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INTERPLANETARY METEOROID ENVIRONMENT MODEL UPDATE

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ABSTRACT

This paper addresses the latest attempts at modeling the effects of tbc sporadic meteoroid population on interplanetary spacecraft. The Jet Propulsion Laboratory has an ongoing requirement to accurately model the survivability of interplanetary space missions to determine the possibility of mission loss. Galileo and Cassini for example both required detailed modeling and, ultimately, meteoroid shield designs to assure their survivability. A primary component of this modeling has been the sporadic meteoroid environment. As a result, Dr. Neil Divine developed a comprehensive model of the interplanetary meteoroid environment suitable for' carrying out detailed angular calculations of tbc impact rates of interplanetary meteoroids on interplanetary missions. This model is being considered as an international standard. Here wc present current efforts at formalizing the existing Divine meteoroid model so that it can be more available to the NASA and space community at large. The model makes usc of the ncw meteoroid data obtained since the 1970s when the original NASA meteoroid models were developed and allows estimates of the meteoroids' directionality and variation with distance from tbc Sun. It incorporates several different "populations" of interplanetary meteoroids, each population being described in terms of a distribution function in velocity phase space. These distribution functions can be integrated along a spacecraft trajectory to give the meteoroid fluence as function of velocity and angle relative to a specified surface. In the latest version of the model, shortcomings in the relative normalizations of the individual populations, usability, and issues of newly available data are add ressed.

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INTRODUCTION

Collisions with meteoroids have been a concern for spacecraft designers since the early days of tbc space program, The sources of these particulates arc believed to be the debris from asteroids and comets or the ejecta from collisions of meteoroids with large bodies such as the Earth m Moon. Given the pervasive nature of meteoroids, the effects of the macroscopic particulate environment must be quantified over the lifetime of a space system to project the life expectancy of exposed mechanical and electrical systems. For the last two and a half decades, the primary tools for modeling the meteoroid environment have been the models described in NASA SP-8013[1] and NASA SP-8038[2]. New data, primarily from Helios, Voyager, and Earth-based radar, have become available since these models were formulated. The older models do not readily lend themselves to tile determination of angular impacts (the models basically assume normal incidence) nor a realistic distribution of impact velocities with direction and mass (note: the older models do include an approximation for a distibution of velocities through the so-called "delta function"). The need to incorporate the latest meteoroid data anti to mode] the angular variations in the meteoroid fluence for interplanetary missions led to tile development a more detailed model by Dr. N. Divine in the early 1990's3. Since then, that model has seen wide acceptance in the international community. Unfortunately, the model has proven difficult for the general user and requires intimate knowledge of the code to modify it and incorporate new results or features. This paper will describe tests of a new version of the Divine meteroid COLIC that has recently been developed to address these issues. The results of that code will be compared with the older NASA models and the new angular and velocity distribution features will be exploited to illustrate the practical value of the model.

METEOROID PARTICLES—THE ENVIRONMENTS

In practice, methods for modelling the meteoroid environment fall into 3 groups:

1.) Modeling of single particle dynamics where the trajectories of individual particles are followed. This resembles the plasma physics "particle in box" approach and is used where, in the case of asteroids, there arc a few well defined "particles".

2.) Identification of organized "streams" (i.e., meteor streams), "rings" (i.e., Saturn's rings) or "shells" (Earth space debris that has been radomized at a fixed orbital altitude).

3.) Algorithmic fits to tile background, random environment. This is primarily the so-called sporadic meteors or the zodiacal light.

In principle, tile single particle physics applicable to the first group can be used to model each of the other groups. Unfortunately, models of the latter two would involve the tracking of millions of particles 10 adequately describe tile actual environments.

NASA INTERPLANETARY METEOROID MODELS

The current NASA meteroid models do not attempt to treat individual particles, but, like the algorithms or numeric expressions that define the neutral atmosphere, arc fits to observations. They therefore represent a very compact, though physically limited, representation of the meteoroid environment. As of this dale, tile NASA models are the accepted engineering meteoroid environment "tool". The principle documents describing these models arc tbc "NASA Space Vehicle Design Criteria (Environment); Meteoroid Environment Model (Near Earth to Lunar Surface)" [1] and "NASA Space Vehicle Design Criteria (Environment); Meteoroid Environment Model (Interplanetary anti Planetary)"[2].

The first document defines the meteoroid environment between the Earth's surface and the moon in terms of simple numeric expressions. It provides working definitions of the three principle quantities needed to define the meteoroid environment: [heir mass versus number density, their velocity distribution, and their density (composition). Included in the document arc listings of interplanetary meteor streams (the "predictable" component—about 10% of the observed flux for particles of -1 g at the Earth) and tile Earth-based meteor observations on which the "sporadic" models (sporadic is taken here to mean the background flux of meteoroids that arc basically random). The second document presents an extrapolation of the Earth-based observations to interplanetary space for sporadic meteoroids of different "origins''--cometary and asteroidal. These models of the sporadic meteors have served well for almost 25 years and only now, as new data on the interplanetary meteoroid environment has become available are changes in these models being proposed[4,3]. As the NASA meteoroid environment models arc currently the basis for most engineering studies of the effects of the meteroid environment, they will be briefly described.

Meteoroids as defined by the NASA documents are solid particles orbiting in space that arc either of cometary or asteroidal origi n, The spatial volume of interest ranges from 0.1 to 30.0 astronomical units (AU). The mass range is from 10^{-12} to i 0^{2} g. Kn owledge of these particles is based primarily on Iiartil-based observations of meteors, comets, asteroids, the zodiacal l ight, and in-situ rocket and spacecraft measurements. The flux versus mass of tile particles, the basic quantity required to model the meteoroid environment, is not directly measured but must be inferred (e. g., from light intensity, crater distributions, etc.). The ground-based measurements consist principality of photographic and radar obser vat i ons. Sufficient information does exist to justify dividing the sporadic meteoroid component into those of cometary origin and those of asteroidal origin. The distinction between these two groups will become clear in the following (note: the newer model[3] divides the meteoroid populations up into 5 groups based on their orbital characteristics).

In the following development, one problem in particular should be kept in mind--that of the "penetration speed" or, less accurately, "impact velocity". The precise definition of "impact velocity" has proven to be difficult as tile actual particulate environment is characterized by a velocity distribution. Based primarily on how the impact velocities should be weighted when taking a mean or average, variations in estimates of the cff'eels of impacts arc possible. The problem is due to the fact that the mass capable of causing failure varies with velocity--typically decreasing with increasing velocity. In practical terms, the "average" velocity wii i typical i y differ from a weighted velocity required for impact probability calculations. A second issue arises because the average impact velocity anti meteoroid fluence both vary in time (or position) during the spacecraft mission so that the probability does not increase linearly in time but in a complex fashion. The actual value of the impact velocity to be used will depend on the orbital position of the spacecraft and its instantaneous velocity vector. The precise treatment of the velocity and the velocity distribution function pose an uncertainly in any calculations.

COMETARY METEORS

In terms of tbc NASA models, cometary meteoroids in the mass range of interest (<10 g) are believed to bc the solid remains of large water-ice comets that have long since evaporated or broken up duc to collisions, or simply fragmented/dispersed from comet surfaces without destroying the comet, The remaining silicate or chondritic material is of very low density (0. 16 to 4 g/cm[3]) with an assumed value of 0.5 g/cm[3] for tbc NASA models. The primary flux inside 1.5 AU is made up of these cometary meteoroids as the denser asteroidal meteoroids are assumed to be concentrated in the asteroid belts and peak at 2.5 AU. NASA 8038[2] describes the integral cometary meteor density (p) for a mass m or larger by:

$$\mathrm{Log}_{10}(\rho) = -18.173-1.213\,\mathrm{Log}_{10}(m) -1.5\,\mathrm{Log}_{10}(R) -.869\,|\sin(\beta)| \quad (1)$$

where:

- m = mass (g)
- p = spatial density (particles/m³)
- R = heliocentric distance (AU)
- β = the heliocentric latitude

The "average" impact velocity, as a function of spacecraft orbital parameters "σ" (the ratio of the heliocentric spacecraft speed to the speed of a circular orhit at the same distance from the Sun), "θ" (angle between spacecraft velocity vector and circular orbit in same plane), U_c (a cometary velocity function decribed in NASA 80382), and R (distance from Sun in AU) is given by:

$$\langle V_c(\sigma,\theta, R)\rangle = R^{-1/2}\, U_c(\sigma,\theta) \quad (2)$$

Once a number density is determined and the impact velocity computed, tbc cometary flux to a ramdomly tumbling plate can bc estimated by the following simple formula:

$$f_c = 1/4\,\rho\langle V_c\rangle\delta^{-1} \quad (3)$$

where:

- f_c = cometary flux (particles/m^{2}s)
- p = particles/m^3 (here, p corresponds to the number density for all particles with a mass m or larger)

The total fluence, F_c, is the integral of f_c over time. The "delta factor" is a small correction factor included [0 account for the fact that there is a distribution of velocities. It is given as a function of σ and θ in NASA 8038[2].

ASTEROIDAL METEORS

As for the cometary meteoroids, the basic computation of the asteroidal flux follows three steps: determine the penetrating mass based on the density and impact velocity, determine the number density at the given mass, and compute f_a (the asteroidal flux) from $1/4\,\rho\langle V_a\rangle$. Unlike the cometary population of meteoroids, however, which is assumed to be fairly uniform in its characteristics with heliocentric distance, the asteroidal component shows a marked heliocentric variation in number density. Visual observations down to masses on the order of 10^{19} to 10^{20} g demonstrate the existence of the well-known asteroid belts between roughly 1.5 and 3.5 AU. It is assumed from the comparative (with respects to the cometary meteoroids) rarity of asteroidal meteoroid fal Is al the Earth that the lower mass component of the asteroidal meteoroids is similarly confined to the 1.5-3.5 AU range. From laboratory studies of presumed asteroidal meteorites, tbc density of these particles is assumed to average about 3.5 g/cm[3]--substantially denser then the cometary meteoroids. (Note: Observations[4] on Pioneer 10 and 11 imply that this population c1ocs not exist al masses below 10-9 g (see Blue-Ribbon Panel recommendations) and, by extrapolation, may not exist in the mass range of interest to impact studies.)

In parallel with the cometary meteoroid model, NASA 8038[2] has also provided functional relationships for the variation of the asteroidal meteoroids with relative impact velocity, heliocentric longitude, and heliocentric latitude. U_a and $\langle V_a\rangle$ arc the asteroidal versions of U_c and $\langle V_c\rangle$. U_a and $\langle V_a\rangle$ are related by:

$$\langle V_a\rangle = U_a\, R^{-1/2} \quad (4)$$

Unlike U_c, U_a and its relationship to σ and θ vary with R. NASA 8038[2] lists three different variations for U_a corresponding to R = 1.7 AU, R = 2.5 AU, and R = 4.0 AU. As a final component of the asteroidal model, δ is also introduced but as this is so c1osc to 1 (the asteroidal meteoroids have a very sharply peaked velocity distribution function), it is ignored in the NASA model. Again, all variations are assumed to be essentially independent of each other so that the flux is the product of all the components. For the mass range of interest, the resulting equation is:

$$\mathrm{Log}_{10}(\rho) = -15.79-.84\,\mathrm{Log}_{10}(m)+F(R) + G(R)\cos(\lambda)+h(\beta) \quad (5)$$

where:

- λ,β,R = heliocentric longitude, latitude, radius
- h = asteroid population latitudinal variation
- G = asteroid population radial variation

As before:

f_a = 1/4 p <vi> (6)

GALILEO METEOROID MODEL

Tcr reflect Pioneer in-sits meteoroid observations[4], the NASA models were modified by a blue-ribbon panel convened by NASA in 1978-1980 to incorporate the latest Pioneer 10/1 1 meteoroid data for the Galileo mission. 'l'he major recommendations of the panel were as follows:

1. Based on the Pioneer results, which indicated the absence of an asteroidal component at masses below about 10-9, the panel recommended that only the cometary component be considered.

2. The NASA Cometary Meteoroid model has a $R^{-1.5}$ dependence of the spatial density. As a conservative assumption, the panel recommended assuming a constant density twice that of the NASA cometary model at 1 AU between 1 and 5 AU. (It has since been tacitly assumed that the factor of two and constant density also be applied within 1 AU.)

3. As in the case of the NASA Cometary Meteoroid model, the flux was assumed to be isotropic.

4. The so-called "δ factor" which takes into account the cometary relative velocity distribution is assumed to be δ = 1.

Of the assumptions, the elimination of the "δ factor", used to comet for the velocity distribution, has caused the most concern. The consequences of this effect were found to be minimal, however, in direct comparisons with the results of the original NASA cometary model which included the factor.

DIVINE MODEL

Whereas the NASA models are empirical fits (o the mass distribution and average impact velocity, the model developed by Divine[3] takes as a starling point the particle phase space density. To make this clear, consider first the fundamental physical concepts associated with meteoroids. 'l'he physics of macroscopic particles in principle resembles that of a charged plasma environment as gravity, the principle controlling force (light pressure anti electrostatic forces arc ignored in this paper but they can be very important for tbc smaller- or low density particles), varies as the inverse of the distance between interacting objects. just as in the case of electrostatic forces. It is common practice in defining the characteristics of a plasma to define a phase space distribution function. In particular, a particle in space has a mass m, a position vector t (with components x, y, z), and a velocity vector $v = dr/dt$ (components v_x, v_y, v_z). The particle can be described as representative of a' continuous distribution defined by:

$$dN = [\, H_m dm \,]\left[g_o \left(dxdydz\right)\left(dv_x\, dv_y\, dv_z\right)\right] \quad (7)$$

where dN is the mean number of particles with mass, position, and velocity in the intervals $(m, m+dm)$, $(x, x+dx)$, and (v_z, v_z+dv_z). (x, y, z, v_x, v_y, v_z) are in heliocentric coordinates.

In the Divine model for meteoroids, the dependence on mass m is assumed to reside exclusively in the function H_m (independent of r and v). It is related to the cumulative mass distribution, H_M, by:

$$H_M = \int_m^\infty dm H_m \quad (8)$$

and g_o is a density in position-velocity space like that for a gas or plasma and is independent of m and t. For meter-oicis, g_o can be taken as a function of the constants of motion in a gravity field (e. g., the six Keplerian orbital elements). In particular, it can be shown that g_o can be described for the interplanetary meteoroids as

$$g_0 = \frac{1}{2\pi e}\left(\frac{r_1}{GM_o}\right)^{3/2} N_1 p_e p_i \quad (9)$$

where:

i = inclination;	pi depends only on i
e = eccentricity;	p_e depends only on e
t, = perihelion distance;	N, depends *only* on r_1

Given the distributions p_i, p_e, and N_1, Divine[3] demonstrated that onc can derive particle concentrations, fluxes (as functions of angle), fluences, and impact velocities (as functions of angle) along an orbit. The concentration, for example, is given by:

$$N_M = H_M \sum_{l=1}^{4} \int dr_1 \int de \int di \cdot g_0 \frac{\partial(v_x, v_y, v_z)}{\partial(r_1, e, i)} \quad (10)$$

where:

l = 1-4 (represents 4 possible particle directions)

The flux is given by:

$$J_M = \sum_{l=1}^{4} \int dr_1 \int de \int di \cdot g_0 \frac{\partial(v_x, v_y, v_z)}{\partial(r_1, e, i)} \cdot (\eta_D v_D)_l \quad (11)$$

where:

h_D = weighting factor for detector effects

v_D = speed with respect to detector

$$dN = (H_m dm) g_0 (dxdydz)(dv_x dv_y dv_z) \quad (12)$$

DATA INPUTS TO DIVINE MODEL

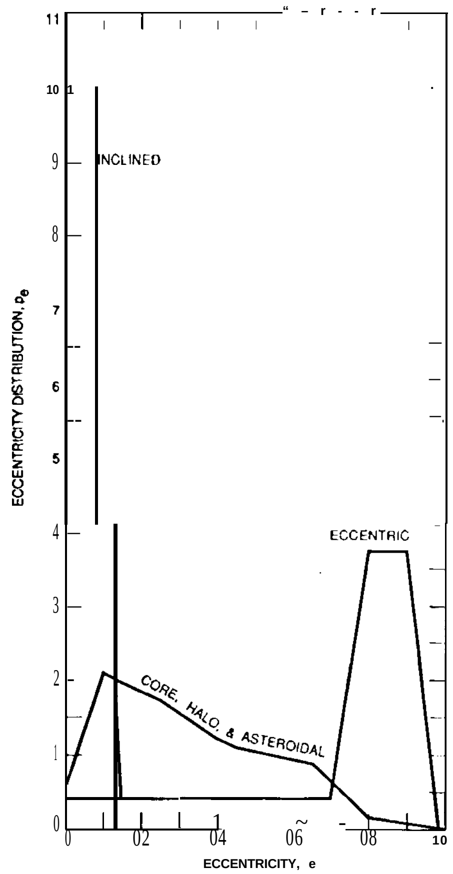
The Divine meteoroid model represents a much more comprehensive representation of the environment than the earlier NASA models. Rascal on tbc preceeding concepts, Divine fit as much of the existing meteoroid data as he could. This included: the Interplanetary Flu x Model of Grün, the Pioneer 10/11 data set, the Helios ftuxcs/events measurements, the Galileo Dust Detector, data from the Ulysses Dust Experiment, radar meteor observations, and estimates of the distribution of' the zodiacal light population. These data sets, their sources, and distance and mass ranges arc listed in Table 1.

I'able 1. Sources and ranges of input data for the Divine meteoroid model.

		Heliocentric Dist (AU)	Mass (g)
IF Model[5]		0.98-1.02	10 lx-10[0]
Pioneer 106		1-18	> 3X10 [10]
Pioneer 11[6]		1-9	> 10 [9]
Helios[7]	fluxes:	0.31-().98	> 1010
	events:	0.31-0.98	> 10 [14]
Galileo Dust Det[8]		0.88-1.45	> 10 [13]
Ulysses Dust Exp[8]		1.0 -4.0	> 10 [13]
Radar Meteors[9]		0.98-1.02	> 10 [4]
Zodiacal Light[10]		().3- 1.0	10 [8]-10 [5]
Ref 11		1	10 [8]-10 [5]
Ref 12		3	10 [8]-10 [5]

Divine found that 5 distinct "populations" were necessary to fit these data. In particular, the "core population" is the best single population fit to the data and reproduces the Gali leo data. The "inclined population" fits the Helios data not fit by the core population. The "eccentric population" fits the remaining Helios data not fit by the other two. The "halo population') fits the Pioneer and Ulysses data Sets. The "asteroidal population" fits Grun's Interplanetary Flux Model at large masses and the outer component of the meteor data. The appropriate distributions corresponding to these "populations" are presented in Figures I, 2, 3, and 4. The densities assumed for these populations are .25 g/cm^3 for the eccentric population (note: this population contributes very little to any of tile fluence calculations anti can be ignored in general) anti 2.5 g/cm^3 for all the others. These figures and the density compromise the basis of the new meteoroid model. Flux, fluence, impact speed, etc. are all computed using equations 7-12 and similar relationships.

Fig. i. Eccentricity Distribution, p_e.



NASA-DIVINE COMPARISONS

The NASA models have been the baseline meteoroid models for over 25 years, As such, it is of great value to compare the predictions of these models with the newer Divine model. Given the different formulations and data sources, it is expected that there wiii be observable differences between the models. To compare the models on an equal bases, 3 representative mission scenarios were selected: i) a spacecraft in Earth orbit (in the absence of the Earth); 2) a representative Cassini trajectory to Saturn; anti 3) an inner solar system mission--Helios. These orbit scenarios are illustrated in Figs. 5 anti 6.

A primary use of meteoroid models has been to predict the integral fluence for a given mass threshold or the probability of a system failing due 10 meteoroid impact. The former requires calculating the fluence of particles with a mass m or higher to a (typically) randomly tumbling plate. As an adjunct, the "average" velocity is usually desired. In the latter case, one requires a definition of a "failure criteria", Typically this is a surface penetration formula--a meteroid puncture fails a tank, battery, solar cci 1, etc. Here the standard single surface penetration formula of Cour-Palais[13] for particles from 50 μm to ~1 cm diameter impacting aluminum will be assumed. The Cour-Palais formula is based on empirical fits to data and gives:

$$t_c = C_o \rho_m^{1/6} m^{.352} V_m^{.857} \qquad (13)$$

where:

- t_c = critical thickness of shield for which penetration will occur for particles equal to or greater than the critical size (cm).
- C_o = constant for shield material = 0.35 1 (for Al)
- m = meteor mass (g)
- ρ_m = density of projectile (g/cm^3)
- V_m = velocity of impact (km/s)

Here, for simplicity, it will be assumed that t_c is the thickness of an aluminum shield that would just be penetrated by a 1g particle of 2.5 g/cm^3 density and impact speed of 20 km/s. All other densities, masses, and velocities of particles will be scaled according to eq. 13 using this thickness.

Fig. 2. Mass cumulative distribution, H_M.

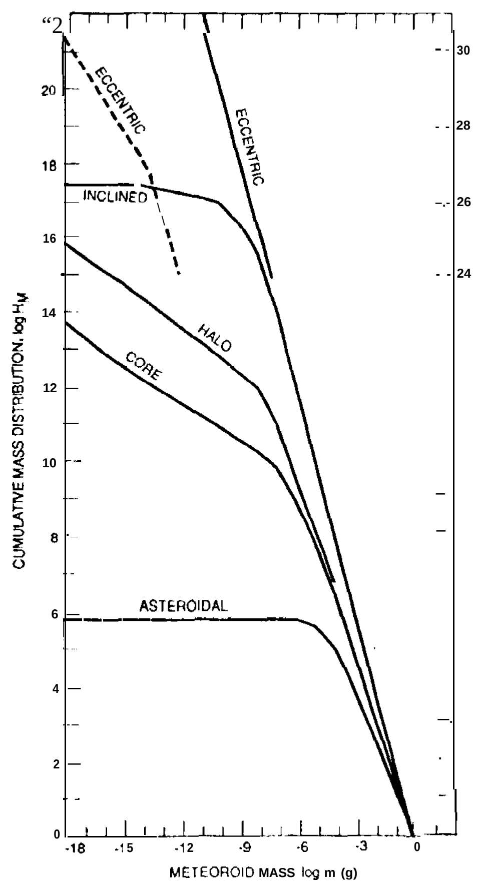


Fig. 3. Radial distribution, N_1

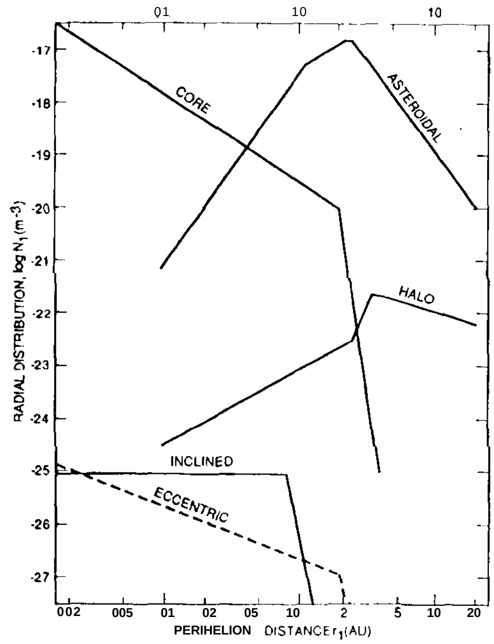
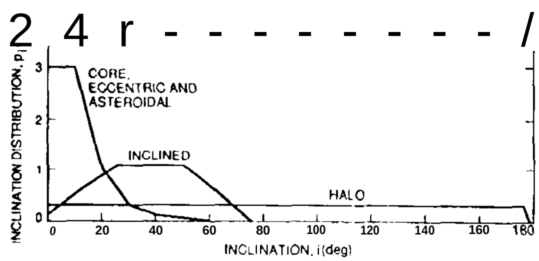


Fig. 4. Inclination distribution, p_i.



Once a failure criteria is established, the total fluence at each trajectory position to a randomly tumbling plate is estimated over the entire range of velocities and masses that just penetrate the surface. The probability of failure is then computed from an estimate of the appropriate sensitive area multiplied by this critical fluence. In statistical terms, the probability of X impacts on a spacecraft is given by:

$$P(X,t) = \frac{(f_p A't)^X e^{-f_p A't}}{X!} \qquad (14)$$

The probability of one or more impacts occurring is, by experience, very low. Thus, to a high degree of accuracy, the probability of one or more impacts of a meteoroid is given by subtracting the probability of no hit ($P(0) = 1 - f_p(t)A't + \ldots$) from 1:

$$P(X>0,t) = 1 - P(0) \approx f_p(t)\, A'\, t \qquad (15)$$

Figure 5. Trajectories for the Helios and "1 AU" mission scenarios.

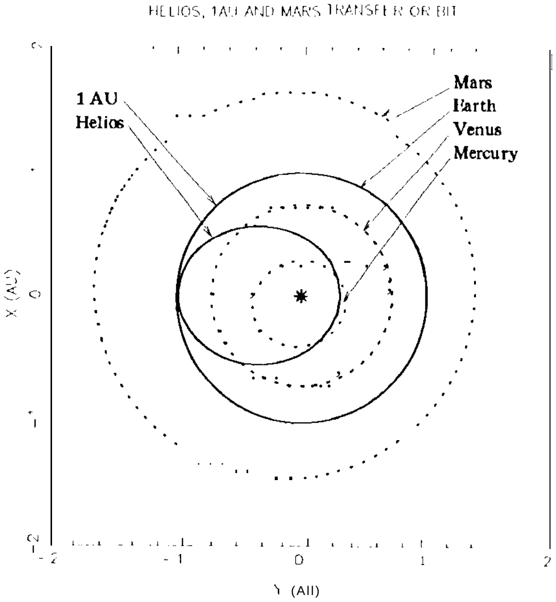
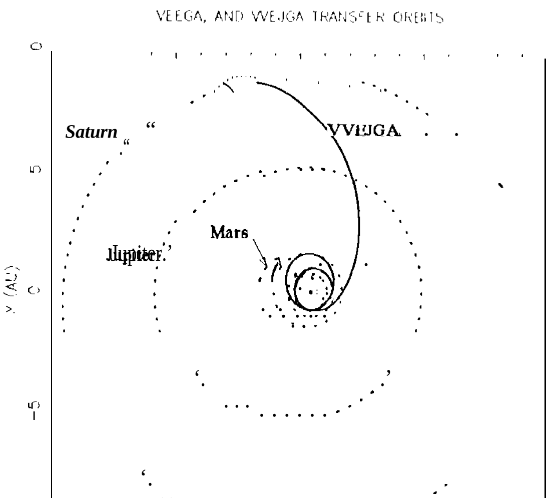


Figure 6. Trajectory assumed for a representative Cassini mission to Saturn--a VVEJGA or "Venus-Venus-Earth-Jupiter" gravity assist trajectory.



or

$$P(X > 0, T) = \int_0^T f_p A' dt \qquad (16)$$

where:

t = small time interval

T = time (mission duration)

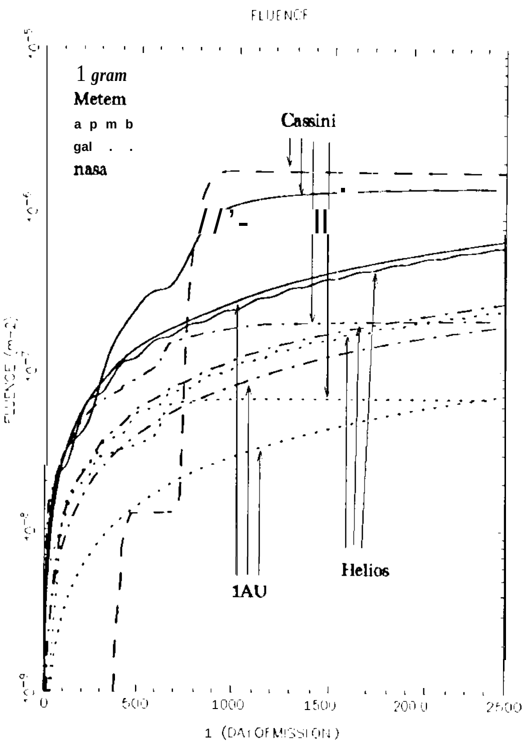
f_p = Penetrating meteoroid flux as function of time

A' = Equivalent sensitive area

Here, rather then compare the probability of failure, the fluence for the critical mass m_c (impacts per unit area for the mass/velocity combinations that will just penetrate the surface) will be estimated as a function of mission duration for each model--to convert to probability, the fluence can be multiplied by the area of the sensitive surface.

Figures 7 and 8 compare the mission fluences for the Divine model (labeled METEM, the name of the new code) and the three NASA models: the asteroid component (APROB), the cometary component (NASA), and the Galileo cometary model (GAL) for the three missions. Figure 7 is for a mass threshold of 1 g while Figure 8 is for the Cour-Palais single surface penetration formula.

Figure 7. Fluence as a function of mission elapsed time for a mass threshold of 1g.



The final mission fluences for Figures 7 and 8 are tabulated in Table 2. The main points to note for these results are that the NASA asteroidal component typically dominates if the spacecraft passes through the asteroid belt between 1.5 and 3.5 AU. The Divine model estimates, which are the sums of 5 different populations, are within a factor of 2 (Helios) to 10 (1 AU and Cassini) for the 1 g mass threshold-this is not surprising as the densities are substantially different: 0.5 g/cm^3 for the cometary models; 2.5 g/cm^3 for 4 of the 5 Divine populations. Similar results hold for the penetration formula. Qualitatively, the Divine fluences follow the same temporal patterns as the cometary model fluences. The Divine model predicitions appear to exceed those of the NASA models in the inner solar system and to approximate then] (the asteroidal component) in the outer solar system (beyond 1.5 AU).

Figure 8. Fluence as a function of mission elapsed time for a fixed aluminum shield thickness equivalent to a 1 g particle of 2.5 g/cm density and impacting at 20 km/s.

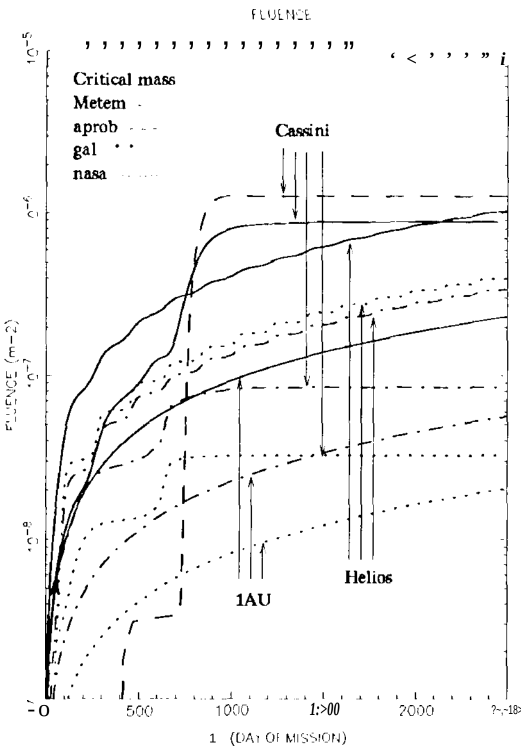
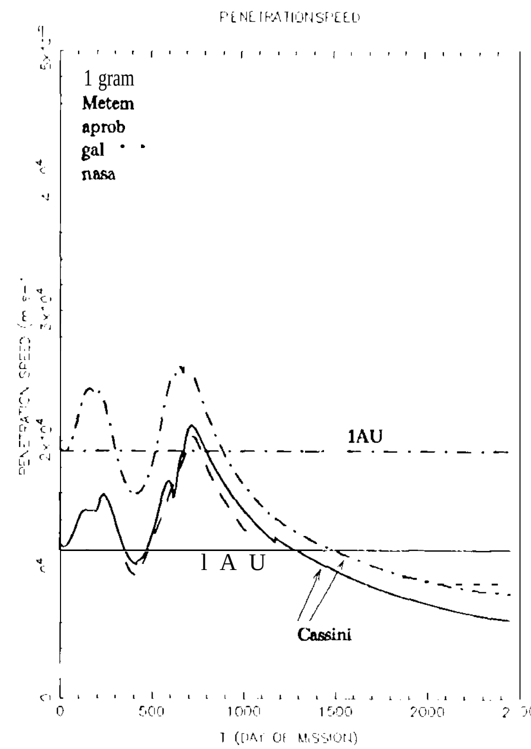


Table 2. Total mission fluences for the Helios, 1 AU, and Cassini missions

Mission		Helios	1 AU	Cassini
Days		187.3	365.6	2447
Fluence (m >1 g) m^{-2}				
	metem	4.48E-8	9.79E-8	1.40E-6
	aprob	0.0	0.0	1.74E-6
	gal	2.07E-8	2.84E-8	2.14E-7
	nasa	1.88E-8	1.03E-8	6.66E-8
Fluence (m_c) m^{-2}				
	metem	7.75E-8	3.39E-8	8.80E-7
	aprob	0.0	0.0	1.28E-6
	gal	2.57E-8	8.20E-9	8.45E-8
	nasa	3.04E-8	2.97E-9	3.25E-8

While not unanticipated (the models are based on different data and distribution assumptions), the differences between the models are interesting. Aside from the density differences, the other properly is the average impact velocity. To study this behavior, the mean impact velocity (estimated by eqs. 2 and 4 for the NASA models and by the ratio of the integral of the product of the fluence and velocity divided by the integral of the fluence for the Divine model) has been computed as a function of mission elapsed time. These values are plotted in Figs. 9, 10, 11, and 12.

Figure 9. Impact speed as a function of mission elapsed time for a mass threshold of 1 g for the Cassini and 1 AU trajectories.



The major factor in these estimates is the fact that the impact speed for the Divine model is averaged over 5 populations. The individual populations have average impact speeds that range from ~10 km/s to almost 40 km/s for a fixed threshold mass. Figures 9-10 reflect this averaging. In the NASA models, the asteroidal component is lower than the cometary component (the Galileo model has the same velocity as the NASA cometary model). This component has a higher velocity than the average impact speed for the Divine model--~20 km/s versus ~12 km/s. Indeed, the NASA asteroid component and the Divine model speeds are very close. However, when a penetration relation is considered, the velocities agree closely. This is most likely due to the increased weighting in the Divine model of the lower mass but high velocity particles with their higher' flux.

FLUENCE TO AN ORIENTED PLATE

The final property to be presented is the variation in fluence as a function of orientation. Unlike the

Figure 10. Impact speed as a function of mission elapsed time for a mass threshold of 1 g for the Helios trajectory.

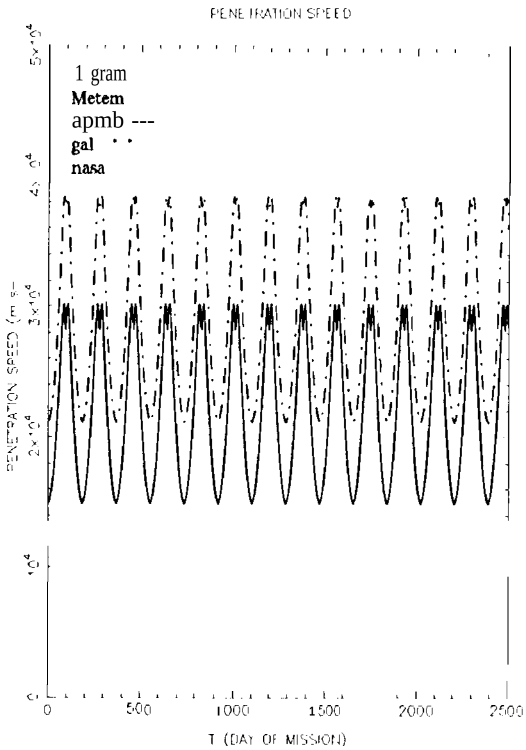


Figure 11. Impact speed for a fixed shield thickness for the Cassini and 1 AU trajectories.

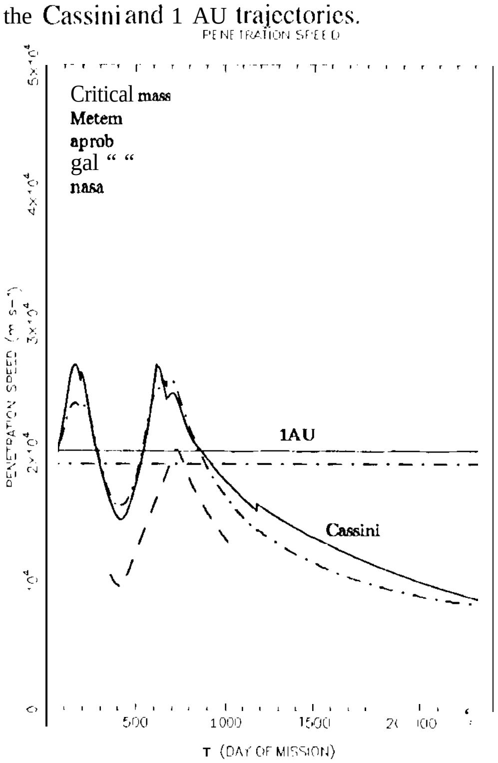


Figure 12. Impact speed for a fixed shield thickness for the Helios trajectory.

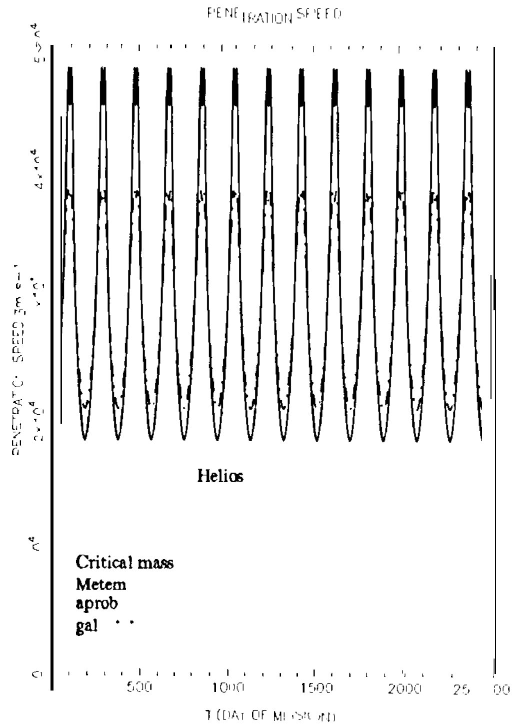
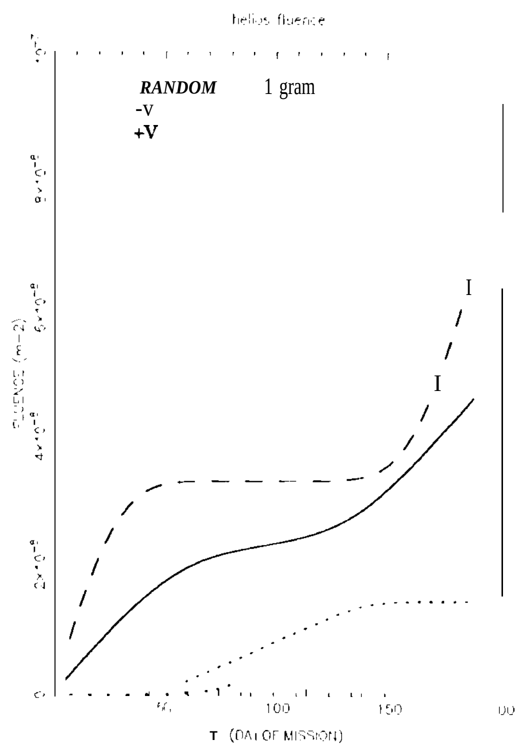


Figure 13. Fluence for Helios to randomly tumbling plate compared to direction in spacecraft velocity vector and opposite to that direction,



NASA models, the Divine model can estimate the fluence on an oriented surface as opposed to the randomly tumbling plate. This is a valuable improvement as a spacecraft can be deliberately flown in a specific orientation to limit the impacts on a particular surface (e.g., a rocket nozzle or tank surface). Figures 13, 14, and 15 present estimates of the meteoroid fluence to a randomly tumbling surface, a surface oriented in tbc spacecraft velocity direction, and in a direction opposite to the velocity vector.

The differences in fluence to the forward and tail ward surfaces of a spacecraft are striking. When the spacecraft is moving slower than tbc circular orbit speed at a given distance, it sees more fluence in the direction opposite the velocity vector and on its sides (as approximated by the randomly tumbling surface) than from tbc forward ciirection--thc meteoroid flux is overlaying tbc spacecraft. For Fig. 14, the flux to the sides (the randomly tumbling results) actually dominates. Finally, for the outer solar system mission, when tbc spacecraft is moving faster than the circular orbit velocity, the flux in the direction of the velocity vector dorninatcs--thc spacecraft overtakes the meteoroids. Note in particular the switch over in behavior around day 700 for the Cassini trajectory.

Figure 14. The fluence (for a spacecraft at 1 AU) to a randomly tumbling plate compared to a surface oriented in tbc direction of the spacecraft velocity vector and opposite to that direction.

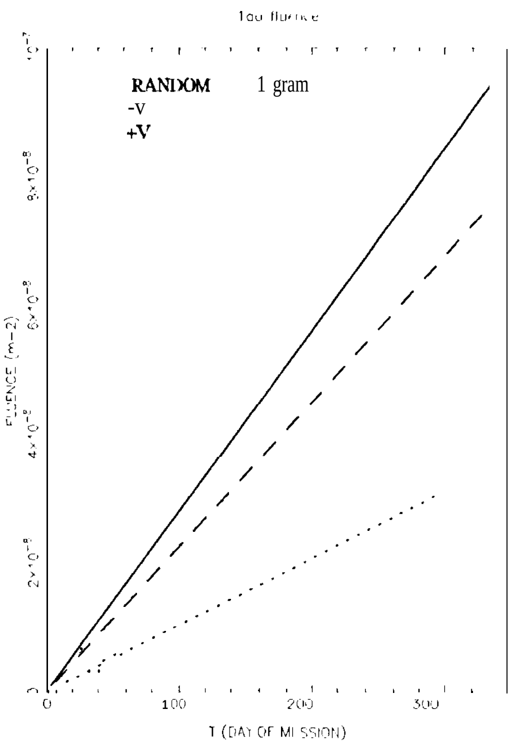
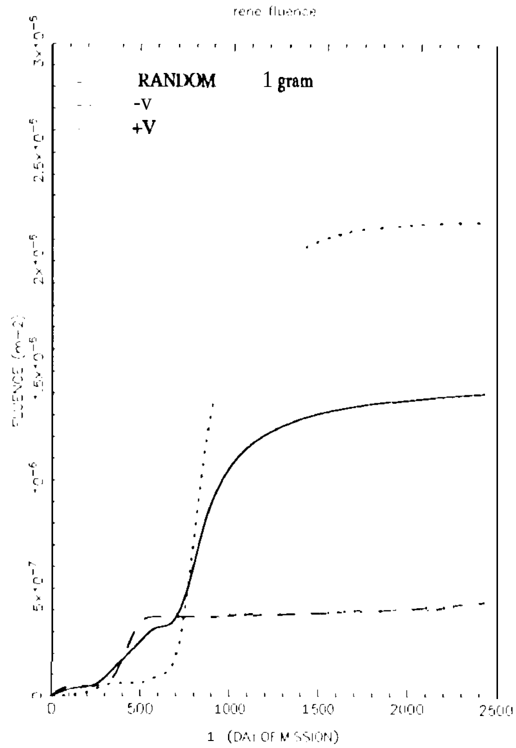


Figure 15. The fluence (for a Cassini trajectory) to a randomly tumbling plate compared to a surface oriented in the direction of the spacecraft velocity vector and opposite to that direction.



CONCLUSIONS

The new Divine model produces results that at least subjectively resemble the older NASA meteoroid models. The differences in assumed populations, however, make a quantitative comparison difficult. Even so, this paper has provided a link between the older models and the newer one that should prove useful for those seeking to compare their predictions. As a secondary objective, tile paper has demonstrated tile capabilities of the new model--in particular, its capability to estimate fluences to oriented surfaces. The Divine model is now available to tile general community as a compiled code that can be run on a wide range of PCs anti main frame computers. The reader is refered to the authors for copies of the code.

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