R(1)*R(1)+R(2)*R(2)
      ANS2=R(3)*R(3)+R(4)*R(4)
      DO 440 I=1,4
      IF(ABS(RL(I)/R(I)-1.)-.001)440,440,125
  440 CONTINUE
  480 IF(IFLA-1)495,505,495
  495 IF(ABS(A)-ABS(AL))505,505,500
  500 IFLA=1
  505 IF(IFLB-1)510,525,510
  510 IF(ABS(B)-ABS(BL))525,525,520
  520 IFLB=1
  525 IF(IFLC-1)530,545,530
  530 IF(ABS(C)-ABS(CL))545,545,540
  540 IFLC=1
  545 IF(IFLD-1)550,565,550
  550 IF(ABS(D)-ABS(DL))565,565,560
  560 IFLD=1
  565 ISUM=IFLA+IFLB+IFLC+IFLD
      IF(ISUM-4)125,600,125
  600 ANS1=ANS1L
      ANS2=ANS2L
      RETURN
      END
```

```
RFORTRAN LS,GO,ADP
          SUBROUTINE VWYZ(V,W,Y,Z,X)
          COMMON/BK1/AK1,AK2,H,AOR,R22,X1,X2,FACX1,FACX2,X12,X22,XL,N,NL1,
         1F,EN,NL2
          DIMENSION F(700),X(4)
          NL1=(N-1.)/2.+1.
          NL2=N/2.+1.
          CALL DGGP(1,X)
          DX1=X(1)
          DX2=X(2)
          QX1=X(3)
          QX2=X(4)
          CALL DGGP(2,X)
          GX1=X(1)
          GX2=X(2)
          PX1=X(3)
          PX2=X(4)
          ANG=X1 +N*1.5707963
          SANG=SIN(ANG)
          CANG=COS(ANG)
          ELX1=(-FACX1)*(PX1*(SANG+CANG/X12)+QX1*(CANG-SANG/X12)-GX1*CANG
         1  +DX1*SANG)
          AKX1=FACX1*(PX1*CANG-QX1*SANG)
          CALL HJ(HX1,AJX1,X1,N,PX1,QX1,GX1,DX1,FACX1)
          CALL HJ(HX2,AJX2,X2,N,PX2,QX2,GX2,DX2,FACX2)
          FKX1=SQRT(1.5707963*X1)
          FKX2=SQRT(1.5707963*X2)
          X0=(-1)**(N+1)*FKX1
          FX1=X0*AKX1
          GX1=X0*(ELX1+AKX1/X12)
          PSIX1=FKX1*AJX1
          PSIX2=FKX2*AJX2
          EX1=FKX1*(HX1+AJX1/X12)
          EX2=FKX2*(HX2+AJX2/X22)
          EM=EN*PSIX1*EX2-EX1*PSIX2
          S=EN*EX2*FX1-PSIX2*GX1
          T=EN*EX1*PSIX2-PSIX1*EX2
          U=EN*PSIX2*GX1-EX2*FX1
          DEN=EM*EM+S*S
          V=(-EM)*EM/DEN
          W=EM*S/DEN
          DEN=T*T+U*U
          Y=(-T)*T/DEN
          Z=T*U/DEN
          RETURN
          END
```

```
RFORTRAN LS,GO,ADP
      SUBROUTINE HJ(HX,AJX,X,N,P,Q,G,D,FAC)
      X2=2.*X
      ANG=X-N*1.5707963
      SANG=SIN(ANG)
      CANG=COS(ANG)
      HX=FAC*(P*(CANG-SANG/X2)-Q*(SANG+CANG/X2)+G*SANG+D*CANG)
      AJX=FAC*(P*SANG+Q*CANG)
      RETURN
      END
```

```
RFORTRAN LS,GO,ADP
      SUBROUTINE DQUP(ITYP,X)
      COMMON/BK1/AK1,AK2,H,AOR,R22,X1,X2,FACX1,FACX2,X12,X22,XL,N,NL1,
     1F,EN,NL2
      DIMENSION X(4),F(700)
      DO 50 I=1,4
   50 X(I)=0.
      GO TO (60,70)ITYP
   60 NL=NL1
      GO TO 100
   70 NL=NL2
  100 DO 1000 I=1,NL
   90 GO TO (110,120)ITYP
  110 II=2*I-1
      GO TO 125
  120 II=2*(I-1)
  125 IF((I/2)*2-I)140,130,140
  130 NUM1=1
      GO TO 150
  140 NUM1=-1
  150 NUM2=N+II
      XNUM2=F(NUM2)
      IDEN1=II-1
      GO TO(300,500)ITYP
  300 IF(IDEN1)370,360,370
  360 XDEN1=0.
      GO TO 380
  370 XDEN1=F(IDEN1)
  380 IDEN2=N-II
      IF(IDEN2+1)400,728,400
  400 IF(IDEN2)420,410,420
  410 XDEN2=0.
      GO TO 700
  420 XDEN2=F(IDEN2)
      GO TO 700
  500 IDEN2=N-II
      IF(IDEN2)520,510,520
  510 XDEN2=0.
      GO TO 530
  520 XDEN2=F(IDEN2)
  530 IF(IDEN1+1)550,728,550
  550 XDEN1=F(IDEN1)
  700 XND=XNUM2-XDEN1-XDEN2
  725 DEN1=II*ALOG10(2.*X1)
      DEN2=II*ALOG10(2.*X2)
      X(1)=X(1)+NUM1*EXP(2.30258509*(XND-DEN1-ALOG10(X1)))
      X(2)=X(2)+NUM1*EXP(2.30258509*(XND-DEN2-ALOG10(X2)))
  728 IF(II)740,730,740
  730 X(3)=1.
      X(4)=1.
      GO TO 1000
  740 YI=II
      XDEN3=XDEN1+ALOG10(YI)
```

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```
  800 XND=XNUM2-XDEN3-XDEN2
      X(3)=X(3)-NUM1*EXP(2.30258509*(XND-DEN1))
      X(4)=X(4)-NUM1*EXP(2.30258509*(XND-DEN2))
 1000 CONTINUE
      RETURN
      END
```

```
RFORTRAN LS,GO,NS,ADP                                       7254EL
      SUBROUTINE RADAT(T,T2,L,EM)
      INTEGER T2
      IF(L-1) 10,20,10
   20 EM=1.0
      RETURN
   10 EM= 1.0-0.21*(T-T2)/365.
      IF(EM)30,40,40
   30 EM=0.0
   40 RETURN                                                7254EL
      END
```

```
RFORTRAN LS,GO,NS,ADP
      SUBROUTINE CLDAT(X,Y,LZ,LL)                                  7254EL
      EL=1                                                         7254EL
      RETURN                                                       7254EL
      END                                                          7254EL
```

```
RFORTRAN LS,GO,NS,ADP
      SUBROUTINE DSTAT (AGOIN, TAU, KFLAG, AT)
      COMMON /BERNIE/ RHO, ENN, EN
      COMMON /DUSTY/ A, ETA, GNU
      COSX = SIN (AGOIN)
      IF (KFLAG) 1, 2, 1
    1 AT = 1.0
      RETURN
    2 H = 0.96E12 * (1.0 + 0.343E-8/A) * EN * TAU * A ** 5
      AT = EXP (-ETA * H/COSX) * (1.0 - GNU * (1.0 - EXP (-H/A)))
      RETURN
      END
```

```
RFORTRAN LS,GO,NS,ADP                                                7254JLN0
      SUBROUTINE  JTIME(MO,DAY,IYR ,JDAY)
      INTEGER DYOFM     ,S,MO,DAY,IYR,JDAY
      DIMENSION DYOFM (11)                                           7254JLN0
      DYOFM(1)=31                                                    7254JLN0
      DYOFM(2)=28                                                    7254JLN0
      DYOFM(3)=31                                                    7254JLN0
      DYOFM(4)=30                                                    7254JLN0
      DYOFM(5)=31                                                    7254JLN0
      DYOFM(6)=30                                                    7254JLN0
      DYOFM(7)=31                                                    7254JLN0
      DYOFM(8)=31                                                    7254JLN0
      DYOFM(9)=30                                                    7254JLN0
      DYOFM(10)=31                                                   7254JLN0
      DYOFM(11)=30                                                   7254JLN0
      S=(IYR -1967)*365                                              7254JLN0
C                 **ADD A DAY FOR EACH INTERVING LEAP YEAR           7254JLN0
      IF(1968-IYR) 100,130,110                                       7254JLN0
  100 DO 120I=1968,IYR,4                                             7254JLN0
      IF(I-IYR)120,130,150                                           7254JLN0
  120 S=S+1                                                          7254JLN1
  110 IM=1964                                                        7254JLN0
  115 IF(IM-IYR)150,140,160                                          7254JLN1
  160 S=S-1                                                          7254JLN0
      IM=IM-4                                                        7254JLN0
C                ***ADD ONE TO DAYS IF YEAR IS A LEAP YEAR AND MO IS 3  7254JLN0
      GO TO 115                                                      7254JLN0
  130 IF(MO-3)150,180,180                                            7254JLN0
  180 S=S+1                                                          7254JLN0
      GO TO 150                                                      7254JLN0
  140 IF(MO-3)155,150,150                                            7254JLN1
  155 S=S-1                                                          7254JLN0
C                 **ADD NUMBER OF DAYS IN YEAR UP TO SPECIFIED MONTH(MO)7254JLN0
  150 I=MO-1                                                         7254JLN0
      IF(I)170,190,170                                               7254JLN0
  170 DO 175 J=1,I                                                   7254JLN0
  175 S=S+DYOFM(J)                                                   7254JLN0
C                 **ADD NUMBER OF DAYS + SUBTRACT 110 DAYS (1-1 TO 4-20)7254JLN0
  190 JDAY = S+DAY-110                                               7254JLN0
      RETURN                                                         7254JLN0
      END
```

```
RFORTRAN LS,GO,NS,ADP
      SUBROUTINE TEMP (LAT,TIME,FGS,PHI,IMPFG,PTEMP)
C     LAT=LATITUDE
C     TIME=HOURS FROM DAWN
C     FGS=F*GS IN MILLIWATTS/CM SQ
C     PHI - PHI  RADIANS
C     TMPFG - MUST BE SET = 0. IN INITIALIZATION AREA OF MAIN PROGRAM
C     PTEMP=PANEL TEMPERATURE IN DEGREES C
      REAL LAT
      DIMENSION  TS0(13),TA0(13),TS40(13),TA40(13)
      IF(TMPFG)100,10,100
   10 TMPFG=1.
C     TEMP. AT 90 DEG. LATITUDE       - DEG. F
      T90=-109.3
C     SURFACE TEMPS AT 0 DEG. LAT.    - DEG. F
      TS0( 1)=-171.5
      TS0( 2)=-123.
      TS0( 3)=- 66.
      TS0( 4)=- 25.
      TS0( 5)=   4.
      TS0( 6)=  23.
      TS0( 7)=  38.
      TS0( 8)=  46.
      TS0( 9)=  18.
      TS0(10)=- 15.
      TS0(11)=- 46.
      TS0(12)=- 73.
      TS0(13)=- 92.5
C     ATMOSPHERIC TEMPS AT 0 DEG. LAT.      DEG. F
      TA0( 1)=-162.5
      TA0( 2)=-158.5
      TA0( 3)=-150.
      TA0( 4)=-135.
      TA0( 5)=-107.5
      TA0( 6)=- 89.
      TA0( 7)=- 76.5
      TA0( 8)=- 70.
      TA0( 9)=- 73.
      TA0(10)=- 80.5
      TA0(11)=- 90.
      TA0(12)=- 98.5
      TA0(13)=-107.
C     SURFACE TEMPS AT 40 DEG. LAT.              DEG.F
      TS40( 1)=-198.5
      TS40( 2)=-172.
      TS40( 3)=-113.
      TS40( 4)=- 57.
      TS40( 5)=- 25.
      TS40( 6)=-  2.
      TS40( 7)=  14.5
      TS40( 8)=  26.
      TS40( 9)=- 20.
      TS40(10)=- 56.
```

```
      TS40(11)=- 81.
      TS40(12)=-103.
      TS40(13)=-119.
C     ATMOSPHERIC TEMPS AT 40 DEG. LAT.
      TA40( 1)=-192.
      TA40( 2)=-189.
      TA40( 3)=-182.
      TA40( 4)=-170.
      TA40( 5)=-149.
      TA40( 6)=-115.5
      TA40( 7)=- 94.5
      TA40( 8)=- 84.
      TA40( 9)=- 90.
      TA40(10)=-104.
      TA40(11)=-116.
      TA40(12)=-126.
      TA40(13)=-134.5
C     CALC. SURF. AND ATMOS. TEMPS AT 0 AND 40 DEG. LAT.FOR GIVEN TIME
  100 ITM=TIME
      PART=TIME-ITM
      IT1=ITM+1
      IT2=ITM+2
      IF(IT2-13)500,500,510
  500 TS40I=TS40(IT1)+PART*(TS40(IT2)-TS40(IT1))
      TA40I=TA40(IT1)+PART*(TA40(IT2)-TA40(IT1))
      GO TO 520
  510 TDIFF=(TIME-12.)/12.
      TS40I=(TS40(1)-TS40(13))*TDIFF + TS4 (13)
      TA40I=(TA40(1)-TA40(13))*TDIFF + TA4 (13)
C     CALC. SURF. AND ATMOS. TEMPS AT GIVEN LAT.
  520 ALAT=ABS(LAT)
      IF(ALAT-40.)150,150,200
  150 IF(IT2-13)530,530,540
  530 TS0I=TS0(IT1)+PART*(TS0(IT2)-TS0(IT1))
      TA0I=TA0(IT1)+PART*(TA0(IT2)-TA0(IT1))
  550 TSDIF=TS0I-TS40I
      TADIF=TA0I-TA40I
      ARG=ALAT/40.*1.5708
      DTA=TADIF*COS(ARG)
      DTS=TSDIF*COS(ARG)
      TS=TS40I+DTS
      TA=TA40I+DTA
      GO TO 225
  540 TS0I=(TS0(1)-TS0(13))*TDIFF+TS0(13)
      TA0I=(TA0(1)-TA0(13))*TDIFF+TA0(13)
      GO TO 550
  200 TS=TS40I+(ALAT-40.)*(190-TS40I)/50.
      TA=TA40I+(ALAT-40.)*(190-TA40I)/50.
C     CONVERT TO DEGS. K
  225 TA=(TA-32.)/1.8+273.1
      TS=(TS-32.)/1.8+273.1
C     CONVERT TO WATTS/ IN SQ.
      FGS=FGS*.0064516
```

```
C     CALC. PANEL TEMP. USING NEWTON - RAPHSON METHOD
      C=FGS*(.729*COS(PHI)+.09)+3.111E-12*TA**4+31.11E-12*TS**4+
     1  .00454*TS
      TNEW=TA+10.
  250 F=66.22E-12*TNEW**4+.00454*TNEW-C
      FAB=ABS(F)
      IF(FAB-.1)400,400,300
  300 TNEW=TNEW-F/(2.6488E-10*TNEW**3+.00454)
      GO TO 250
C     CONVERT TO DEG. C
  400 PTEMP=TNEW-273.1
      RETURN
      END
```

```
RLOAD )GO*,)UNSAT,)F4LIB**,)SL,7*
RRUN
RDATA
0.32
0.0          0.0
0.085        100.0                                   7
2.48         0.0
2.216        55.0
2.19         100.0                                   7
  .1119999        0
  .1119999  .0030000
  .1119999  .0060000
  .1119999  .0090000
  .1119999  .0120000
  .1119999  .0150000
  .1119999  .0180000
  .1119999  .0210000
  .1119999  .0240000
  .1119998  .0270000
  .1119998  .0300000
  .1119998  .0330000
  .1119998  .0360000
  .1119998  .0390000
  .1119998  .0420000
  .1119998  .0450000
  .1119997  .0480000
  .1119997  .0510000
  .1119997  .0540000
  .1119997  .0570000
  .1119997  .0600000
  .1119996  .0630000
  .1119996  .0660000
  .1119996  .0690000
  .1119995  .0720000
  .1119995  .0750000
  .1119995  .0780000
  .1119994  .0810000
  .1119994  .0840000
  .1119993  .0870000
  .1119993  .0900000
  .1119992  .0930000
  .1119992  .0960000
  .1119991  .0990000
  .1119991  .1020000
  .1119990  .1050000
  .1119989  .1080000
  .1119988  .1110000
  .1119987  .1140000
  .1119986  .1170000
  .1119985  .1200000
  .1119984  .1230000
  .1119983  .1260000
  .1119982  .1290000
```

.1119981	.1320000
.1119979	.1350000
.1119978	.1380000
.1119976	.1410000
.1119974	.1440000
.1119972	.1470000
.1119970	.1500000
.1119968	.1530000
.1119966	.1560000
.1119963	.1590000
.1119960	.1620000
.1119957	.1650000
.1119954	.1680000
.1119951	.1710000
.1119947	.1740000
.1119943	.1770000
.1119939	.1800000
.1119934	.1830000
.1119929	.1860000
.1119924	.1890000
.1119918	.1920000
.1119912	.1950000
.1119906	.1980000
.1119899	.2010000
.1119891	.2040000
.1119883	.2070000
.1119874	.2100000
.1119865	.2130000
.1119855	.2160000
.1119844	.2190000
.1119833	.2220000
.1119820	.2250000
.1119807	.2280000
.1119792	.2310000
.1119777	.2340000
.1119760	.2370000
.1119743	.2400000
.1119723	.2430000
.1119703	.2460000
.1119681	.2490000
.1119657	.2520000
.1119631	.2550000
.1119604	.2580000
.1119574	.2610000
.1119543	.2640000
.1119509	.2670000
.1119472	.2700000
.1119433	.2730000
.1119390	.2760000
.1119345	.2790000
.1119296	.2820000
.1119244	.2850000
.1119188	.2880000

.1119127	.2910000
.1119062	.2940000
.1118992	.2970000
.1118917	.3000000
.1118837	.3030000
.1118750	.3060000
.1118657	.3090000
.1118557	.3120000
.1118450	.3150000
.1118334	.3180000
.1118210	.3210000
.1118077	.3240000
.1117934	.3270000
.1117780	.3300000
.1117614	.3330000
.1117437	.3360000
.1117246	.3390000
.1117041	.3420000
.1116820	.3450000
.1116584	.3480000
.1116329	.3510000
.1116055	.3540000
.1115762	.3570000
.1115447	.3600000
.1115108	.3630000
.1114743	.3660000
.1114352	.3690000
.1113931	.3720000
.1113480	.3750000
.1112994	.3780000
.1112472	.3810000
.1111912	.3840000
.1111310	.3870000
.1110662	.3900000
.1109967	.3930000
.1109220	.3960000
.1108417	.3990000
.1107555	.4020000
.1106628	.4050000
.1105633	.4080000
.1104563	.4110000
.1103413	.4140000
.1102178	.4170000
.1100851	.4200000
.1099425	.4230000
.1097893	.4260000
.1096247	.4290000
.1094478	.4320000
.1092578	.4350000
.1090536	.4380000
.1088342	.4410000
.1085985	.4440000
.1083452	.4470000

```
.1080731   .4500000
.1077807   .4530000
.1074665   .4560000
.1071289   .4590000
.1067662   .4620000
.1063765   .4650000
.1059577   .4680000
.1055078   .4710000
.1050244   .4740000
.1045050   .4770000
.1039469   .4800000
.1033472   .4830000
.1027029   .4860000
.1020106   .4890000
.1012668   .4920000
.1004676   .4950000
.0996089   .4980000
.0986862   .5010000
.0976948   .5040000
.0966296   .5070000
.0954851   .5100000
.0942554   .5130000
.0929341   .5160000
.0915144   .5190000
.0899890   .5220000
.0883501   .5250000
.0865890   .5280000
.0846[illegible]   .5310000
.0826039   .5340000
.0804794   .5370000
.0781323   .5400000
.0756105   .5430000
.0729009   .5460000
.0699895   .5490000
.0668613   .5520000
.0635002   .5550000
.0598686   .5580000
.0560085   .5610000
.0518392   .5640000
.0473595   .5670000
.0425463   .5700000
.0373746   .5730000
.0318179   .5760000
.0258474   .5790000
.0194323   .5820000
.0125395   .5850000
.0051335   .5880000
-0.0028240   .5910000
-0.0113740   .5940000
-0.0205607   .5970000
1  ELECTRO-OPTICAL SYSTEMS  JPL CONTR 952035
2   02701774  03705774  02701774  10002 40.00.0  0.0   20.  100. 0 0.0    5  50
3   6.26      1.5                     0.5E-09   1.0E 06   0.5
```

```
1  ELECTRO-OPTICAL SYSTEMS  JPL CONTR 952035
2   02/01/74  03/05/74  02/01/74  10102 40.00.0  0.0   20.  100. 0 0.0   5  50
3   6.28     1.5      3.0E 15   0.5E-09   1.0E 06   0.5
REOD
REOD
RFIN
```

4.4 TYPICAL PRINTOUT OF SAMPLE PROBLEM

The data cards listed in 4.3 were used to run a sample problem. The associated printout follows here. The first page reiterates the input configuration data. The second page is representative of the output to be expected, but does not include the total printout from this run; only the first two pages are shown.

RUN TITLE... ELECTRO-OPTICAL SYSTEMS JPL CONTR 952035

```
ANALYSIS PERIOD FROM  2/ 1/74  TO   3/ 5/74
SPACECRAFT LANDING DATE- 2/ 1/74

ATTENUATION FACTORS USED-

SMALL A =    .50E-09 KM
RHO =     6.28
LARGE N =  1.50
SMALL N =    .30E 16 KM(-3)
ZETA =    .10E 07 KM(-1)
NU =   .500

RADIATION MODEL FLAG = 2

DUST STORM IN PROGRESS

SPACECRAFT POSITION-
 LATITUDE                   40.0 DEG
 PANEL INCLINED FROM
  HORIZONTAL BY               .0 DEG
 DIRECTION OF INCLINE
  (AZIMUTH)                   .0 DEG

SOLAR PANEL AREA           20.0 SQ.FT.
REQUIRED POWER OUTPUT     100.0WATTS

DEFINED HORIZON               .0 DEG

PRINTER CONTROL-
   PRINT,SUMMARY EVERY    5 DAY(S)
   PRINT DETAIL EVERY     .493 HRS DURING DAYLIGHT
    (ONLY ON SUMMARY DAYS)

SOLAR PANEL OUTPUT BASED ON MARINER 1969 S/N 2, 2X2 CM SOLAR CONVERTER I-V CURVE,N/P .018 IN,2 OHM-CM/
MISCELLANEOUS POWER LOSSES  5.01 PER CENT
```

987n9E

RUN TITLE... ELECTRO-OPTICAL SYSTEMS JPL CONTR 952035

LATITUDE = 40.0 DEG

TIME OF DAY (HOUR)	UNIT CELL POWER (MW)	MAX PANEL POWER (WATT)	REQUIRED AREA (SQ.FT.)	ACCUM ENERGY (WATT-HOURS)	SI AT UPPER ATMOS	TRANSMISSION FACTORS ATMO	CLOUD	DUST	S.I. AT PANEL MAG (MW/SQ. CM)	NORMAL	PANEL TEMP (CEN)	CELL POWER BEFORE RADIAT	RADIAT DEGRAD FACTOR	SUN ELEV (DG)	SUN AZIM-UTH (DEG)	INCIDENCE ANGLE ON PANEL
MARS DAY = 1, EARTH TIME = .0000 DAYS PAST HOUR 0.0 OF 2/ 1/74 GMT																
*** DAWN - SUN ON PANEL																
6.28	.00	.00	45970.4	.0	57.72	.00	1.00	1.00	.03	.00	-114.4	.00	1.00	90.0	92.4	90.0
7.00	.03	.14	14151.4	.0	57.71	.01	1.00	1.00	.51	.07	-113.2	.03	1.00	81.9	99.3	81.9
7.50	.16	.74	2684.6	.3	57.71	.02	1.00	1.00	1.44	.34	-111.9	.17	1.00	76.4	104.3	76.4
8.00	.46	2.11	947.9	1.0	57.71	.05	1.00	1.00	2.85	.93	-109.9	.48	1.00	71.1	109.4	71.1
8.50	.87	4.03	496.3	2.5	57.71	.08	1.00	1.00	4.55	1.86	-79.5	.92	1.00	65.9	114.9	65.9
9.00	1.39	6.42	311.4	5.2	57.71	.11	1.00	1.00	6.31	3.07	-64.0	1.47	1.00	60.9	121.0	60.9
9.50	1.95	8.97	223.0	9.0	57.70	.14	1.00	1.00	7.96	4.42	-51.3	2.05	1.00	56.3	127.6	56.3
10.00	2.49	11.49	174.1	14.2	57.70	.16	1.00	1.00	9.41	5.78	-42.4	2.62	1.00	52.1	134.9	52.1
10.50	2.97	13.71	145.8	20.5	57.70	.18	1.00	1.00	10.60	7.04	-35.1	3.13	1.00	48.4	143.1	48.4
11.00	3.37	15.53	128.8	27.9	57.70	.20	1.00	1.00	11.52	8.08	-29.8	3.55	1.00	45.4	152.2	45.4
11.50	3.63	16.74	119.5	36.0	57.70	.21	1.00	1.00	12.14	8.85	-25.3	3.82	1.00	43.3	162.2	43.3
12.00	3.75	17.29	115.7	44.6	57.69	.22	1.00	1.00	12.48	9.27	-21.7	3.95	1.00	42.0	172.9	42.0
12.50	3.72	17.16	116.6	53.3	57.69	.22	1.00	1.00	12.53	9.33	-18.7	3.92	1.00	41.9	183.8	41.9
13.00	3.55	16.35	122.3	61.7	57.69	.21	1.00	1.00	12.28	9.02	-16.4	3.74	1.00	42.8	194.5	42.8
13.50	3.34	15.41	129.8	69.7	57.69	.20	1.00	1.00	11.75	8.36	-21.0	3.52	1.00	44.6	204.8	44.6
14.00	3.11	14.33	139.5	77.2	57.69	.19	1.00	1.00	10.92	7.39	-33.2	3.27	1.00	47.4	214.2	47.4
14.50	2.70	12.47	160.4	84.0	57.68	.17	1.00	1.00	9.81	6.20	-44.0	2.85	1.00	50.9	222.7	50.9
15.00	2.27	10.47	190.9	89.8	57.68	.15	1.00	1.00	8.44	4.85	-63.4	2.39	1.00	54.9	230.3	54.9
15.50	1.62	7.47	267.8	94.3	57.68	.12	1.00	1.00	6.85	3.48	-67.1	1.71	1.00	59.4	237.1	59.4
16.00	1.01	4.68	427.7	97.3	57.68	.09	1.00	1.00	5.11	2.22	-70.4	1.07	1.00	64.3	243.3	64.3
16.50	.53	2.42	825.0	99.1	57.68	.06	1.00	1.00	3.38	1.19	-73.5	.55	1.00	69.4	249.0	69.4
17.00	.20	.94	2131.6	100.0	57.68	.03	1.00	1.00	1.84	.49	-76.3	.21	1.00	74.7	254.2	74.7
17.50	.05	.22	9000.1	100.3	57.67	.01	1.00	1.00	.74	.13	-78.9	.05	1.00	80.1	259.2	80.1
18.00	.00	.02	04189.5	100.3	57.67	.00	1.00	1.00	.18	.01	-81.2	.00	1.00	85.6	264.0	85.6
*** DUSK - SUN CUT OFF OF PANEL ***																
18.40	.00	.00	22509.6	100.3	57.67	.00	1.00	1.00	.03	.00	-82.8	.00	1.00	90.0	267.7	90.0
*** MAXIMUM POWER POINT ***																
12.12	3.76	17.32	115.5	46.6	57.69	.22	1.00	1.00	12.52	9.32	-20.9	3.96	1.00	41.9	175.3	41.9

SUMMARY =
DAWN = 6.28 HRS, HOURS OF SUN = 12.12, MAX OUTPUT = 17.32W, ENERGY FOR DAY = 100.3WH, ENERGY TO DATE = 100.3WH

	SHORT CIRCUIT CURRENT	MAXIMUM POWER VOLTAGE	OPEN CIRCUIT VOLTAGE
NEAR DAWN (18.9 DEG.)	.8	.608	.722
PERIOD OF MAX. POWER	8.8	.489	.596
NEAR DUSK (9.9 DEG.)	.1	.463	.563

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

The overall Planetary Solar Array Development program undertaken by EOS during the past several years has defined the important aspects of the Mars hard and soft lander solar power problem. The work reported here has provided a means for computing the probable panel output for a large number of configurations of the cells and panels, for various geometries and, most important, under the expected environmental conditions.

Earlier reports have described designs which would successfully meet many difficult constraints of power, weight, and structural integrity. In addition, important test data were generated, showing solar cell shock response as a function of radius of curvature and of loading up to 5000 g's. The entire body of work contains many important theoretical and engineering advances in the areas of orbital dynamics, light scattering, the physics of blown sand and dust, solar cell models, and computer programming, as well as a rather complete structural analysis of the statics and dynamics of hard and soft landing and panel deployment.

It is recommended that the computer program described in this report be modified, either for the JPL computer facility or for the EOS machine, to produce plots of the important parameters computed during the Mars day. These graphs would then be used to define envelopes of worst- and best-case conditions which could be published in the form of a design handbook for Mars lander vehicles. In the event it should be desirable to produce these plots manually, the computer program in its present form will be adequate, and only the input parameters remain to be specified.

As a further recommendation, it appears feasible to adapt the present computer program to calculate the power output of an orbiting panel.

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7254-Q-2	6 Jan 68
7254-Q-3 (3 Volumes)	15 Apr 68
7254-Final	28 Feb 69