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SPATIAL BIAS CORRECTION FOR SPORADIC METEORS PHOTOGRAPHED IN NEW MEXICO

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16. Abstract

The McCrosky and Posen data on Super-Schmidt sporadic meteors were studied for spatial bias. This bias is a function of meteor direction and velocity, camera location, and observing intervals. For each meteor, a number useful in correcting for spatial bias was computed. It is a measure of the likelihood of encountering a meteor with the same relative velocity vector during the 30-month span of photographing intervals.

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SUMMARY

The McCrosky and Posen data for the sporadic Super-Schmidt meteors photographed in New Mexico were studied for spatial bias. This bias is a function of the meteor direction and velocity relative to Earth, the location of cameras in New Mexico, and the observing intervals.

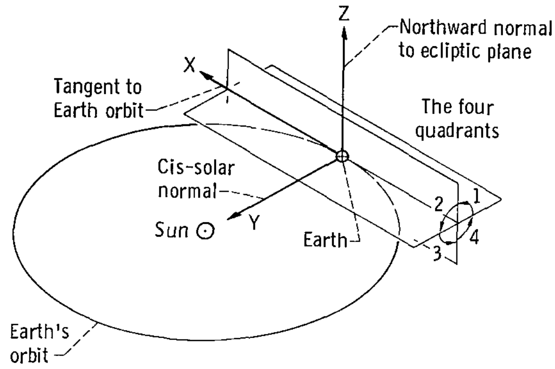
For each meteor, a number A useful in correcting for spatial bias was computed. It is the time-average over all observing intervals of a measure L of the momentary likelihood of encounter of a meteor with the same relative velocity vector, where L is a ratio of possible source area for such meteors to the actual impact area under scrutiny. The data for each meteor should be weighted with the reciprocal of A to correct for spatial bias.

Such a weighting factor has been used in statistical analysis at Lewis. The values of this factor may be useful for others who might make similar or related analyses.

INTRODUCTION

McCrosky and Posen give data in reference 1 for 2048 sporadic meteors photographed simultaneously at two sites in New Mexico by Super-Schmidt cameras over a 30-month period from February 1952 to July 1954. A statistical study of the data was undertaken at Lewis for the insight it might provide regarding the hazard for space vehicles of possible collision with meteoroids. One of the several biasing effects involved in the meteor photography, which needed to be considered in the study, was that resulting from the location of the camera sites and the periods during which cameras were operated. The computation of numbers (one for each meteor) useful in correcting for this spatial bias is described in this report.

The following sketch will be useful in explaining the principles underlying the computation:



Orbital system

It displays the base vectors of the orbital system, a system which moves along with the Earth. The X-axis is in the direction of the forward tangent to Earth's orbit. It points toward the apex. The Y-axis is in the ecliptic plane and is the cis-solar normal to Earth's orbit. The Z-axis is the northerly normal to the ecliptic plane. The sketch further shows four quadrants in which a vector may lie. Because New Mexico is in the northern hemisphere and the cameras operated at night, most of the meteors came from quadrant 1. The number of meteors from each quadrant was as follows:

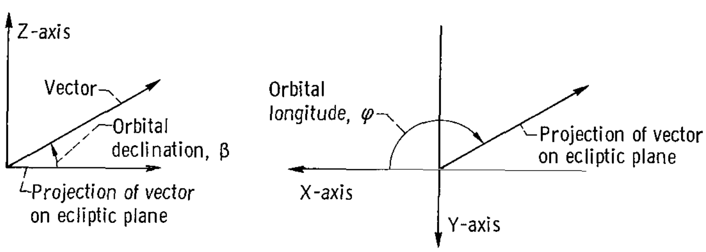
(1) Quadrant 1 (outside, above), 1282

(2) Quadrant 2 (inside, above), 225

(3) Quadrant 3 (inside, below), 32

(4) Quadrant 4 (outside, below), 509

Every vector in the orbital system is characterized by two angles, β and φ. (All symbols are defined in appendix A.) The following sketch displays these angles:



Orbital angles

The four quadrants have the following ranges of orbital declination and longitude:

(1) Quadrant 1: $0^{\circ} < \beta < 90^{\circ}$, $0^{\circ} < \varphi < 180^{\circ}$

(2) Quadrant 2: $0^{\circ} < \beta < 90^{\circ}$, $180^{\circ} < \varphi < 360^{\circ}$

(3) Quadrant 3: $-90^{\circ} < \beta < 0^{\circ}$, $180^{\circ} < \varphi < 360^{\circ}$

(4) Quadrant 4: $-90^{\circ} < \beta < 0^{\circ}$, $0^{\circ} < \varphi < 180^{\circ}$

The direction from which a meteor comes is called its true radiant. For each meteor, whatever its true radiant, we pose the question: Given the history of camera usage, what is the likelihood of photographing, during the 30-month period, a meteor with the same velocity vector relative to this moving orbital system? A study of meteor orbits, discussed in the section ANALYSIS, gives a measure of this likelihood at any instant. It is the ratio of the cross-sectional area perpendicular to the meteor path at a great distance from Earth, through which the meteor might have passed, divided by the corresponding area on the surface of the Earth at the camera sites in New Mexico within which the meteor might have arrived. This ratio will be seen to depend on the magnitude G of the meteor velocity vector and on the angle θ between the true radiant vector and the instantaneous local zenith vector.

The ratio so determined for each hour was weighted with the number of minutes of camera operation within that hour. The sum of such weighted ratios, divided by the total number of minutes of operation of the cameras, is a measure of the likelihood asked for above. A table of this likelihood, denoted by A, and called the spatial bias correction number, appears in appendix C along with orbital declination, orbital longitude, and the associated quadrant number. The table is arranged in order of the meteor serial number.

The material contained in this report is presented in the following order: an introduction to the process of computing the spatial bias correction number A; information about coordinate systems and their interrelations, and the derivation of needed meteor orbit equations; a more detailed description of the process of computing the spatial bias correction number A; samples of input data, namely sidereal data and camera usage history (appendix B); a table of results (appendix C).

PRELIMINARY DESCRIPTION OF COMPUTING PROCESS

Each of the 2048 sporadic meteors had a velocity vector $-G\vec{v}$ relative to the Earth before capture by the Earth. The unit vector $\vec{v}$ is called the true radiant of the meteor.

Each of the 1772 observing intervals has associated with it a time t, a duration d, and a unit vector $\vec{z}$. Let P be the point halfway between the two cameras. Then $\vec{z}$ is the vector pointing upward from P at time t. It is called the zenith vector of the interval. Let θ be the angle between a true radiant vector and a zenith vector.

It will be shown that the momentary likelihood of encountering a meteor with velocity vector $-G\vec{v}$ at point P at time t is a function of θ and G. Let $L(\theta_{j,k}, G_j)$ denote the measure of this likelihood for a given meteor j during an observing interval k. It is a ratio of possible source area for such meteors to actual impact area under scrutiny by the cameras.

The next section discusses coordinate systems and how to change a true radiant vector from sidereal coordinates to orbital coordinates, when the time is known. For each meteor, the data includes the time of photographing t, the velocity G, and the true radiant vector in terms of its sidereal angles. We carry this fixed vector $\vec{v}$, converted to orbital coordinates, with Earth through the 30-month span of time, computing for each observing interval k the likelihood measure L. The time average of L is given by

$$A_j = \frac{\sum_{k=1}^{1772} d_k L(\theta_{j,k}, G_j)}{\sum_{k=1}^{1772} d_k} \tag{1}$$

The proposed weight that should be given to meteor j to correct its spatial bias is F_j, the reciprocal of A_j; that is,

$$F_j = \frac{1}{A_j} \tag{2}$$

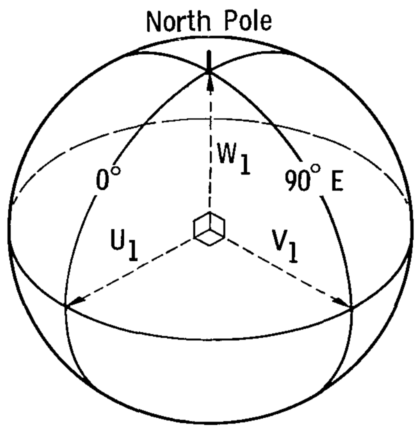
Use of the weighting factor F_j, however, can correct spatial bias only if the population of meteors to be studied is of adequate size and is restricted to values of $\vec{v}$ within a suitable solid angle and values of G within a suitable range such that no observed meteors can exist with $A_j = 0$.

A study of coordinate systems is needed to show how to compute zenith and true radiant vectors in orbital coordinates. A study of hyperbolic geocentric orbits is needed to derive the formula for L as a function of θ and G. These two topics are the subject of the following section.

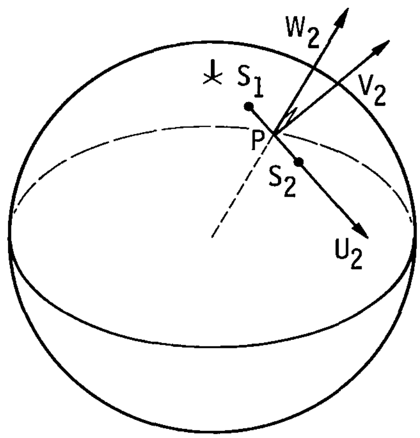
ANALYSIS

Four Coordinate Systems

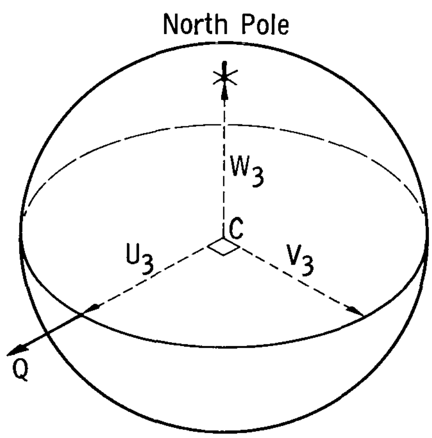
We need to consider four coordinate systems, which will be called geographical, local, sidereal, and orbital. In each system, the coordinates are denoted by X, Y, and Z, and unit base vectors by $\vec{U}$, $\vec{V}$, and $\vec{W}$. The following sketch is an aid to understanding these systems.



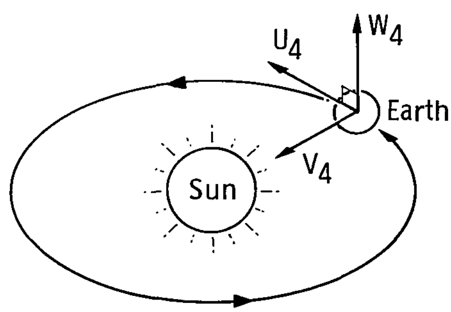
System 1 - geographical



System 2 - local



System 3 - sidereal (U_3 points at Sun on vernal equinox of 1950)



System 4 - orbital

System 1 (the geographical) is Earth-centered with $\vec{W}_1$ pointing from Earth center to the North Pole, the $\vec{U}_1$ vector pointing to zero longitude, and the $\vec{V}_1$ vector to 90° east longitude.

System 2 (the local) is centered at P, the point midway between camera sites S_1 and S_2. Site 1 has latitude $32^\circ\ 30'\ 15.5''$ N and longitude $7^h\ 7^m\ 11.9^s$ W. Site 2, about 28.6 kilometers southeast, has latitude $32^\circ\ 18'\ 20.0''$ N and longitude $7^h\ 6^m\ 26.8^s$ W. The $\vec{U}_2$ vector points toward S_2, the $\vec{W}_2$ vector points to the zenith, and the $\vec{V}_2$ vector is $\vec{W}_2 \times \vec{U}_2$.

System 3 (the sidereal) is Earth-centered with the $\vec{U}_3$ vector pointing at the equator at a position whose longitude is that of the vernal equinox of 1950. This longitude is simply related to the momentary hour angle of the Sun. The $\vec{W}_3$ vector equals $\vec{W}_1$, and the $\vec{V}_3$ vector is $\vec{W}_3 \times \vec{U}_3$.

System 4 (the orbital) is Earth-centered with the $\vec{U}_4$ vector being the forward tangent to the Earth's orbit, the $\vec{V}_4$ vector the interior normal to $\vec{U}_4$ in the ecliptic plane, and the $\vec{W}_4$ vector equal to $\vec{U}_4 \times \vec{V}_4$.

The sidereal system includes two important angles, called the declination and the right ascension. The declination δ is the angle with the equatorial plane. The right ascension α is the angle between $\vec{U}_3$ and $(X_3, Y_3, 0)$. A unit vector $\vec{v}$ then has components

$$\left.\begin{aligned} X_3 &= \cos\delta \cos\alpha \\ Y_3 &= \cos\delta \sin\alpha \\ Z_3 &= \sin\delta \end{aligned}\right\} \qquad (3)$$

The orbital system includes two important angles, denoted here by β and φ. The angle β is measured from the ecliptic plane; φ is the angle between $\vec{U}_4$ and $(X_4, Y_4, 0)$. A unit vector $\vec{v}$ then has components

$$\left.\begin{aligned} X_4 &= \cos\beta \cos\varphi \\ Y_4 &= -\cos\beta \sin\varphi \\ Z_4 &= \sin\beta \end{aligned}\right\} \qquad (4)$$

Later analysis will require knowledge of the relations between the local and geographical systems, as well as of relations between the sidereal and orbital systems. The procedure used is to express base unit vectors in one system in terms of the base unit vectors of the other system. With the coefficients thus obtained, any vector can be converted from one system to the other.

Let us first examine the relations between systems 1 and 2. If we use the approximation of a spherical Earth, the geographical coordinates of a unit zenith vector $\vec{N}_i$ at a point S_i with north latitude λ and west longitude μ are given by

$$\left.\begin{aligned} X_i &= \cos\lambda\cos\mu \\ Y_i &= -\cos\lambda\sin\mu \\ Z_i &= \sin\lambda \end{aligned}\right\} \qquad (5)$$

If $\vec{N}_1$ and $\vec{N}_2$ are such vectors for the camera sites S_1 and S_2, their sum is in the direction of W_2. Dividing their sum vector by its length yields the unit vector $\vec{W}_2$. The vector difference $\vec{N}_2 - \vec{N}_1$ is in the direction of $\vec{U}_2$. Again dividing by the vector length yields the unit vector $\vec{U}_2$. Then $\vec{V}_2$ is $\vec{W}_2 \times \vec{U}_2$. At this stage we may summarize by writing

$$\left.\begin{aligned} \vec{U}_2 &= b_{11}\vec{U}_1 + b_{12}\vec{V}_1 + b_{13}\vec{W}_1 \\ \vec{V}_2 &= b_{21}\vec{U}_1 + b_{22}\vec{V}_1 + b_{23}\vec{W}_1 \\ \vec{W}_2 &= b_{31}\vec{U}_1 + b_{32}\vec{V}_1 + b_{33}\vec{W}_1 \end{aligned}\right\} \qquad (6)$$

where $b_{i,j}$ is a general element in the coefficient matrix B.

The matrix version of these equations is $Q_2 = BQ_1$, where Q is the column vector (U, V, W). Because each set of base vectors is right-handed and mutually perpendicular, the coefficient matrix for the conversion in the opposite direction is the transpose of B, denoted by B^*; that is,

$$\left.\begin{aligned} \vec{U}_1 &= b_{11}\vec{U}_2 + b_{21}\vec{V}_2 + b_{31}\vec{W}_2 \\ \vec{V}_1 &= b_{12}\vec{U}_2 + b_{22}\vec{V}_2 + b_{32}\vec{W}_2 \\ \vec{W}_1 &= b_{13}\vec{U}_2 + b_{23}\vec{V}_2 + b_{33}\vec{W}_2 \end{aligned}\right\} \qquad (7)$$

In matrix language, $Q_1 = B^*Q_2$. The same two matrices, B and B^*, serve to express the coordinates in either system in terms of the other. To be specific, equation

$$\left.\begin{aligned} X_2 &= b_{11}X_1 + b_{12}Y_1 + b_{13}Z_1 \\ Y_2 &= b_{21}X_1 + b_{22}Y_1 + b_{23}Z_1 \\ Z_2 &= b_{31}X_1 + b_{32}Y_1 + b_{33}Z_1 \end{aligned}\right\} \tag{8}$$

converts coordinates from geographical to local. And equation

$$\left.\begin{aligned} X_1 &= b_{11}X_2 + b_{21}Y + b_{31}Z \\ Y_1 &= b_{12}X_2 + b_{22}Y + b_{32}Z \\ Z_1 &= b_{13}X_2 + b_{23}Y + b_{33}Z \end{aligned}\right\} \tag{9}$$

converts coordinates from local to geographical. The matrix version of all four sets of equations is

$$\left.\begin{aligned} Q_2 &= BQ_1 \\ Q_1 &= B^*Q_2 \\ E_2 &= BE_1 \\ E_1 &= B^*E_2 \end{aligned}\right\} \tag{10}$$

Let us next examine the relations between sidereal and orbital coordinates. Sidereal data in the nautical almanac of 1952 to 1954 (ref. 2) provided Earth-to-Sun vectors $\vec{V}(t)$ at five times each month; that is, at 0^h universal time (7 hr later than mountain standard time) on the first day of the month, and weekly thereafter. Lagrangian five-point interpolation formulas yielded the sidereal coordinates of this vector at any time t. Let $\vec{V}(t_1)$ and $\vec{V}(t_2)$ be the vectors associated with times 12 hours before and 12 hours after time t. Then normalizing the vector difference $\vec{V}(t_2) - \vec{V}(t_1)$ yields the unit vector $\vec{U}_4$. Normalizing the cross product of $\vec{U}_4$ and either $\vec{V}(t_1)$ or $\vec{V}(t_2)$ yields the unit vector $\vec{W}_4$. Then $\vec{V}_4$ is $\vec{W}_4 \times \vec{U}_4$. If the coefficient matrix of equation

$$\left.\begin{aligned} \vec{U}_4 &= b_{11}\vec{U}_3 + b_{12}\vec{V}_3 + b_{13}\vec{W}_3 \\ \vec{V}_4 &= b_{21}\vec{U}_3 + b_{22}\vec{V}_3 + b_{23}\vec{W}_3 \\ \vec{W}_4 &= b_{31}\vec{U}_3 + b_{32}\vec{V}_3 + b_{33}\vec{W}_3 \end{aligned}\right\} \tag{11}$$

is denoted by B, then the matrix versions of equation (11) and the other three sets of equations relating sidereal and orbital coordinates are

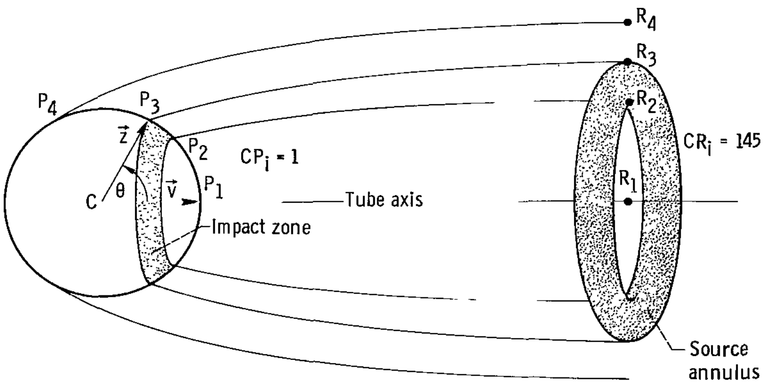
$$\left.\begin{aligned} Q_4 &= BQ_3 \\ Q_3 &= B^*Q_4 \\ E_4 &= BE_3 \\ E_3 &= B^*E_4 \end{aligned}\right\} \qquad (12)$$

This completes the required analysis of coordinate systems.

Hyperbolic Orbits

A good approximation to the part of a meteor path within Earth's sphere of influence is a hyperbola with focus at Earth's center. Meteors with a relative velocity G move along one of a family of possible paths. This section presents the equations for these curves and discusses the relation between meteoroid velocity vectors and the likelihood of such meteoroids being photographed. Recall that θ is the angle between the true radiant vector of the meteoroid and the vector pointing straight up at the point midway between camera sites.

Consider all paths for meteors of a given true radiant vector and given velocity G. The following sketch shows four such paths:



One, from R_1 to P_1, strikes the Earth perpendicularly, along what we call the axis of the tube of possible paths. One, from R_4 to P_4, grazes the Earth along a path which lies on the surface of the tube. The other two, from R_2 to P_2 and from R_3 to P_3, are intermediate paths. The angle θ appears here as the angle $\angle P_1CP_3$, where P_3 is thought of as the point of impact. All R points are meant to be at a distance of 145 Earth radii from C.

Meteors that have their source in an annulus between R_2 and R_3 impact on a spherical zone on the Earth between P_2 and P_3. The ratio of the annulus area A_a to the zone area A_z is

$$L(\theta, G) = \frac{A_a}{A_z} \tag{13}$$

It is a measure of the relative likelihood that a meteor of a given type will be encountered within the impact area.

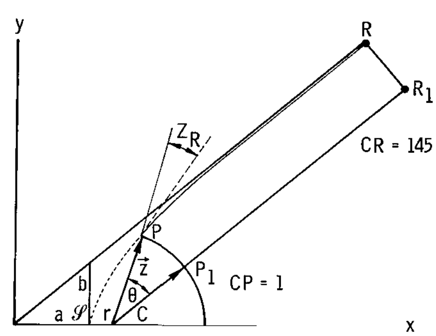
If lengths are measured in terms of Earth radii, the two areas A_a and A_z can be seen to be

$$A_a = \pi\left[(\overline{R_3R_1})^2 - (\overline{R_2R_1})^2\right] \tag{14}$$

and

$$A_z = 2\pi(\cos\theta_2 - \cos\theta_3) \tag{15}$$

In the following sketch the meteor path is arranged so that it is a central conic with the Earth's center C on the positive X-axis:



The axis of the tube is again CP_1R_1, as in the preceding sketch. The angle between the X-axis and the tube axis will differ for different source points R. The equation of the path is

$$\left(\frac{x}{a}\right)^2 - \left(\frac{y}{b}\right)^2 = 1 \tag{16}$$

with x and y positive. The center of the Earth is at C with coordinates a + r,Q. The source point R is at x_2, y_2. The impact point P is at x_1, y_1. Because

$$a^2 + b^2 = (a + r)^2 \tag{17}$$

b can be removed from equation (16), and the point on the incoming path at any arbitrary distance w (Earth radii) from C is found to have coordinates x, y satisfying

$$x(a + r) = a(a + w) \tag{18}$$

and

$$y^2 = w^2 - \frac{(aw - 2ar - r^2)^2}{(a + r)^2} \tag{19}$$

The coordinates of P and R result from using w = 1 and w = 145 in equations (18) and (19). These values, in turn, lead to the equation for θ

$$\tan \theta = \frac{m_1 - m_2}{1 + m_1 m_2} \tag{20}$$

where m_1 is the slope of the line $\overline{CP}$ and m_2 is the slope of the line $\overline{CR_1}$.

We assert the following theorem:

Theorem I: The parameter a depends on G only.

Proof will be given at the end of this section. By using equations (16) to (20), r can be varied from 0 to 1, and a table of cos θ and $L(\theta, G)$ against r can be compiled for fixed G. Doing this for a sequence of G values results in the desired table of $L(\theta, G)$.

The zenith angle Z_R is the angle between the line $\overline{CP}$ and the tangent to the orbit at P. It satisfies the equation

$$\tan Z_R = \frac{m_1 - m_3}{1 + m_1 m_3} \tag{21}$$

where the slope m_3 of the tangent line is given by

$$m_3 = \left(\frac{b}{a}\right)^2 \cdot \left(\frac{X_1}{Y_1}\right) \tag{22}$$

Proof of Theorem I: Let $V_E(s)$ be the velocity of escape from Earth at s units from C in the preceding sketch. Let V_m equal the velocity the meteor would have if it came to point $\mathscr{S}$, the vertex of the hyperbolic path. Then a kinetic energy balance at the vertex yields

$$0.5\ mV_m^2 = 0.5\ mG^2 + 0.5\ mV_E^2(r) \tag{23}$$

The balance of potential and kinetic energy gives

$$\frac{Km}{r} = 0.5\ mV_E(r) \tag{24}$$

at the vertex, and

$$\frac{Km}{1} = 0.5\ mV_E(1) \tag{25}$$

at the point P, where K is a constant. Finally, the balancing of centrifugal and gravitational forces at the vertex gives

$$\frac{Km}{r^2} = m\,\frac{V_m^2}{\rho} \tag{26}$$

where ρ is the radius of curvature of the path at the vertex. Multiplying equation (26) by r and using equation (24) gives one equation for ρ, namely

$$\rho = 2r \frac{V_m^2}{V_E^2(r)} \tag{27}$$

Differentiating equation (16) twice with respect to y gives another equation for ρ, namely

$$\rho = \frac{1}{x''} = \frac{b^2}{a} \tag{28}$$

Factoring 0.5 m out of equation (23) yields

$$V_m^2 = G^2 + V_E^2(r) \tag{29}$$

Dividing equation (25) by equation (24) gives

$$V_E^2(1) = rV_E^2(r) \tag{30}$$

Equating the two formulas for ρ gives

$$b^2V_E^2(r) = 2arV_m^2 \tag{31}$$

Using equations (17), (29), and (31) yields

$$(2ar + r^2)V_E^2(r) = 2ar(G^2 + V_E^2(r)) \tag{32}$$

From equations (30) and (32),

$$V_E^2(1) = 2aG^2 \tag{33}$$

and finally,

$$a = 0.5\left(\frac{V_E(1)}{G}\right)^2 \tag{34}$$

which displays a as a function of G only.

COMPUTING PROCESS

Preliminary Table Preparation

Two tables were prepared for repeated use in the program (see appendix B for samples). One was a table of sidereal data: the hour angle τ and the coordinates of the Sun. The other was a table of camera-operating intervals.

The nautical almanac of 1952 to 1954 (ref. 2) lists the sidereal coordinates of the Sun relative to the vernal equinox of 1950 for every day at 0^h universal time. These were copied to a rounded accuracy of five decimal places for the first, eighth, 15th, 22nd, and 29th of each month. The hour angle τ associated with the longitude of the vernal equinox of 1950 at 0^h universal time was also copied for the same five days of each month. Sidereal data were read into the program by means of punched cards.

The camera data were sent to us by Professor McCrosky, one of the authors of reference 1. There were 1772 hours spread over 349 nights, during which the two cameras were in use. For each of these hour intervals, the duration d of camera operation time was given in minutes. Observing always took place in the 12 hours from 6 P.M. to 6 A.M., mountain standard time. In universal time, this is 1^h to 13^h. Camera data were also read in by means of punched cards.

Processing of Camera Data

The raw camera data for each of the observing nights include the month, the day of the month, and 12 d numbers for the 12 hours of the night. There were 1772 1-hour intervals for which d was nonzero. For each of these, the program computes the three orbital coordinates of the associated zenith vector $\vec{z}$.

In a given hour, among other possibilities, the d-minute observing interval could have been the first d minutes, the last d minutes, or the middle d minutes of that hour. Early versions of the program tested the effect of this choice on the average A defined in equation (1) of the INTRODUCTION. The effect was slight. Thereafter, with a few exceptions the entire period was treated as the middle d minutes of the 1-hour observing interval.

The vector $\vec{z}$ is (0,0,1) in local coordinates. Its conversion to geographical coordinates always yields the same vector. Its conversion to sidereal coordinates involves a rotation through an angle related to the time t_k. The equations for this are

$$X_3 = X_1 \cos \tau - Y_1 \sin \tau \qquad (35)$$

$$Y_3 = X_1 \sin \tau + Y_1 \cos \tau \qquad (36)$$

where τ is obtained by linear interpolation from the hour angles of the sidereal data table. The hour angle goes through seven-and-a-fraction revolutions each week. If, for example, the time t_k were 17.23, meaning 0.23 day after 0^h universal time of the 17th of the pertinent month, the hour angle τ_{t_k} corresponding to the time t_k would be found by linear interpolation between the values τ_{15} and $\tau_{22} + 14\pi$, where τ_{15} and τ_{22} are the recorded hour angles for 0^h universal time for the 15th and 22nd of that month. From the result of the interpolation, the largest multiple of 2π would be deducted, and the remainder would be used as τ_{t_k}.

The remaining step in the computation of the orbital coordinates of the zenith vector $\vec{z}$ is the conversion from sidereal coordinates to orbital. This results from the use of equation (12) derived in the ANALYSIS section.

A table of processed camera data, including the three orbital coordinates for each of the 1772 zenith vectors is thus ready for repeated use (once for each of the 2048 sporadic meteors) in the formula of equation (1).

Momentary Likelihood Table

One more table is needed before equation (1) may be applied to any meteor. It is a table of the momentary likelihood number $L(\theta, G)$ for a range of possible angles θ between the zenith vectors and the true radiant vector, and possible relative meteoroid velocities G. This table was stored in the computer once it was generated.

The equations for L and other numbers needed to compute it are derived in the section ANALYSIS. In particular, for fixed G, as the parameter r of equation (18) is varied from 0 to 1, $\cos \theta$, $\cos Z_R$, and R source coordinates are obtained for all possible orbits. These, in turn, lead to values of L as a function of $\cos \theta$ for fixed G.

Possible G values ranged from 0.8 to 78.0 kilometers per second. Eighty G classes result from dividing the interval from log (0.8) to log (78.0) into 80 equal parts. For a fixed G, at the center of its class, the preceding paragraph describes how to construct a table of L and $\cos Z_R$ as a function of $\cos \theta$. As $\cos Z_R$, the zenith angle cosine, varies from 1 (for a meteor on the tube axis) to zero (for a meteor in grazing orbit), $\cos\theta$ varies from 1 to some negative value.

For each G class, there are 50 to 100 $\cos\theta$ classes, each of width 0.02. The L value is set to zero for any class where all the associated $\cos Z_R$ values are below 0.2. Smaller G values require more $\cos\theta$ classes.

Finding Orbital Coordinates of a True Radiant Vector

For each sporadic meteor with relative velocity vector $-G\vec{v}$, the meteor data include a sighting time t, the cosine of the zenith angle Z_R, and sidereal angles associated with the true radiant vector $\vec{v}$. These angles are the declination δ and the right ascension α. Equation (3) shows how to compute the sidereal coordinates of the true radiant vector $\vec{v}$. The conversion to orbital coordinates is the same as for the zenith vector $\vec{z}$ (see section Processing of Camera Data).

Since the time of sighting determines the zenith vector $\vec{z}$ and therefore the angle θ between $\vec{z}$ and $\vec{v}$, the computed value of $\cos Z_R$ for a given meteor may be compared with the meteor data value. Comparison was good in the cases checked this way. This was a check that the program was correct and the data consistent.

Averaging Process

Let j be a meteor index, running from 1 to 2048. Then $\vec{v}_j$ is the true radiant vector associated with meteor j. The method of the preceding paragraph yields $\vec{v}_j$ in orbital coordinates. Let k be the index of a 1-hour camera-operating interval, with associated zenith vector z_k. If $\theta_{j,k}$ is the angle between $\vec{z}_k$ and $\vec{v}_j$, then $\cos\theta_{j,k}$ is easily found as the scalar product of these two vectors.

The value G_j lies in a certain G class, and $\cos\theta_{j,k}$ lies in a certain $\cos\theta$ class. This determines a specific $L(\cos\theta, G)$ value from the momentary likelihood table. The sum of products in equation (1) may now be evaluated.

The number A_j is then a time average, over all camera-operating intervals, of the relative likelihood of a meteor with the same orbital coordinates and the same true radiant vector as meteor j being encountered, given the passage of such a meteor in the vicinity of Earth. The relative likelihood is high for a common event deserving low weight; it is low for a rare event deserving high weight. Thus the weighting factor F_j is computed by equation (2) as the reciprocal of A_j. Observed frequency of meteors like j should be multiplied by weighting factor F_j to compensate relatively for the spatial bias affecting its rarity.

The averaging process for the first meteor began as follows:

(1) Meteor 1 with serial number 2982 was sighted at February 24.32, 1952. This is about $7^h 41^m$ universal time on the 24th. Other meteor data are $\cos Z_R = 0.88$, $G = 20.6$, $\alpha = 153^o$, and $\delta = 12^o$.

(2) The orbital coordinates of the true radiant vector $\vec{v}$ turn out to be (-0.059, -0.998, 0.014). The orbital angles are $\beta = 0^o$, $\varphi = 93^o$. It is very close to the antisolar normal to the Earth's orbit. The meteor falls within the 77th G class from 19.5 to 22.5.

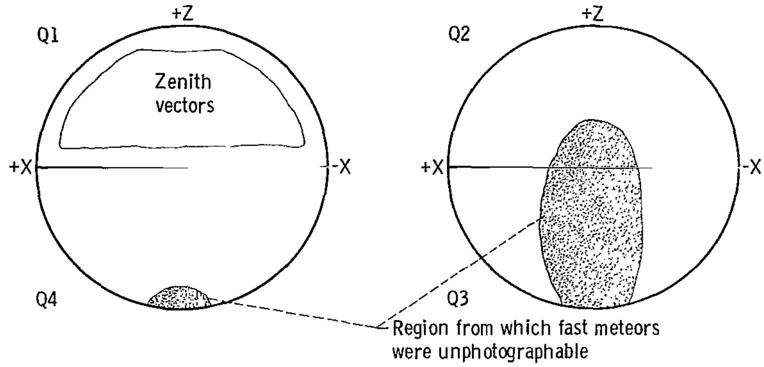
(3) The first camera-operating interval was 9 to 10 p.m. mountain standard time on February 16, 1952, with a duration of 27 minutes. The associated $\cos\theta$ value is 0.766, which is in the $\cos\theta$ class centered about 0.77. The L value for this cell is 0.904, and the $L \times d$ product is 24.408.

A 25-minute interval in the next hour is associated with the 0.87 $\cos\theta$ cell and an L of 1.005. This contributes a product of 25.125. The third camera-operating interval is 23 minutes in the hour after midnight in the early morning of February 24th. This is associated with the 0.93 $\cos\theta$ cell and an L of 1.066. This contributes a product of 24.518. The next 4 hours contain operating intervals of 42, 45, 45, and 12 minutes. The right $\cos\theta$ cells are 0.89, 0.77, 0.63, and 0.45. The right L values are 1.022, 0.904, 0.764, and 0.581. The sum of products after these four steps is about 199.

CONCLUDING REMARKS

The principal purpose of this computation of spatial bias correction numbers was for use in statistical studies that are outside the scope of this report. Appendix C contains a table of such numbers computed for all 2048 sporadic meteors observed from 1952 to 1954. The A number listed for each meteor is proportional to the probability of impact of such a meteor - one with the same true radiant vector relative to the orbital system and the same velocity - upon the atmosphere above the camera sites. The A number is the reciprocal of the weighting factor F that should be given to that meteor to correct for spatial bias.

The use of the weighting factor on a particular meteor is without meaning if a fast meteor from that direction were never photographable at New Mexico throughout the 30-month viewing period. The shaded region in the following sketch shows the direction from which the fastest meteors could never be photographed:



X-Z Projections of the four quadrants

By limiting analyses to data for meteors from quadrant 1, the spatial bias present in data from the other three quadrants can be avoided.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, June 1, 1970,
125-23.

APPENDIX A

SYMBOLS

A average likelihood of meteor with velocity vector $-G\vec{v}$ being photographed during 30-month observing period

A_a annulus area

A_z impact zone area

a semitransverse axis of hyperbola

B coefficient matrix in equations relating two different coordinate systems

C center of Earth

d duration of camera-operating-time interval, min

E_n column vector (X_n, Y_n, Z_n)

F factor to correct for spatial bias, 1/A

G velocity of meteor relative to Earth, km/sec

L measure of momentary likelihood of meteor with velocity vector $-G\vec{v}$ being encountered

m mass of meteoroid

$\vec{N}_i$ vector from Earth center to camera site S_i

P approximate point of impact of meteor, halfway between two cameras

Q column vector $(\vec{U}, \vec{V}, \vec{W})$

R source point of meteor at distance of 145 Earth radii

R_1 R for meteor striking Earth perpendicularly, at P_1

R_2, R_3 R for meteors following paths between those for R_1 and R_4

R_4 R for meteor grazing Earth, at P_4

r distance from vertex to focus of hyperbola, Earth radii

$\mathcal{S}$ vertex of hyperbola

S_1 site of camera 1, longitude $7^h\,7^m\,11.9^s$ W, latitude $32^\circ\,30'\,15.5''$ N

S_2 site of camera 2, longitude $7^h\,6^m\,26.8^s$ W, latitude $32^\circ\,18'\,20.0''$ N

t time at center of camera-operating interval

$\vec{U}, \vec{V}, \vec{W}$ unit vectors in given system

V_∞ velocity of meteor at camera site corrected for atmospheric drag, km/sec

$\vec{v}$ true radiant unit vector of meteor with velocity $-G\vec{v}$

w arbitrary distance, Earth radii

X, Y, Z components of vector

z_R zenith angle of meteor

$\vec{z}$ zenith unit vector at camera site at time t

α sidereal angle of right ascension for meteor radiant

β orbital angle with ecliptic plane

δ sidereal angle of declination for meteor radiant

θ angle between zenith vector $\vec{z}$ and true radiant vector $\vec{v}$

λ north latitude

μ west longitude

τ hour angle associated with time t, fraction of revolution

φ angle between (X, Y, 0) and (1, 0, 0) in orbital system

Subscripts:

i camera site, $i = 1, 2$

j meteor index from 1 to 2048

k time index for camera-operating interval - from 1 to 1772

1 geographic system

2 local system - centered at P ($W_2 = \vec{z}$)

3 sidereal system

4 orbital system

APPENDIX B

SAMPLES OF SIDEREAL AND CAMERA DATA

Sidereal data rounded from five places to three are given for March, April, and May of 1952.

Month	Day 1	8	15	22	29
	X_3 of Sun				
March, 1952	0.933	0.969	0.990	0.996	0.988
April, 1952	.980	.952	.910	.855	.787
May, 1952	.766	.684	.593	.494	.387
	Y_3 of Sun				
March, 1952	-0.306	-0.200	-0.090	0.021	0.131
April, 1952	.178	.285	.388	.486	.576
May, 1952	.601	.681	.751	.811	.859
	Z_3 of Sun				
March, 1952	-0.133	-0.087	-0.039	0.009	0.057
April, 1952	.077	.124	.168	.211	.250
May, 1952	.261	.295	.326	.352	.373
	Hour angle τ of Sun - fraction of revolution				
March, 1952	0.441	0.460	0.479	0.498	0.518
April, 1952	.526	.545	.564	.583	.602
May, 1952	.608	.627	.646	.665	.685

Camera Data for Twelve Nights

The 1772 camera-operating-time intervals were spread over 349 nights. Data are given in the following table for 12 of those nights. Each night is close as possible to the 22nd of the month, subject to having at least 6 consecutive hours of viewing.

Date	Mountain standard time											
	18-19	19-20	20-21	21-22	22-23	23-24	24-1	1-2	2-3	3-4	4-5	5-6
	Universal time											
	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13
	Number of minutes of camera use											
2/26/52	0	0	0	0	11	44	43	47	47	24	0	0
3/20/52	↓	↓	12	48	44	42	34	22	42	11	0	↓
4/23/52	↓	↓	0	0	19	46	46	46	46	46	12	↓
5/21/52	↓	↓	0	12	12	5	33	45	45	34	0	↓
6/22/52	↓	↓	0	33	44	46	46	46	45	23	0	↓
7/26/52	↓	↓	12	46	46	↓	↓	34	12	0	0	↓
8/21/52	↓	↓	20	46	46	↓	↓	46	46	46	12	↓
9/19/52	↓	↓	0	44	46	↓	↓	46	46	46	24	↓
10/22/52	↓	12	46	46	42	48	48	48	48	48	48	↓
11/20/52	↓	0	0	0	0	11	46	46	44	45	47	24
12/14/52	12	48	48	48	48	48	48	48	48	48	48	24
1/17/53	0	24	48	48	48	48	48	48	48	0	0	0

Zenith Vectors for Twelve Nights

Orbital coordinates were computed for zenith vectors for all 1772 camera-operating intervals. The X, Z pairs, multiplied by 100, appear in the following table for the 12 nights of the last section:

Date	Mountain standard time											
	18-19	19-20	20-21	21-22	22-23	23-24	24-1	1-2	2-3	3-4	4-5	5-6
	Universal time											
	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13
	Orbital coordinates × 100											
	X, Z	X, Z	X, Z	X, Z	X, Z	X, Z	X, Z	X, Z	X, Z	X, Z	X, Z	X, Z
2/26/52					-42, 26	-30, 30	-10, 38	10, 47	28, 56	38, 61		
3/20/52			-80, 23	-71, 27	-54, 34	-35, 42	-15, 51	5, 60	23, 68	32, 72		
4/23/52				-48, 56	-35, 62	-14, 69	6, 76	25, 80	41, 82	48, 83		
5/21/52				-59, 64	-48, 68	-28, 75	-6, 80	15, 82	34, 83	48, 81		
6/22/52				-49, 77	-35, 80	-13, 82	9, 83	70, 80	50, 76	61, 72		
7/26/52			-47, 82	-37, 83	-19, 82	2, 80	24, 75	45, 69	56, 64	78, 52		
8/21/52			-39, 82	-29, 81	-11, 77	10, 71	30, 63	50, 55	68, 46	82, 37	89, 33	
9/19/52				-24, 70	-9, 64	11, 56	31, 47	50, 38	68, 30	82, 24	89, 16	
10/22/52		-53, 67	-47, 63	-33, 54	-15, 45	4, 37	25, 29	45, 23	63, 18	79, 16	89, 16	
11/20/52						5, 21	17, 19	38, 16	58, 16	74, 18	86, 22	91, 26
12/14/52	-80, 47	-76, 41	-66, 33	-51, 26	-32, 20	-11, 17	11, 16	32, 17	52, 20	68, 25	79, 32	85, 37
1/17/53		-84, 23	-75, 19	-60, 16	-41, 16	-20, 17	1, 21	22, 26	39, 33			
11/2/53[a]	-63, 69	-60, 65	-50, 57	-36, 48	-19, 39	1, 31	22, 25	43, 19	56, 17			

[a]The 13th night appears because the other November date had only late slots.

APPENDIX C

PROBABILITIES OF IMPACT

Table I lists the A number of each meteor - a number proportional to the probability of impact of a meteor of the same direction and velocity upon the atmosphere above the camera sites during the 30-month period of viewing. The table is arranged in the order of serial number, with 280 meteors per page in four columns. The table also contains the orbital angles φ and β for each meteor, as well as the quadrant number. The A number is scaled to be in the 1 to 9999 range. The angles are given in degrees.

TABLE I. - PROBABILITY OF IMPACT

Serial number	Orbital angles, deg φ	Orbital angles, deg β	Quadrant	A
2982	93	1	1	369
2988	70	16	1	435
2991	88	-3	4	644
2993	37	6	1	258
2995	25	-9	4	167
2996	0	50	1	225
3000	344	59	2	195
3001	84	41	1	416
3005	115	32	1	355
3007	60	0	1	297
3009	39	5	1	258
3011	34	82	1	306
3013	244	42	2	151
3015	93	-8	4	331
3019	47	64	1	335
3021	75	9	1	383
3024	8	16	1	184
3025	70	37	1	395
3028	50	45	1	378
3032	12	56	1	265
3034	80	60	1	570
3037	35	-26	4	120
3038	0	45	1	218
3040	85	49	1	425
3042	90	55	1	470
3046	84	42	1	488
3048	103	28	1	466
3050	97	9	1	474
3053	148	-42	4	116
3054	145	6	1	484
3056	95	41	1	445
3058	69	3	1	323
3060	97	-4	4	402
3067	102	60	1	412
3069	116	62	1	392
3072	59	5	1	313
3074	48	-17	4	194
3076	122	21	1	463
3077	35	24	1	299
3079	224	84	2	243
3085	141	32	1	661
3088	249	83	2	226
3204	148	6	1	183
3206	200	-18	3	65
3210	79	4	1	351
3212	83	64	1	510
3228	40	66	1	318
3231	96	44	1	544
3234	77	14	1	400
3239	98	28	1	436
3242	24	49	1	311
3244	65	2	1	364
3246	104	-12	4	329
3250	85	10	1	391
3251	95	-4	4	348
3257	73	1	1	355
3259	61	27	1	485
3261	339	14	2	85
3265	309	57	2	111
3268	13	39	1	251
3272	7	37	1	226
3277	9	56	1	256
3280	93	7	1	376
3282	133	6	1	723
3288	96	-22	4	259
3292	65	55	1	389
3295	72	16	1	385
3296	5	41	1	229
3300	119	38	1	526
3303	110	6	1	436
3304	91	26	1	440
3307	171	69	1	315
3308	141	-18	4	231
3312	188	55	2	293
3313	97	37	1	735
3317	178	58	1	374
3319	55	46	1	481
3323	316	-5	3	231
3327	72	-2	4	322
3332	94	29	1	441
3334	44	38	1	346
3335	116	43	1	430
3340	16	33	1	250
3342	106	-20	4	273
3344	195	68	2	263
3346	230	77	2	238
3348	48	-24	4	327
3356	45	20	1	353
3361	67	6	1	331
3365	81	41	1	433
3367	106	82	1	317
3373	257	88	2	406
3377	7	30	1	213
3380	148	32	1	428
3389	100	56	1	422
3393	73	38	1	414
3402	356	47	2	208
3417	95	20	1	408
3419	71	7	1	340
3431	56	38	1	375
3434	101	0	1	374
3443	66	-16	4	226
3445	352	44	2	188
3464	346	-17	3	43
3466	78	34	1	416
3474	1	35	1	199
3476	66	-6	4	278
3480	351	39	2	177
3482	348	38	2	162
3484	87	16	1	424
3491	321	26	2	56
3497	299	81	2	228
3568	73	81	1	328
3573	60	9	1	345
3574	61	7	1	340
3578	3	37	1	210
3586	47	-9	4	239
3597	83	7	1	365
3601	33	-75	4	0
3604	106	88	1	274
3605	50	1	1	291
3607	57	24	1	363
3615	76	9	1	370
3623	9	44	1	244
3633	140	82	1	317
3640	154	34	1	387
3646	81	4	1	487
3648	25	31	1	280
3652	104	70	1	365
3655	96	11	1	386
3657	340	44	2	151
3660	358	21	2	161
3663	71	4	1	347
3664	100	14	1	407
3667	62	14	1	602
3786	91	-5	4	361
3787	42	88	1	288
3795	66	-11	4	271
3798	119	20	1	475
3800	346	73	2	224
3802	125	36	1	439
3804	8	-4	4	128
3810	360	20	2	164
3813	199	83	2	270
3816	83	23	1	422
3819	132	-39	4	259
3827	65	-6	4	279
3829	6	30	1	208
3831	14	11	1	193
3833	114	1	1	382
3837	113	17	1	463
3841	15	13	1	202
3844	16	-22	4	96
3847	0	42	1	212
3848	28	-14	4	153
3850	76	13	1	517
3852	64	-1	4	299
3854	0	11	1	143
3856	0	-6	4	102
3861	22	48	1	290
3864	53	-6	4	269
3870	345	19	2	111
3872	356	-3	3	96
3877	65	4	1	353
3878	79	71	1	423
3881	16	68	1	274
3883	321	28	2	61
3890	328	28	2	79
3892	336	24	2	94
3894	62	25	1	373
4004	359	64	2	362
4008	201	37	2	253
4010	71	34	1	412
4012	89	14	1	417
4016	129	-19	4	157
4018	128	-18	4	416
4020	21	45	1	285
4084	259	15	2	576
4086	92	-8	4	475
4088	11	70	1	264
4090	84	35	1	451
4092	48	73	1	328
4094	55	46	1	372
4096	330	57	2	696
4103	126	60	1	415
4104	139	68	1	324
4106	158	64	1	359
4108	147	52	1	421
4111	121	-13	4	328
4112	169	69	1	359
4114	142	31	1	454
4125	128	49	1	438
4128	88	9	1	404
4131	50	21	1	354
4133	28	51	1	308
4136	23	48	1	293
4138	347	15	2	109
4141	217	53	2	204
4143	84	14	1	385
4144	113	-13	4	336

TABLE I. - Continued. PROBABILITY OF IMPACT

Serial number	Orbital angles, deg φ	β	Quadrant	A	Serial number	Orbital angles, deg φ	β	Quadrant	A	Serial number	Orbital angles, deg φ	β	Quadrant	A	Serial number	Orbital angles, deg φ	β	Quadrant	A
4147	96	6	1	387	4340	97	-10	4	314	4467	9	-17	4	96	4605	83	-6	4	327
4148	108	31	1	440	4341	2	73	1	263	4469	86	22	1	419	4607	77	32	1	415
4151	352	10	2	115	4351	86	-15	4	298	4472	159	80	1	303	4609	12	-12	4	119
4153	105	6	1	387	4352	6	-24	4	69	4476	80	-0	4	335	4618	101	-3	4	360
4154	167	9	1	1018	4355	353	4	2	105	4478	81	-2	4	344	4622	352	24	2	146
4156	101	19	1	365	4357	170	34	1	361	4482	98	-1	4	354	4624	114	5	1	398
4158	63	58	1	776	4360	53	36	1	368	4484	81	-11	4	287	4625	90	-0	4	368
4161	89	-12	4	315	4363	79	8	1	367	4486	38	13	1	280	4627	98	21	1	462
4167	106	13	1	409	4369	90	8	1	380	4492	114	-1	4	373	4629	100	30	1	453
4169	96	13	1	409	4370	81	-3	4	326	4494	37	15	1	284	4633	359	17	2	154
4171	86	60	1	478	4372	117	4	1	524	4496	21	26	1	257	4637	86	20	1	398
4173	53	3	1	293	4374	43	36	1	1094	4498	73	-4	4	329	4639	74	29	1	394
4175	95	3	1	377	4378	73	14	1	738	4501	23	2	1	197	4645	37	-27	4	116
4177	6	37	1	222	4380	9	74	1	275	4505	92	-2	4	342	4646	37	27	1	316
4181	86	12	1	379	4382	10	23	1	207	4507	75	-7	4	320	4648	360	-28	3	50
4184	344	5	2	80	4385	95	5	1	507	4508	68	-12	4	253	4650	18	-12	4	136
4186	79	-3	4	325	4388	134	11	1	407	4510	71	-3	4	317	4652	60	8	1	326
4188	111	10	1	445	4391	80	-1	4	332	4516	84	3	1	350	4654	349	48	2	190
4190	107	35	1	628	4394	75	-3	4	319	4518	21	20	1	242	4657	96	-9	4	319
4192	291	36	2	19	4398	64	-22	4	381	4520	79	-4	4	319	4659	89	-13	4	366
4194	327	19	2	60	4400	16	-5	4	155	4522	31	48	1	315	4660	17	14	1	212
4196	2	44	1	224	4402	4	5	1	143	4524	100	53	1	485	4662	66	16	1	377
4200	23	37	1	282	4404	91	-25	4	1471	4526	152	-4	4	470	4666	77	-6	4	309
4203	117	33	1	419	4406	67	14	1	374	4528	201	73	2	251	4668	14	12	1	194
4205	102	12	1	396	4408	19	19	1	234	4531	91	7	1	375	4670	76	-13	4	271
4207	168	33	1	340	4410	17	-12	4	132	4534	45	79	1	305	4673	82	37	1	417
4211	76	-19	4	221	4412	304	29	2	40	4535	171	2	1	754	4677	0	73	1	245
4213	157	68	1	307	4414	33	24	1	293	4537	99	-25	4	258	4679	122	8	1	399
4216	2	40	1	214	4416	358	-35	3	37	4539	89	-18	4	259	4683	351	27	2	148
4219	64	7	1	332	4418	73	9	1	366	4542	89	-7	4	336	4684	80	2	1	344
4229	311	70	2	174	4420	338	28	2	109	4544	94	6	1	387	4688	73	-9	4	290
4286	131	33	1	460	4422	345	10	2	95	4546	71	-5	4	308	4690	63	15	1	355
4289	119	15	1	415	4424	118	12	1	300	4548	358	-17	3	67	4692	339	5	2	67
4290	66	26	1	382	4426	60	47	1	394	4550	57	40	1	376	4694	8	28	1	211
4292	103	8	1	398	4428	334	68	2	207	4552	8	-35	4	49	4696	344	6	2	82
4294	115	8	1	449	4430	143	17	1	603	4554	354	19	2	141	4698	86	19	1	430
4298	104	6	1	429	4432	110	1	1	375	4556	64	2	1	325	4722	148	1	1	300
4300	106	18	1	634	4434	68	6	1	348	4558	25	21	1	260	4724	106	-0	4	380
4302	73	28	1	392	4436	79	-28	4	272	4560	73	1	1	338	4726	91	2	1	358
4304	133	56	1	423	4439	60	7	1	337	4565	338	-23	3	25	4730	53	10	1	1012
4307	118	46	1	444	4442	69	-7	4	297	4567	347	16	2	111	4732	78	-5	4	332
4311	107	-23	4	254	4444	81	27	1	427	4571	99	14	1	407	4734	128	47	1	481
4313	139	27	1	458	4446	33	36	1	398	4575	91	1	1	370	4736	99	70	1	385
4318	93	34	1	412	4448	12	-8	4	132	4577	90	24	1	518	4738	99	-8	4	321
4325	138	70	1	306	4453	355	19	2	145	4582	90	3	1	364	4740	10	84	1	269
4328	95	19	1	408	4454	357	22	2	159	4586	30	4	1	225	4742	73	-15	4	260
4330	15	30	1	242	4455	71	-6	4	321	4596	100	63	1	407	4744	62	23	1	386
4331	120	25	1	507	4457	72	-14	4	243	4597	14	-11	4	128	4747	75	-4	4	315
4335	113	40	1	455	4460	357	21	2	155	4599	9	-25	4	72	4750	5	59	1	249
4337	65	50	1	383	4464	97	12	1	421	4603	357	-20	3	60	4752	65	6	1	326
4754	75	-4	4	317	4966	86	-8	4	318	5250	105	-8	4	326	5477	65	-8	4	265
4756	159	17	1	331	4967	94	8	1	394	5254	112	-24	4	252	5479	84	-46	4	129
4760	75	41	1	415	4974	24	-18	4	128	5262	14	15	1	204	5485	49	11	1	308
4762	159	-19	4	238	4977	95	7	1	391	5266	35	-9	4	193	5487	316	-15	3	3984
4767	88	2	1	361	4987	94	-4	4	347	5268	27	-7	4	178	5489	35	22	1	295
4774	88	10	1	387	4992	73	24	1	611	5270	56	14	1	352	5491	16	-16	4	117
4778	80	-11	4	1301	4997	103	-20	4	303	5284	348	-6	3	69	549[illegible]	23	23	1	255
4781	26	22	1	263	4999	85	-8	4	315	5289	323	-1	3	22	5499	87	-1	4	350
4783	89	40	1	431	5003	82	-4	4	336	5292	93	24	1	453	5503	105	-0	4	382
4787	131	35	1	506	5007	98	56	1	463	5294	31	52	1	316	5505	359	-13	3	81
4791	132	-28	4	194	5009	59	7	1	320	5298	74	-5	4	310	5508	81	-1	4	721
4793	82	-0	4	335	5019	88	-9	4	309	5304	8	-28	4	63	5523	65	15	1	372
4795	76	-8	4	411	5027	48	-40	4	83	5313	33	-15	4	163	5527	115	17	1	480
4799	81	53	1	402	5029	31	21	1	279	5315	8	44	1	242	5529	82	-8	4	298
4813	87	22	1	561	5031	24	24	1	262	5319	75	8	1	365	5531	96	8	1	470
4817	83	-29	4	169	5034	36	24	1	304	5323	31	38	1	310	5535	127	15	1	429
4824	37	15	1	284	5045	22	62	1	290	5325	65	26	1	1514	5537	82	-5	4	313
4827	347	5	2	88	5047	106	-11	4	412	5327	27	-7	4	180	5539	86	39	1	744
4832	77	-4	4	316	5048	102	35	1	515	5329	6	20	1	184	5541	111	-33	4	134
4839	93	8	1	394	5050	227	52	2	160	5332	100	32	1	438	5546	138	-3	4	399

TABLE I. - Continued. PROBABILITY OF IMPACT

Serial number	Orbital angles, deg φ	β	Quadrant	A	Serial number	Orbital angles, deg φ	β	Quadrant	A	Serial number	Orbital angles, deg φ	β	Quadrant	A	Serial number	Orbital angles, deg φ	β	Quadrant	A
4842	118	−8	4	366	5058	133	5	1	432	5333	239	−13	3	33	5548	57	−11	4	239
4847	69	7	1	338	5064	87	−4	4	354	5335	105	16	1	420	5551	40	13	1	286
4852	67	16	1	362	5073	124	60	1	399	5339	110	23	1	425	5554	126	−11	4	319
4854	80	3	1	366	5080	13	14	1	198	5351	88	4	1	368	5557	104	−32	4	160
4856	82	10	1	388	5087	121	−20	4	327	5357	85	2	1	362	5558	89	−21	4	240
4864	8	−9	4	118	5091	53	35	1	368	5363	76	−8	4	314	5572	146	50	1	402
4866	70	2	1	337	5107	31	75	1	378	5380	76	9	1	368	5583	114	−21	4	280
4870	83	1	1	359	5117	21	−45	4	45	5382	109	21	1	420	5587	102	−62	4	79
4872	101	−32	4	245	5121	97	69	1	677	5384	107	22	1	2658	5596	69	28	1	405
4877	99	−9	4	295	5124	86	−6	4	325	5388	81	−10	4	305	5602	111	35	1	478
4891	79	−7	4	322	5136	115	43	1	452	5390	91	−21	4	235	5606	159	−56	4	100
4895	17	−29	4	76	5138	71	−46	4	424	5392	108	21	1	425	5620	82	3	1	364
4903	142	37	1	423	5142	68	6	1	348	5394	108	−4	4	322	5622	83	3	1	400
4905	115	10	1	557	5147	78	−2	4	345	5400	140	7	1	387	5675	96	4	1	398
4918	101	−19	4	315	5159	99	24	1	485	5402	80	25	1	425	5688	3	16	1	167
4920	230	−73	3	6	5192	63	10	1	354	5405	15	33	1	246	5695	48	13	1	328
4924	72	−8	4	752	5204	341	−9	3	46	5407	82	−32	4	152	5725	61	−11	4	246
4926	115	5	1	438	5206	15	28	1	238	5409	97	5	1	529	5742	98	−28	4	202
4928	74	−1	4	329	5212	14	−25	4	84	5413	16	−18	4	110	5750	86	13	1	453
4930	48	37	1	357	5217	163	0	1	367	5419	75	5	1	353	5752	120	19	1	465
4933	318	71	2	174	5221	85	14	1	438	5421	61	−8	4	259	5762	114	41	1	472
4938	82	3	1	365	5225	105	−36	4	172	5423	58	6	1	312	5770	143	59	1	394
4940	55	−10	4	383	5227	152	−20	4	544	5427	97	14	1	409	5783	152	8	1	423
4942	31	5	1	234	5231	23	10	1	223	5437	343	19	2	105	5795	87	−6	4	325
4948	344	−55	3	6	5234	66	−6	4	346	5439	84	−27	4	182	5801	181	−12	3	177
4950	23	62	1	292	5237	95	−21	4	236	5444	351	−1	3	89	5810	138	56	1	389
4952	71	−24	4	1396	5238	85	1	1	342	5461	56	48	1	373	5848	95	65	1	761
4954	59	−17	4	227	5242	110	7	1	398	5463	343	43	2	156	5864	355	40	2	188
4959	47	−57	4	34	5244	73	−2	4	325	5472	13	59	1	270	5876	106	40	1	633
4964	191	48	2	275	5246	50	36	1	5068	5473	109	58	1	557	5880	96	−34	4	162
5886	88	4	1	367	6114	133	66	1	305	6247	80	7	1	398	6387	99	30	1	455
5907	340	−6	3	49	6116	88	7	1	684	6251	58	−1	4	286	6389	119	−4	4	361
5922	69	10	1	365	6119	84	18	1	448	6254	85	2	1	361	6391	85	8	1	383
5935	107	48	1	527	6123	113	−24	4	267	6256	96	12	1	386	6393	101	−8	4	337
5948	112	42	1	499	6125	145	17	1	822	6258	82	−5	4	316	6395	92	−32	4	3815
5962	153	15	1	570	6129	109	35	1	441	6260	88	13	1	415	6398	99	23	1	409
5970	122	23	1	449	6131	77	−50	4	67	6262	59	8	1	323	6399	84	14	1	401
5972	69	−5	4	289	6133	110	−41	4	100	6266	68	28	1	404	6401	84	−9	4	311
5974	98	−14	4	292	6135	121	40	1	547	6268	133	8	1	425	6403	62	36	1	384
5980	141	−4	4	183	6137	78	−4	4	319	6270	92	15	1	741	6405	100	−6	4	387
5988	27	22	1	267	6139	62	−9	4	259	6272	111	−23	4	280	6408	52	−1	4	306
5996	85	66	1	385	6143	71	−24	4	237	6275	25	34	1	285	6410	15	27	1	1092
5998	38	59	1	343	6145	344	78	2	244	6276	137	45	1	427	6416	75	21	1	416
6001	96	−9	4	128	6147	43	8	1	282	6278	69	56	1	392	6420	78	0	1	409
6003	95	−5	4	86	6150	10	35	1	235	6280	61	47	1	380	6424	83	−29	4	167
6007	6	8	1	160	6154	67	−2	4	298	6282	63	3	1	312	6426	7	65	1	620
6011	33	18	1	279	6158	79	−37	4	1017	6284	115	1	1	376	6429	62	6	1	339
6015	17	−19	4	109	6160	138	−2	4	329	6286	106	4	1	380	6430	28	67	1	298
6023	110	−11	4	356	6162	96	6	1	403	6288	355	21	2	151	6433	2	28	1	188
6025	41	32	1	334	6164	79	−11	4	283	6290	26	−19	4	132	6434	325	38	2	93
6027	25	22	1	262	6166	65	−27	4	156	6292	84	6	1	375	6437	8	−16	4	98
6029	21	−19	4	117	6168	117	28	1	497	6294	72	30	1	426	6438	23	34	1	277
6031	351	3	2	94	6170	91	10	1	386	6296	89	15	1	419	6440	90	2	1	359
6035	71	−26	4	169	6172	75	4	1	464	6298	163	−38	4	411	6443	66	9	1	357
6037	32	4	1	232	6174	57	17	1	346	6300	55	63	1	498	6447	115	1	1	399
6038	23	21	1	252	6176	82	2	1	360	6302	69	−2	4	300	6454	90	16	1	622
6042	114	27	1	461	6179	98	12	1	439	6304	131	39	1	465	6458	94	−2	4	358
6044	32	−14	4	165	6184	28	8	1	713	6310	64	−6	4	276	6460	86	16	1	407
6046	70	−1	4	307	6185	74	6	1	355	6312	101	61	1	668	6463	88	−4	4	741
6048	140	31	1	460	6187	64	10	1	356	6315	35	−6	4	206	6465	116	2	1	404
6050	80	11	1	376	6189	83	−3	4	341	6317	4	61	1	248	6467	86	21	1	400
6052	81	3	1	365	6191	33	17	1	276	6320	351	−15	3	58	6469	79	19	1	414
6054	352	−11	3	67	6193	289	79	2	212	6322	356	37	2	189	6471	25	53	1	298
6059	64	−30	4	141	6197	78	−1	4	402	6326	83	14	1	384	6473	91	−11	4	299
6062	155	−54	4	82	6199	87	−15	4	282	6329	96	−6	4	337	6475	112	4	1	543
6069	86	1	1	358	6201	35	−31	4	99	6330	75	−6	4	308	6484	89	8	1	399
6071	7	34	1	222	6204	38	−34	4	95	6336	243	62	2	176	6486	82	63	1	431
6076	76	36	1	681	6206	62	22	1	367	6338	100	12	1	416	6488	61	−5	4	306
6081	81	0	1	338	6208	158	60	1	612	6340	275	77	2	560	6491	102	36	1	436
6083	113	28	1	425	6210	62	−4	4	350	6343	83	10	1	444	6494	59	3	1	2450

TABLE I. - Continued. PROBABILITY OF IMPACT

Serial number	Orbital angles, deg φ	Orbital angles, deg β	Quadrant	A	Serial number	Orbital angles, deg φ	Orbital angles, deg β	Quadrant	A	Serial number	Orbital angles, deg φ	Orbital angles, deg β	Quadrant	A	Serial number	Orbital angles, deg φ	Orbital angles, deg β	Quadrant	A
6090	109	-16	4	268	6212	77	-6	4	379	6346	26	-25	4	955	6496	71	2	1	340
6093	324	64	2	164	6214	36	9	1	263	6348	58	71	1	457	6500	9	-8	4	123
6095	4	56	1	271	6218	357	11	2	132	6350	82	-37	4	200	6511	128	-10	4	939
6096	3	-15	4	85	6227	117	67	1	380	6355	66	35	1	459	6512	81	-3	4	529
6098	87	22	1	419	6231	175	-41	4	79	6359	328	-38	3	7	6516	353	54	2	210
6102	84	14	1	401	6233	110	-5	4	409	6363	86	38	1	470	6518	24	28	1	271
6105	332	55	2	154	6237	93	-9	4	288	6365	61	7	1	642	6521	7	23	1	199
6106	356	42	2	198	6239	60	2	1	301	6367	228	19	2	114	6523	58	4	1	324
6110	360	50	2	224	6241	359	57	2	230	6369	123	2	1	4428	6525	22	66	1	460
6112	21	75	1	290	6245	108	8	1	406	6376	81	-0	4	336	6527	120	82	1	348
6531	84	-4	4	739	6915	107	25	1	435	7058	86	0	1	428	7190	94	36	1	428
6533	62	4	1	314	6918	104	-1	4	364	7060	53	-30	4	423	7193	31	69	1	316
6535	249	68	2	157	6921	84	47	1	596	7062	12	8	1	178	7195	181	-6	3	1362
6537	65	29	1	384	6927	103	20	1	493	7064	66	12	1	401	7201	94	12	1	427
6539	60	5	1	313	6929	76	-4	4	429	7067	118	25	1	444	7203	145	65	1	505
6546	349	32	2	153	6932	71	75	1	335	7069	91	60	1	402	7205	163	-0	4	520
6636	39	17	1	297	6933	103	48	1	722	7070	170	68	1	295	7207	109	-2	4	406
6766	98	6	1	421	6936	76	24	1	439	7073	75	2	1	342	7210	194	14	2	234
6768	163	70	1	277	6938	67	9	1	452	7075	138	49	1	430	7211	73	38	1	398
6770	123	-7	4	353	6940	101	6	1	395	7076	178	14	1	301	7213	146	14	1	408
6772	65	-74	4	626	6944	89	15	1	403	7078	151	-57	4	126	7216	87	-17	4	249
6774	62	6	1	341	6946	63	32	1	454	7080	111	23	1	481	7218	108	10	1	413
6776	99	4	1	373	6949	86	6	1	375	7082	172	45	1	2594	7220	125	9	1	778
6778	116	-16	4	306	6950	77	45	1	549	7084	100	-33	4	610	7222	119	55	1	1154
6788	93	11	1	423	6952	344	26	2	124	7088	81	15	1	596	7224	86	-2	4	346
6790	128	-27	4	265	6954	50	20	1	534	7090	153	36	1	442	7226	118	15	1	487
6795	168	60	1	346	6959	309	40	2	56	7097	73	21	1	397	7228	93	2	1	374
6801	33	38	1	313	6964	46	55	1	346	7098	91	40	1	467	7231	49	8	1	589
6802	34	41	1	322	6966	86	-8	4	352	7102	91	9	1	381	7237	94	31	1	544
6805	128	6	1	372	6971	103	23	1	437	7104	123	19	1	359	7240	97	7	1	405
6811	39	-8	4	209	6972	140	-15	4	395	7106	104	16	1	505	7244	93	38	1	526
6814	114	4	1	301	6975	57	26	1	398	7108	64	71	1	348	7246	75	73	1	344
6824	142	29	1	449	6977	145	3	1	195	7110	109	-6	4	388	7248	58	-1	4	304
6826	121	-21	4	329	6979	87	13	1	399	7114	81	1	1	342	7250	77	3	1	438
6828	64	48	1	400	6981	102	17	1	467	7116	85	3	1	365	7252	180	12	2	188
6830	90	24	1	403	6983	7	34	1	222	7118	87	13	1	398	7254	131	52	1	451
6832	76	14	1	365	6985	108	48	1	525	7120	70	-4	4	309	7256	121	33	1	541
6834	133	4	1	570	6987	93	12	1	466	7124	102	31	1	491	7259	71	6	1	335
6842	37	-9	4	200	6989	89	28	1	569	7126	105	11	1	485	7261	98	42	1	424
6843	55	37	1	373	6992	103	16	1	404	7128	101	72	1	377	7263	91	-14	4	470
6847	93	-2	4	325	6993	64	14	1	369	7133	98	-0	4	358	7265	133	53	1	490
6849	77	6	1	413	6995	99	1	1	361	7135	110	23	1	424	7267	111	16	1	466
6853	83	41	1	712	6998	90	-11	4	285	7139	121	2	1	427	7269	110	27	1	563
6855	64	3	1	624	6999	236	74	2	213	7141	105	8	1	394	7272	79	12	1	379
6857	27	24	1	272	7002	55	-1	4	298	7145	79	3	1	366	7273	129	74	1	425
6859	92	42	1	678	7003	317	68	2	177	7149	105	38	1	451	7277	39	-7	4	215
6861	86	38	1	433	7005	90	2	1	378	7151	177	83	1	289	7279	87	1	1	356
6863	57	63	1	600	7019	77	4	1	351	7153	103	33	1	635	7281	337	19	2	88
6869	89	4	1	367	7022	110	89	1	287	7155	90	38	1	449	7283	10	14	1	187
6875	120	15	1	411	7026	63	51	1	380	7158	97	-1	4	358	7285	120	50	1	755
6881	154	43	1	592	7033	99	-9	4	335	7161	315	47	2	90	7287	100	4	1	390
6882	160	43	1	708	7035	315	69	2	299	7162	55	62	1	366	7291	93	27	1	422
6887	69	-1	4	324	7040	100	36	1	457	7164	181	60	2	352	7293	132	37	1	459
6889	75	-7	4	339	7041	222	79	2	388	7166	88	68	1	397	7295	79	40	1	509
6895	358	14	2	145	7044	55	47	1	372	7169	241	33	2	35	7303	101	6	1	417
6899	96	16	1	433	7046	113	-13	4	317	7170	160	15	1	2112	7307	23	61	1	292
6901	351	54	2	205	7047	64	14	1	352	7179	133	49	1	515	7314	112	4	1	570
6904	326	20	2	59	7049	42	48	1	343	7184	92	2	1	375	7316	351	54	2	204
6905	28	9	1	236	7052	24	47	1	294	7185	74	17	1	424	7318	2	47	1	226
6907	66	23	1	1192	7054	91	13	1	396	7188	70	46	1	392	7320	75	20	1	398
7324	111	-6	4	335	7465	98	18	1	419	7598	16	64	1	276	7737	150	81	1	509
7326	162	-6	4	9998	7467	76	29	1	484	7600	100	14	1	505	7742	21	63	1	286
7328	30	66	1	301	7469	92	-5	4	329	7607	290	74	2	169	7744	105	3	1	395
7331	94	47	1	424	7471	99	19	1	419	7608	74	50	1	406	7745	199	40	2	220
7333	81	2	1	344	7474	72	-3	4	320	7610	70	-3	4	318	7750	119	-3	4	391
7334	148	4	1	400	7476	72	6	1	353	7612	49	56	1	384	7754	95	11	1	421
7336	97	8	1	429	7478	76	-10	4	289	7615	90	33	1	448	7757	86	56	1	510
7339	65	-20	4	202	7480	112	-2	4	374	7618	245	72	2	179	7759	31	21	1	277
7344	213	61	2	199	7481	172	-6	4	471	7620	279	57	2	354	7760	19	42	1	275
7346	79	18	1	467	7485	99	67	1	519	7622	91	4	1	365	7762	83	66	1	661

TABLE I. - Continued. PROBABILITY OF IMPACT

Serial number	Orbital angles, deg φ	Orbital angles, deg β	Quadrant	A	Serial number	Orbital angles, deg φ	Orbital angles, deg β	Quadrant	A	Serial number	Orbital angles, deg φ	Orbital angles, deg β	Quadrant	A	Serial number	Orbital angles, deg φ	Orbital angles, deg β	Quadrant	A
7348	80	13	1	381	7487	64	10	1	356	7624	107	-54	4	282	7765	48	52	1	405
7352	36	3	1	242	7491	105	53	1	405	7626	61	56	1	6511	7769	160	-1	4	610
7356	99	-2	4	366	7494	97	-1	4	375	7632	100	-6	4	498	7771	16	39	1	262
7358	71	29	1	443	7496	195	76	2	566	7635	83	9	1	386	777[illegible]	192	17	2	134
7360	348	59	2	205	7499	81	10	1	390	7637	80	-3	4	329	7777	103	45	1	452
7362	340	17	2	92	7500	64	-5	4	296	7641	72	14	1	414	7780	310	65	2	153
7364	16	31	1	248	7504	135	49	1	418	7643	105	37	1	451	7782	80	-8	4	302
7367	110	-10	4	304	7506	100	39	1	440	7645	67	60	1	773	7784	47	42	1	357
7368	173	20	1	234	7508	61	-8	4	279	7647	166	32	1	416	7787	21	58	1	288
7372	102	-6	4	344	7512	115	36	1	428	7651	113	70	1	547	7790	98	60	1	400
7375	149	62	1	361	7520	115	8	1	406	7655	103	22	1	542	7796	192	45	2	325
7377	103	13	1	596	7522	162	79	1	319	7659	65	3	1	315	7802	89	-12	4	294
7379	94	61	1	565	7524	29	78	1	295	7661	149	16	1	424	7804	70	0	1	330
7381	104	30	1	467	7527	71	35	1	428	7664	115	8	1	404	7806	63	24	1	372
7383	106	20	1	489	7529	138	38	1	415	7666	345	66	2	475	7808	80	-4	4	321
7385	93	25	1	437	7534	74	8	1	362	7667	139	4	1	538	7813	10	83	1	270
7388	92	4	1	383	7535	102	56	1	369	7669	101	-8	4	667	7815	259	62	2	135
7389	111	-58	4	385	7537	339	74	2	228	7671	46	64	1	348	7820	139	61	1	406
7392	300	83	2	238	7541	71	54	1	3409	7673	81	6	1	361	7821	121	75	1	578
7395	73	69	1	357	7543	67	21	1	375	7675	32	14	1	266	7823	98	19	1	403
7397	48	19	1	733	7545	353	41	2	188	7682	71	52	1	493	7829	151	12	1	535
7399	5	66	1	253	7550	55	22	1	355	7684	329	67	2	182	7835	79	50	1	423
7404	307	72	2	373	7552	125	47	1	490	7686	1	70	1	246	7838	130	52	1	475
7406	75	14	1	418	7554	112	24	1	483	7688	82	20	1	513	7841	7	-2	4	133
7410	70	82	1	323	7557	93	20	1	629	7692	122	36	1	447	7844	62	-3	4	287
7412	69	24	1	471	7560	72	49	1	405	7694	162	44	1	355	7846	321	32	2	77
7414	60	49	1	377	7562	93	13	1	395	7696	76	3	1	365	7854	112	68	1	331
7416	146	58	1	387	7565	164	66	1	346	7700	139	41	1	340	7857	48	27	1	360
7423	293	83	2	217	7567	74	14	1	474	7702	90	40	1	449	7859	100	63	1	407
7428	77	5	1	354	7569	51	69	1	341	7707	152	-15	4	1728	7862	144	2	1	360
7431	100	55	1	408	7571	98	50	1	759	7713	162	-22	4	265	7866	6	56	1	249
7433	66	83	1	297	7573	83	39	1	2147	7715	6	73	1	269	7868	91	-24	4	362
7437	332	55	2	154	7575	68	5	1	345	7719	116	-8	4	330	7871	82	-8	4	320
7439	92	31	1	463	7577	105	57	1	516	7721	107	-1	4	418	7873	24	25	1	263
7441	93	17	1	1433	7583	89	12	1	377	7726	80	-2	4	329	7874	346	28	2	134
7449	19	11	1	213	7585	80	30	1	709	7727	87	-2	4	343	7877	359	58	2	393
7454	301	28	2	18	7587	94	22	1	993	7729	105	19	1	427	7882	122	46	1	432
7455	31	-13	4	170	7589	63	50	1	396	7731	71	74	1	321	788[illegible]	343	13	2	93
7457	74	55	1	396	7592	183	9	2	289	7734	132	-3	4	379	7891	117	31	1	601
7461	225	39	2	131	7596	92	38	1	550	7735	148	44	1	855	7895	88	-6	4	327
7897	266	55	2	109	8120	15	43	1	261	8379	349	23	2	133	8634	27	-8	4	177
7899	86	-3	4	342	8124	131	75	1	419	8389	12	21	1	214	8640	356	-50	3	17
7902	36	11	1	268	8127	86	33	1	432	8394	141	16	1	464	8651	13	5	1	172
7906	187	82	2	298	8138	116	14	1	593	8413	90	88	1	293	8666	17	50	1	276
7914	16	32	1	250	8143	111	61	1	400	8415	146	4	1	416	8697	349	32	2	155
7920	116	75	1	374	8146	86	7	1	381	8416	69	12	1	388	871[illegible]	65	1	1	305
7922	73	39	1	466	8157	39	79	1	355	8417	67	11	1	383	8725	19	48	1	282
7924	100	14	1	443	8159	53	34	1	474	8427	360	-1	3	114	8736	16	-9	4	138
7926	350	19	2	128	8161	66	18	1	367	8433	61	49	1	488	8753	348	14	2	110
7929	19	3	1	187	8163	206	88	2	293	8441	64	7	1	329	8761	12	24	1	220
7930	27	79	1	963	8165	353	38	2	178	8447	123	52	1	408	8763	95	77	1	327
7934	25	-2	4	192	8169	115	26	1	456	8457	341	14	2	89	8766	93	-8	4	331
7941	37	80	1	298	8176	357	48	2	213	8464	357	77	2	258	8767	82	-1	4	331
7944	102	12	1	415	8180	70	6	1	351	8470	14	33	1	244	8769	90	20	1	412
7946	120	48	1	458	8182	124	14	1	461	8472	53	38	1	368	8771	111	19	1	452
7947	84	-0	4	337	8184	45	28	1	513	8476	128	72	1	371	8773	93	25	1	438
7965	99	29	1	455	8189	105	24	1	436	8477	353	41	2	186	8777	83	-10	4	306
7972	84	27	1	482	8192	64	-9	4	292	8481	68	12	1	367	8782	88	-25	4	214
8003	336	50	2	238	8193	104	27	1	443	8486	113	-4	4	592	8786	44	43	1	348
8005	2	63	1	274	8199	56	40	1	445	8488	360	18	2	160	8790	99	6	1	382
8012	86	22	1	403	8202	94	-2	4	338	8499	356	30	2	174	8794	92	-4	4	636
8014	114	24	1	687	8210	59	8	1	324	8503	27	31	1	287	8796	73	-4	4	317
8017	103	-4	4	352	8215	320	60	2	143	8505	305	53	2	533	8798	87	17	1	409
8018	39	69	1	327	8227	112	66	1	389	8507	98	-2	4	350	8800	92	5	1	370
8022	127	74	1	472	8229	117	-11	4	313	8510	127	50	1	439	8803	72	-5	4	307
8026	91	8	1	396	8233	132	-3	4	355	8514	347	39	2	161	8809	69	36	1	394
8028	45	22	1	360	8235	79	1	1	341	8520	353	16	2	129	8811	77	-4	4	333
8030	57	14	1	339	8240	92	56	1	410	8522	22	60	1	291	8813	70	26	1	387
8032	12	42	1	253	8244	149	48	1	411	8526	4	-5	4	116	8817	345	16	2	107
8035	61	14	1	362	8245	357	43	2	202	8528	54	35	1	369	8819	60	32	1	378

TABLE I. - Continued. PROBABILITY OF IMPACT

Serial number	Orbital angles, deg φ	Orbital angles, deg β	Quadrant	A
8047	35	24	1	300
8050	358	32	2	186
8054	334	46	2	137
8059	3	4	1	134
8061	353	43	2	188
8063	88	9	1	386
8065	65	8	1	337
8069	25	82	1	284
8074	61	12	1	341
8076	338	52	2	163
8079	346	28	2	133
8083	25	6	1	216
8085	81	2	1	347
8089	93	73	1	341
8092	72	-5	4	307
8098	62	-4	4	300
8106	69	-4	4	309
8108	358	66	2	237
8109	82	4	1	352
8113	354	10	2	120
8247	63	27	1	378
8249	268	61	2	156
8257	36	49	1	327
8261	174	41	1	555
8284	86	1	1	375
8294	154	33	1	507
8304	95	5	1	400
8312	131	20	1	648
8314	102	0	1	391
8320	7	47	1	243
8322	63	-10	4	255
8326	63	7	1	344
8328	62	-12	4	245
8336	58	5	1	361
8350	355	23	2	155
8361	124	34	1	420
8363	159	52	1	363
8368	86	12	1	396
8369	155	62	1	385
8371	62	6	1	323
8530	334	46	2	137
8534	21	12	1	223
8540	107	38	1	429
8542	46	17	1	320
8546	112	-9	4	339
8558	57	12	1	364
8560	106	4	1	437
8565	344	13	2	97
8572	29	-8	4	181
8575	37	-44	4	63
8581	29	38	1	302
8583	20	35	1	269
8606	79	2	1	363
8609	8	34	1	223
8610	65	4	1	322
8616	21	-16	4	131
8619	351	4	2	99
8626	71	16	1	384
8630	349	42	2	173
8632	44	-13	4	257
8821	91	8	1	379
8828	101	32	1	537
8830	84	5	1	355
8832	90	4	1	384
8834	76	-9	4	292
8836	74	-5	4	311
8838	95	8	1	395
8844	114	16	1	504
8847	19	24	1	243
8849	72	-4	4	330
8853	49	-71	4	119
8855	72	-6	4	305
8857	82	19	1	397
8859	107	29	1	500
8863	348	37	2	159
8865	19	16	1	224
8867	353	14	2	128
8870	12	-23	4	82
8872	97	3	1	354
8881	209	50	2	194
8882	118	76	1	334
8886	76	-3	4	322
8888	90	-8	4	350
8891	69	77	1	325
8892	24	32	1	278
8899	88	-4	4	332
8917	96	-3	4	369
8918	8	-7	4	121
8920	30	35	1	353
8922	99	19	1	419
8924	100	44	1	438
8926	89	36	1	415
8930	100	14	1	405
8938	66	1	1	311
8948	100	-1	4	353
8952	79	5	1	354
8954	74	-6	4	306
8956	76	-3	4	321
8958	5	-22	4	72
8964	46	-28	4	130
8967	93	-19	4	250
8987	41	7	1	270
8990	69	-3	4	328
8991	104	34	1	450
8996	85	43	1	431
8998	67	1	1	328
9004	77	-5	4	314
9007	85	21	1	401
9009	121	67	1	372
9012	71	20	1	411
9016	71	-4	4	311
9023	26	-15	4	145
9025	83	4	1	367
9027	59	-24	4	167
9030	88	6	1	391
9035	71	-25	4	189
9037	77	-4	4	318
9039	96	23	1	511
9041	73	1	1	337
9046	46	25	1	336
9057	22	16	1	601
9062	327	-12	3	19
9063	74	-6	4	305
9070	84	4	1	368
9074	79	-4	4	320
9087	95	-35	4	187
9088	344	68	2	212
9101	25	-4	4	182
9105	25	-9	4	165
9107	143	15	1	378
9109	104	-9	4	324
9114	95	7	1	562
9121	77	3	1	348
9123	148	58	1	448
9130	207	54	2	200
9131	67	50	1	513
9134	97	-9	4	319
9136	65	9	1	354
9138	72	36	1	413
9144	72	-10	4	281
9147	39	22	1	308
9149	56	29	1	367
9156	130	48	1	1243
9162	36	60	1	322
9164	71	-4	4	312
9170	79	-41	4	107
9180	86	3	1	381
9182	80	3	1	349
9192	58	-4	4	275
9198	31	-42	4	62
9203	19	19	1	233
9208	125	-20	4	252
9220	43	16	1	306
9222	34	-8	4	195
9224	356	-27	3	45
9226	9	-41	4	41
9235	85	69	1	377
9241	70	3	1	340
9243	44	-66	4	23
9247	3	3	1	133
9252	102	0	1	391
9258	29	-6	4	26
9262	84	-21	4	222
9272	61	-40	4	95
9276	77	-2	4	346
9279	85	-21	4	224
9287	68	10	1	347
9311	63	26	1	378
9314	79	4	1	369
9321	87	-5	4	298
9323	115	-9	4	352
9325	89	-0	4	350
9328	83	2	1	346
9335	38	-26	4	125
9346	37	-16	4	173
9348	2	16	1	162
9358	358	35	2	190
9360	32	-13	4	172
9362	64	9	1	337
9364	20	-8	4	153
9385	86	-5	4	315
9387	94	-24	4	252
9390	59	10	1	347
9392	54	9	1	720
9396	87	-17	4	269
9398	102	14	1	420
9400	82	2	1	361
9402	78	-2	4	326
9404	19	-15	4	127
9406	94	-28	4	184
9412	71	-11	4	259
9416	87	-8	4	317
9419	30	-12	4	170
9423	24	-18	4	129
9432	93	-16	4	308
9436	63	-1	4	296
9452	43	-17	4	182
9454	62	7	1	324
9467	42	15	1	301
9483	86	-20	4	247
9488	83	-9	4	311
9495	87	-10	4	637
9498	108	-14	4	326
9510	64	5	1	320
9521	79	-10	4	270
9527	77	-17	4	300
9535	62	-21	4	192
9544	62	-9	4	256
9551	85	-29	4	282
9553	95	-24	4	314
9559	27	19	1	264
9561	6	59	1	251
9589	329	8	2	45
9593	27	23	1	270
9615	108	12	1	422
9659	41	-16	4	179
9674	87	3	1	363
9702	37	-28	4	116
9714	101	-5	4	332
9720	80	5	1	354
9735	97	-61	4	57
9745	83	-9	4	310
9767	344	11	2	94
9781	28	5	1	225
9785	10	-0	4	146
9789	353	-43	3	22
9794	345	28	2	2
9798	78	-5	4	312
9800	1	5	1	131
9802	25	22	1	264
9804	4	5	1	143
9805	43	8	1	282
9814	53	34	1	366
9815	21	37	1	275
9833	93	-28	4	201
9841	118	18	1	521
9843	81	26	1	523
9850	114	12	1	368
9852	126	29	1	408
9854	146	36	1	381
9856	34	-31	4	100
9858	94	41	1	1462
9862	83	4	1	368
9864	36	-16	4	167
9866	82	35	1	531
9873	108	-13	4	290
9875	129	6	1	744
9877	114	-41	4	281
9880	69	-67	4	20
9881	102	47	1	582
9883	91	21	1	556
9885	84	34	1	433
988[illegible]	135	54	1	416
9889	360	67	2	242
9891	59	2	1	300
9893	96	-1	4	375
9895	128	10	1	408
9900	102	60	1	413
9901	65	5	1	327
990[illegible]	31	-11	4	174
9911	37	47	1	332
991[illegible]	15	51	1	271
9920	88	-4	4	371
9926	10	20	1	202
9930	346	51	2	185
9934	17	22	1	233
9940	353	59	2	218
9948	23	22	1	254
9950	34	20	1	289
9956	37	22	1	302
9990	336	65	2	190
10001	358	-13	3	78
10007	65	17	1	364
10013	94	45	1	501
10015	82	-19	4	238
10020	99	-14	4	304
10027	108	22	1	427
10029	22	-5	4	170
10031	97	48	1	640
10041	86	-45	4	85

TABLE I. - Continued. PROBABILITY OF IMPACT

Serial number	Orbital angles, deg φ	Orbital angles, deg β	Quadrant	A
10059	56	−17	4	206
10061	61	−7	4	102
10064	81	−14	4	287
10067	64	−10	4	272
10073	348	15	2	113
10081	6	69	1	254
10085	21	50	1	414
10088	10	24	1	212
10090	88	3	1	399
10094	315	46	2	88
10098	60	33	1	379
10102	12	32	1	237
10108	30	17	1	265
10117	46	43	1	354
10120	70	3	1	326
10127	68	17	1	384
10130	344	49	2	174
10135	338	19	2	89
10138	333	3	2	48
10145	339	9	2	72
10147	23	47	1	292
10149	179	61	1	319
10151	123	−23	4	328
10155	103	−27	4	184
10160	89	−2	4	345
10162	6	58	1	979
10164	94	9	1	398
10168	93	−7	4	336
10178	169	−29	4	204
10187	73	10	1	634
10189	79	−25	4	195
10193	98	14	1	408
10196	82	34	1	1112
10200	75	2	1	342
10204	86	6	1	376
10208	102	6	1	413
10213	76	−4	4	315
10215	140	−8	4	496
10223	108	−21	4	282
10225	10	51	1	256
10237	92	36	1	430
10241	81	−7	4	341
10243	73	52	1	402
10266	99	−5	4	480
10270	97	9	1	395
10276	10	39	1	241
10285	4	34	1	211
10295	115	3	1	409
10297	94	−16	4	268
10299	79	20	1	582
10303	100	16	1	429
10307	95	56	1	628
10309	100	4	1	544
10313	143	46	1	350
10315	122	32	1	561
10317	89	31	1	430
10319	88	13	1	398
10321	70	5	1	350
10330	113	14	1	1671
10342	167	52	1	629
10346	98	27	1	400
10350	121	13	1	445
10353	85	1	1	358
10359	71	47	1	543
10361	53	26	1	556
10370	73	27	1	407
10373	5	−12	4	101
10377	109	−30	4	185
10380	66	−8	4	268
10381	72	26	1	564
10383	79	−2	4	326
10391	84	32	1	416
10395	355	30	2	170
10400	103	51	1	428
10404	10	9	1	176
10406	91	−2	4	397
10411	121	10	1	507
10414	131	−40	4	146
10417	113	−33	4	209
10420	62	65	1	500
10424	112	34	1	540
10426	128	26	1	434
10430	86	7	1	378
10436	129	58	1	411
10439	74	−4	4	317
10441	106	8	1	413
10447	77	−11	4	281
10454	148	76	1	338
10456	29	−8	4	180
10458	18	28	1	248
10462	136	−7	4	530
10464	102	11	1	410
10478	97	−26	4	213
10480	101	−46	4	96
10488	121	61	1	532
10490	68	35	1	840
10492	271	58	2	248
10496	195	85	2	405
10498	56	27	1	416
10506	121	4	1	435
10508	95	15	1	414
10512	78	−0	4	426
10516	153	49	1	465
10519	72	−1	4	326
10522	67	56	1	4087
10524	87	8	1	383
10531	21	54	1	288
10534	239	67	2	173
10536	45	50	1	351
10538	124	46	1	407
10542	108	2	1	365
10545	36	1	1	237
10552	72	11	1	371
10555	178	62	1	304
10556	88	−11	4	337
10567	142	75	1	310
10570	324	43	2	101
10576	118	6	1	431
10584	92	12	1	392
10589	93	54	1	451
10594	73	13	1	363
10597	342	9	2	82
11156	161	69	1	120
11164	77	63	1	379
11166	127	65	1	426
11168	135	4	1	375
11174	98	26	1	433
11178	128	22	1	300
11180	281	72	2	275
11183	84	35	1	417
11188	145	−3	4	315
11190	105	11	1	424
11194	114	35	1	560
11196	220	54	2	234
11198	101	46	1	401
11200	58	53	1	370
11206	138	25	1	411
11208	224	55	2	251
11213	156	−6	4	472
11215	99	−5	4	319
11218	84	−4	4	354
11223	340	59	2	703
11229	91	23	1	561
11231	27	78	1	293
11238	91	20	1	468
11240	4	62	1	713
11778	75	11	1	374
11781	67	63	1	409
11783	73	36	1	414
11788	124	21	1	397
11790	49	59	1	362
11794	115	13	1	537
11797	82	23	1	614
11801	31	36	1	308
11803	77	−1	4	333
11805	86	30	1	448
11807	86	30	1	413
11809	86	18	1	410
11811	91	31	1	446
11813	250	34	2	7
11817	209	11	2	80
11820	110	23	1	426
11822	86	−43	4	227
11826	155	57	1	402
11828	180	67	2	329
11830	77	32	1	414
11832	64	4	1	317
11834	85	41	1	433
11836	174	82	1	1263
11838	358	75	2	258
11840	104	26	1	573
11848	87	68	1	476
11855	31	8	1	303
11857	125	58	1	736
11859	73	48	1	408
11861	333	−1	3	40
11863	99	32	1	439
11865	125	77	1	421
11874	88	−8	4	298
11880	104	−11	4	976
11882	229	60	2	198
11884	203	56	2	312
11886	87	−13	4	274
11888	94	7	1	372
11890	102	56	1	779
11892	129	34	1	488
11894	29	21	1	271
11898	113	23	1	547
11901	96	−4	4	400
11903	66	3	1	337
11907	139	73	1	373
11910	94	63	1	392
11923	97	18	1	520
11926	77	22	1	436
11929	341	4	2	70
11935	72	−2	4	324
11938	335	4	2	54
11941	331	25	2	98
11947	99	−7	4	309
11951	178	−51	4	30
11953	83	12	1	394
11955	116	0	1	415
11957	86	60	1	404
11960	158	11	1	312
11964	132	−9	4	326
11966	104	18	1	487
11970	355	72	2	236
11972	49	47	1	359
11974	72	81	1	466
11976	117	−1	4	363
11983	75	2	1	343
11987	351	43	2	184
11989	74	25	1	405
11991	85	15	1	523
11994	11	75	1	261
11996	71	4	1	380
12057	108	9	1	409
12060	79	61	1	384
12062	117	84	1	306
12064	316	46	2	91
12182	117	23	1	467
12185	112	15	1	441
12187	81	6	1	359
12193	117	17	1	390
12195	107	20	1	531
12197	230	−1	3	95
12212	110	12	1	396
12214	102	36	1	666
12221	82	45	1	808
12225	275	66	2	120
12231	81	6	1	361
12233	96	21	1	464
12235	62	27	1	376
12237	65	1	1	306
12239	23	37	1	281
12241	63	14	1	349
12243	6	30	1	209
12256	292	70	2	488
12260	171	55	1	348
12262	52	49	1	364
12364	112	−19	4	326
12368	91	15	1	400
12370	33	73	1	294
12378	124	45	1	447
12382	113	45	1	565
12384	158	30	1	335
12390	144	14	1	394
12392	79	76	1	347
12398	120	53	1	435
12400	92	32	1	447
12403	104	9	1	382
12405	104	49	1	448
12407	281	72	2	142
12409	6	41	1	230
12412	85	22	1	419
12414	73	73	1	358
12422	87	45	1	527
12424	199	56	2	264
12428	277	64	2	134
12432	87	20	1	414
12534	107	40	1	467
12536	88	4	1	368
12541	79	13	1	383
12546	106	17	1	438
12548	84	79	1	334
12552	3	49	1	232
12554	66	7	1	366
12557	78	0	1	338
12559	71	15	1	400
12561	63	24	1	373
12568	20	13	1	220
12570	108	72	1	355
12572	60	73	1	321
12574	81	8	1	368
12580	80	54	1	416
12583	85	17	1	1510
12585	117	2	1	1443
12589	127	75	1	329
12597	96	22	1	413
12599	131	1	1	314

TABLE I. - Concluded. PROBABILITY OF IMPACT

Serial number	Orbital angles, deg φ	Orbital angles, deg β	Quadrant	A
12068	14	64	1	270
12076	89	7	1	378
12080	212	83	2	464
12084	56	45	1	374
12089	71	-0	4	329
12092	42	46	1	345
12094	336	9	2	66
12096	337	10	2	70
12108	5	29	1	205
12112	87	37	1	509
12115	140	27	1	407
12117	108	17	1	499
12124	107	-8	4	343
12126	81	-15	4	280
12130	81	20	1	433
12134	155	57	1	585
12138	96	-2	4	353
12140	55	76	1	322
12142	122	40	1	452
12146	248	52	2	91
12148	63	-12	4	396
12150	124	4	1	445
12152	131	59	1	567
12156	90	-20	4	321
12165	106	1	1	405
12169	117	47	1	764
12171	97	24	1	451
12175	202	12	2	166
12177	81	2	1	343
12180	76	24	1	405
12264	106	28	1	502
12266	253	37	2	82
12274	50	69	1	342
12277	69	0	1	329
12280	41	51	1	339
12284	209	71	2	289
12286	99	80	1	327
12288	335	30	2	103
12290	86	21	1	384
12292	95	57	1	426
12296	262	32	2	19
12298	93	-4	4	347
12304	100	13	1	421
12308	303	64	2	137
12318	88	68	1	380
12322	71	-6	4	304
12324	129	50	1	395
12326	240	69	2	251
12328	79	10	1	373
12335	90	-14	4	282
12339	23	52	1	294
12341	99	-1	4	355
12343	199	34	2	359
12347	64	5	1	325
12349	85	-6	4	329
12353	94	7	1	782
12355	137	58	1	432
12358	102	13	1	382
12360	109	-19	4	239
12362	150	-34	4	116
12434	115	10	1	374
12436	98	5	1	379
12442	237	66	2	202
12444	0	62	1	240
12446	95	56	1	409
12448	85	8	1	365
12452	72	81	1	323
12454	44	49	1	349
12456	358	21	2	160
12462	124	68	1	349
12468	89	22	1	559
12470	148	45	1	410
12474	76	6	1	343
12478	95	12	1	388
12480	335	77	2	229
12484	74	-6	4	308
12486	110	15	1	443
12490	135	63	1	744
12492	57	59	1	358
12495	200	72	2	250
12499	64	35	1	388
12501	159	78	1	362
12508	101	-5	4	350
12513	145	60	1	411
12515	197	71	2	268
12517	96	16	1	415
12519	11	32	1	230
12528	66	6	1	331
12530	353	25	2	151
12532	106	61	1	486
12603	121	21	1	424
12609	106	-4	4	342
12618	77	-1	4	329
1262[illegible]	68	12	1	354
12624	101	48	1	558
12651	117	1	1	461
12655	101	59	1	1645
12659	34	-5	4	208
12663	356	39	2	190
12667	6	81	1	268
12670	75	3	1	381
12672	75	-0	4	333
12677	69	42	1	409
12680	98	13	1	444
12682	97	19	1	421
12684	61	-10	4	264
12688	124	50	1	426
1269[illegible]	83	17	1	393
12692	93	37	1	466
12694	80	18	1	530
12696	101	38	1	439
12700	115	24	1	432
12702	120	-4	4	336
12704	236	84	2	238
12709	223	77	2	244
12711	150	63	1	378
12713	87	20	1	433
12715	178	-13	4	115
12720	87	8	1	383
12722	51	55	1	372
12726	55	20	1	366
12728	93	39	1	396
12732	13	66	1	489
12734	92	13	1	395
12738	115	22	1	447
12744	120	10	1	358
12750	33	34	1	310
12754	107	37	1	752
12758	138	28	1	438
12763	11	50	1	260
12765	100	-1	4	411
12771	53	7	1	321
12773	86	3	1	363
12864	90	21	1	415
12870	101	21	1	403
12872	105	-5	4	343
12874	113	46	1	474
12878	110	-17	4	282
12886	63	45	1	385
12890	74	66	1	368
12893	36	21	1	297
12895	101	65	1	381
12897	115	70	1	355
12900	91	-9	4	308
12904	122	70	1	346
12908	6	11	1	167
13278	12	17	1	617
13288	296	68	2	144
13293	91	5	1	425
13295	103	-19	4	306
13299	107	-10	4	353
13301	76	29	1	412
13307	355	38	2	187
13309	18	-6	4	157
13317	71	3	1	379
13319	65	-17	4	327
13324	127	12	1	640
13328	74	20	1	380
13332	65	-0	4	302
13335	6	46	1	239
13339	5	26	1	199
16359	201	17	2	207
16771	52	40	1	400
16775	13	9	1	182
16777	87	-6	4	324
16787	51	31	1	393
16789	105	-10	4	358
16791	89	14	1	417

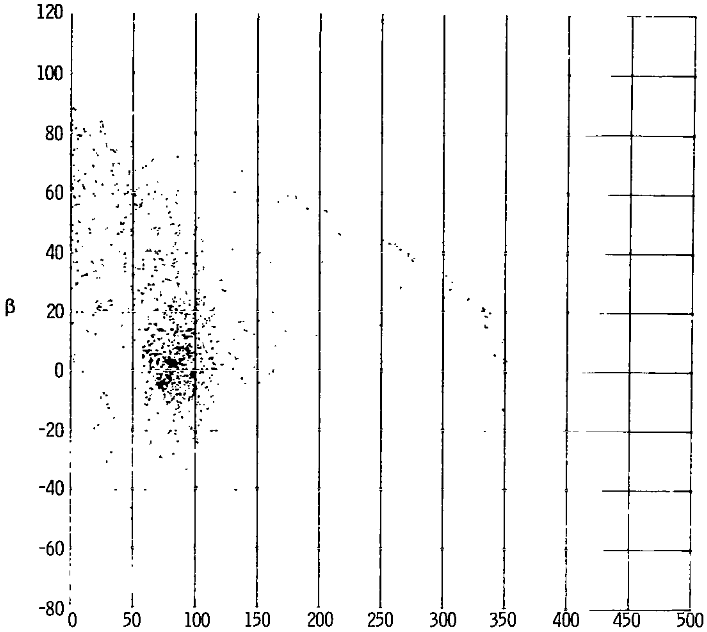
APPENDIX D

COMPUTER RESULTS FOR SELECTED METEORS

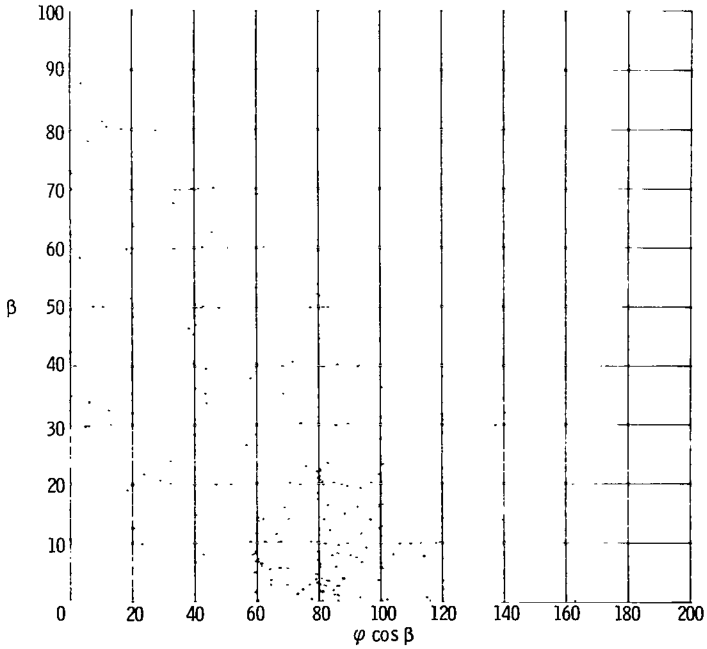
In this appendix are presented 18 prints, made from 35-millimeter film, which were produced by the Control Data Corporation DD280 microfilm unit attached to the Lewis IBM 360/67.

The output information from the calculations was plotted in various combinations partly to serve as a check to see if logical results had been obtained and to spot any glaring inconsistencies if such should occur. Figures 1 to 6 are plots of the meteors from reference 2. In figures 1 to 3 the first plot is of all 2048 meteors, and hence all four quadrants, while the second plot is of the first quadrant only and thus contains only 1282 meteors. In figures 4 to 6 the top two plots are of all 2048 meteors with the second plot having the spatial bias correction factor (SBCF) limited to 2.0; that is, all meteors with SBCF of over 2.0 are plotted at 2.0. The bottom two plots are of the 1282 meteors with the second plot again having the SBCF limited to 2.0.

In figures 1(a) and (b), to prevent the inordinate spreading of data near the North Pole (as in Mercator projections), the orbital longitude φ was multiplied by $\cos \beta$ before plotting it against the orbital declination angle β.

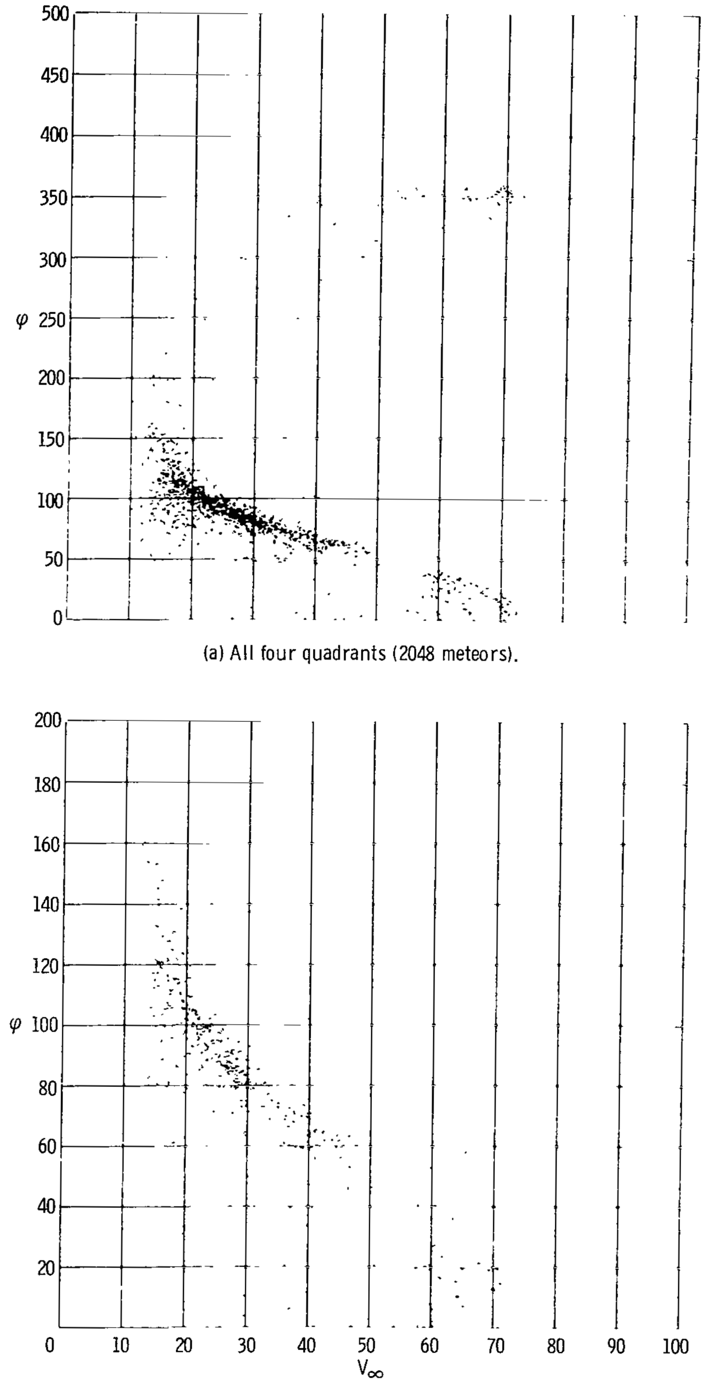


(a) All four quadrants (2048 meteors).



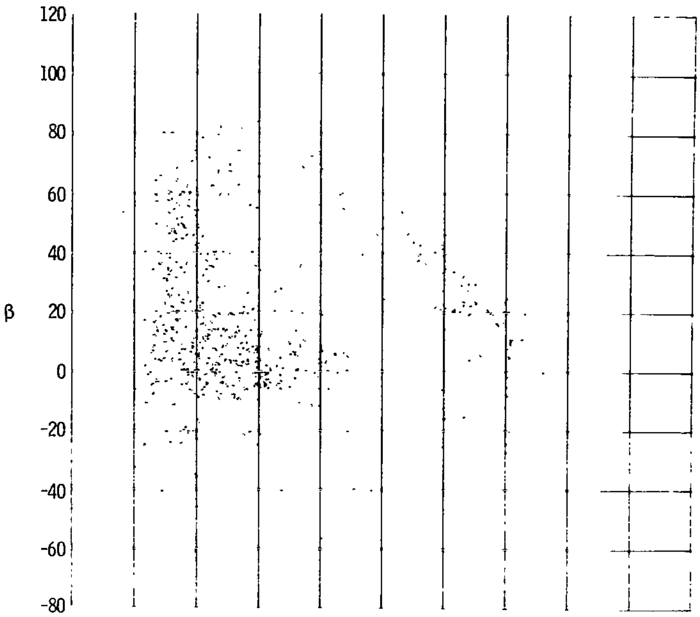
(b) Quadrant 1 only (1282 meteors).

Figure 1. - Distribution of meteors in the space of orbital longitude (times cos β) versus orbital declination β.

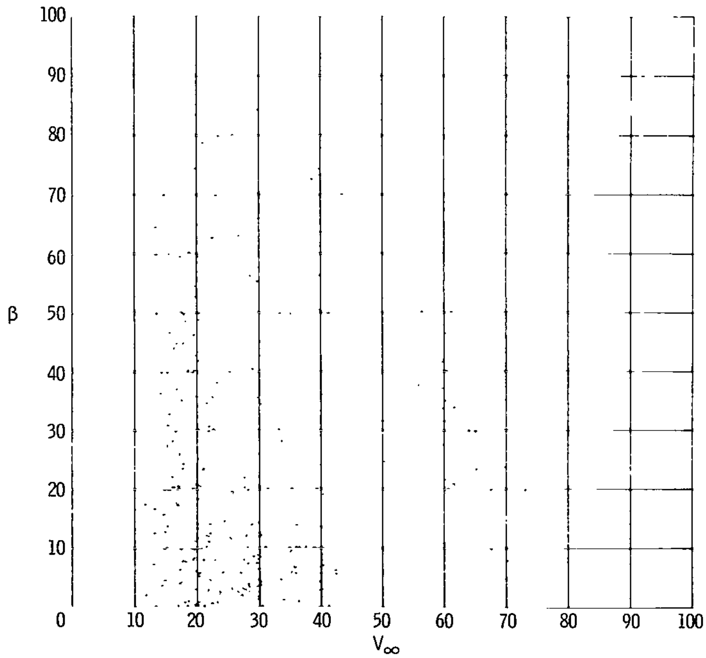


(b) Quadrant 1 only (1282 meteors).

Figure 2. - Distribution of meteors in the space of velocity of meteor at camera site (corrected for atmospheric drag) V_∞ versus orbital longitude φ.

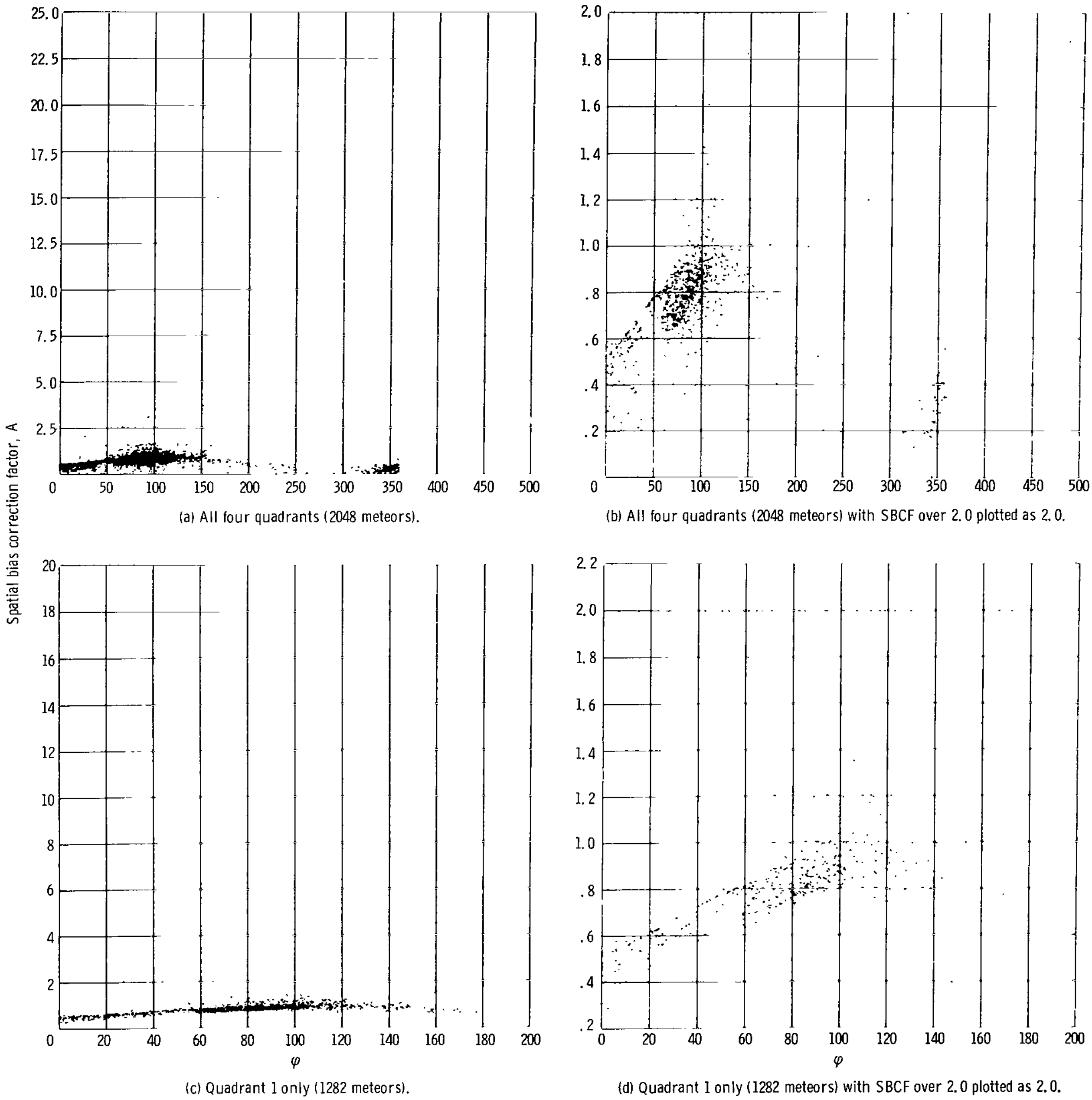


(a) All four quadrants (2048 meteors).



(b) Quadrant 1 only (1282 meteors).

Figure 3. - Distribution of meteors in the space of velocity of meteor at camera site (corrected for atmospheric drag) V_∞ versus orbital declination β.



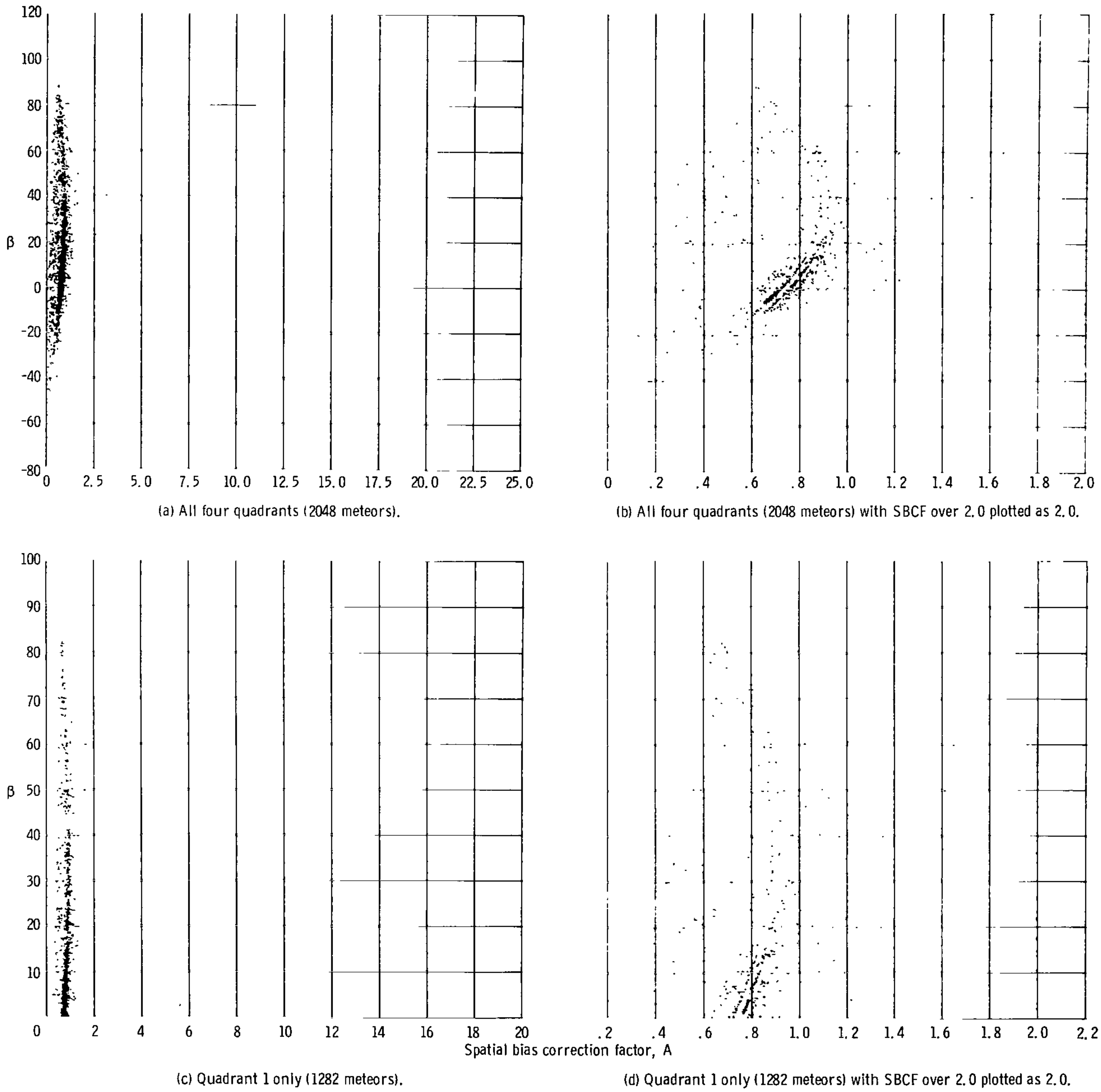
(a) All four quadrants (2048 meteors).

(b) All four quadrants (2048 meteors) with SBCF over 2.0 plotted as 2.0.

(c) Quadrant 1 only (1282 meteors).

(d) Quadrant 1 only (1282 meteors) with SBCF over 2.0 plotted as 2.0.

Figure 4. - Distribution of meteors in the space of orbital longitude φ versus spatial bias correction factor (SBCF).



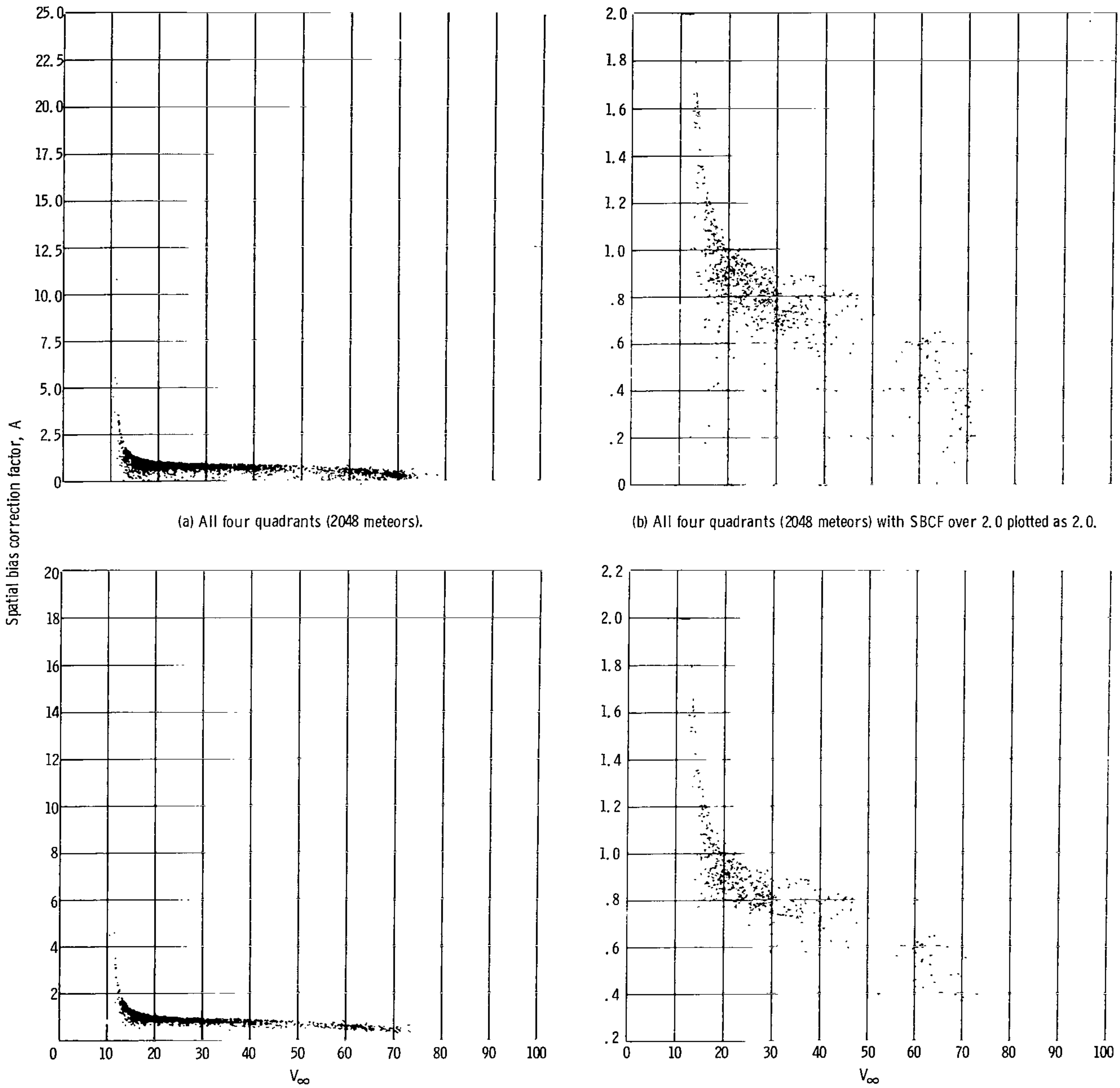
(a) All four quadrants (2048 meteors).

(b) All four quadrants (2048 meteors) with SBCF over 2.0 plotted as 2.0.

(c) Quadrant 1 only (1282 meteors).

(d) Quadrant 1 only (1282 meteors) with SBCF over 2.0 plotted as 2.0.

Figure 5. - Distribution of meteors in the space of spatial bias correction factor (SBCF) versus orbital declination β.



(a) All four quadrants (2048 meteors).

(b) All four quadrants (2048 meteors) with SBCF over 2.0 plotted as 2.0.

(c) Quadrant 1 only (1282 meteors).

(d) Quadrant 1 only (1282 meteors) with SBCF over 2.0 plotted as 2.0.

Figure 6. - Distribution of meteors in the space of velocity of meteor at camera site (corrected for atmospheric drag) V_∞ versus spatial bias correction factor (SBCF).

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