2.1.4 ORBITAL ELEMENTS OF DUST PARTICLES INTERCEPTED BY PIONEERS 8 AND 9

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INTRODUCTION

The instrument measuring particle impacts on PIONEERS 8 and 9 has been extensively described in the literature (Reference 1) and will not be repeated here. This paper concerns itself with the analysis of the data obtained.

The measurements available are front and rear film and grid ID numbers, the pulse height and the time of flight (TOF), i.e., the time delay between signals from front and rear sensors.

ANALYSIS

(1) Velocity Computation. The nominal relative velocity is calculated from the "solar aspect" of the satellite and the TOF and the impacted film and grid ID number. If front and rear film and collector ID agree the impact is termed "normal" and if one or both disagree the impact is "inclined". In both cases the nominal relative direction is parallel to the line joining the centers. The magnitude of the velocity is then obtained from the TOF and the known distance between the sensors. The nominal relative velocity vector may thus be obtained. The actual velocity vector may deviate from the nominal by about $\pm 24^{\circ}$. For impact angles other than nominal, the TOF will lead to different velocity magnitudes. A relative probability value is also attached to each impact value according to a method developed by Dohnanyi (Reference 2). This is a purely geometrical method including consideration of the area presented, corrected for shielding. A properly weighted average of all computed quantities can thus be calculated.

In addition to the uncertainty in impact direction, digitizing the TOF count leads to an uncertainty in the velocity magnitude. The nominal value has been adopted in the set B of trajectories and the low and high extremes in sets A and C, respectively. The relative weights of the three velocities arising were taken as equal in the probability computation.

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(2) Mass Computation. The particle mass is calculated from the pulse height analysis (PHA) by the equation:

$$m V^{2.6} = K V_o^{1.6} 10^{c(PHA)},$$

obtained from the instrument calibration. For the nominal case K = .651, its maximum is 1., its minimum is .424. These three values of K (.424, .651 and 1.) are used in conjunction with low, nominal and high velocity values, respectively, in this analysis.

(3) Element Computation. The orbit of small particles is sensitive to radiation pressure and hence for a calculated mass an "effective" density (or a value of $\frac{A}{m}$) has to be assumed. The computations were carried out for six (6) densities, ∞, 8., 3., 1., .3 and .1, g/cc, respectively. The results are presented for an assumed effective density of 3., considered the most probable value. For each of these densities the maximum projected angle in and normal to the orbital plane is subdivided into nine parts, thus computing eighty one sets of elements for each of three velocity magnitudes and each density. The means and extreme values of each element are thus obtained.

Table I gives the nominal elements for the twenty (20) particles, for the nominal (and most probable) density of 3.0 g/cc.

The mean elements are close to the nominal ones given in Case B, Table I and are therefore not quoted separately.

Table I

Event Number	Date	Spacecraft		a	e	i	ω	Ω	Type of Orbit
1	March 11, 1968	8	A	0.864	0.226	0.00	0.00	0.00	
			B	0.830	0.264	0.00	0.00	0.00	Elliptic
			C	0.816	0.301	0.00	0.00	0.00	
2	March 26, 1968	8	A	0.624	0.729	0.00	0.00	0.00	
			B	0.601	0.791	0.00	0.00	0.00	Elliptic
			C	0.585	0.844	0.00	0.00	0.00	
3	April 13, 1968	8	A	0.786	0.850	0.00	0.00	0.00	
			B	0.812	0.905	0.00	0.00	0.00	Elliptic
			C	0.854	0.946	0.00	0.00	0.00	
4	April 15, 1968	8	A	0.561	0.990	180	0.00	0.00	
			B	0.616	0.866	180	0.00	0.00	Elliptic
			C	0.763	0.624	180	0.00	0.00	
5	August 25, 1968	8	A	0.675	0.626	0.00	0.00	0.00	
			B	0.652	0.685	0.00	0.00	0.00	Elliptic
			C	0.633	0.738	0.00	0.00	0.00	

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Table I (continued)

Event Number	Date	Spacecraft		a	e	i	ω	Ω	Type of Orbit
6	Jan. 24, 1969	8	A	1.010	0.090	4.19	102	88.8	
			B	0.970	0.101	4.53	102	107	Elliptic
			C	0.950	0.118	4.87	102	121	
7	April 19, 1969	8	A	0.979	0.256	5.80	-177	-121	
			B	0.969	0.275	6.34	-177	-123	Elliptic
			C	0.960	0.295	6.87	-177	-125	
8	May 20, 1969	8	A	0.830	0.544	0.00	0.00	0.00	
			B	0.832	0.593	0.00	0.00	0.00	Elliptic
			C	0.830	0.639	0.00	0.00	0.00	
9	Feb. 8, 1969	9	A	-2.010	1.370	0.00	0.00	0.00	
			B	-1.330	1.540	0.00	0.00	0.00	Hyperbolic
			C	-0.984	1.710	0.00	0.00	0.00	
10	Oct. 11, 1969	9	A	0.541	0.999	0.00*	0.00	0.00	
			B	0.602	0.966	180	0.00	0.00	Elliptic
			C	0.757	0.866	180	0.00	0.00	
11	Dec. 15, 1969	9	A	-3.240	1.170	180	0.00	0.00	
			B	-0.135	6.090	180	0.00	0.00	Hyperbolic
			C	-0.051	15.10	180	0.00	0.00	
12	March 17, 1970	9	A	1.130	0.593	0.00	0.00	0.00	
			B	1.160	0.645	0.00	0.00	0.00	Elliptic
			C	1.220	0.695	0.00	0.00	0.00	
13	March 13, 1970	8	A	0.555	0.993	180	0.00	0.00	
			B	0.608	0.875	180	0.00	0.00	Elliptic
			C	0.748	0.840	180	0.00	0.00	
14	April 24, 1970	8	A	0.962	0.801	77.9	166	-147	
			B	1.620	0.827	99.6	166	-128	Elliptic
			C	5.510	0.992	113	166	-102	
15	June 11, 1970	8	A	0.545	0.993	0.00*	0.00	0.00	
			B	0.545	0.827	180	0.00	0.00	Elliptic
			C	0.553	0.993	180	0.00	0.00	
16	July 8, 1970	8	A	7.690	0.994	0.00	0.00	0.00	
			B	-2.110	1.000	0.00	0.00	0.00	Intermediate
			C	-0.825	1.000	180*	0.00	0.00	
17	Nov. 11, 1970	8	A	0.719	0.861	0.00	0.00	0.00	
			B	0.720	0.927	0.00	0.00	0.00	Elliptic
			C	0.735	0.970	0.00	0.00	0.00	
18	Nov. 12, 1970	8	A	-7.780	1.08	125	-16.1	-76.2	
			B	-0.540	2.42	133	-16.1	-51.0	Hyperbolic
			C	-0.241	4.40	138	-16.1	-42.0	
19	Feb. 23, 1970	8	A	0.744	0.519	26.7	86.1	151	
			B	0.712	0.586	31.2	86.1	155	Elliptic
			C	0.690	0.643	36.1	86.1	157	

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Table I (continued)

Event Number	Date	Spacecraft		a	e	i	ω	Ω	Type of Orbit
20	Jan. 23, 1969	9	A	-0.348	2.010	180	0.00	0.00	
			B	-0.087	7.410	180	0.00	0.00	Hyperbolic
			C	-0.039	17.10	180	0.00	0.00	

Here a is the semi-major axis (AU), e is eccentricity, i is inclination (in degrees), ω is the argument of perihelion (in degrees) and Ω is the longitude of ascending node (in degrees). The deviating inclinations denoted by "*" arise from extreme possible velocity deviations and are of extremely low probability (less than 10^{-3}).

Table II presents a classification of particles as elliptic or hyperbolic together with their relative probability for three (3) densities.

Table II

	ρ = 3.0				ρ = 8.0				ρ = 1.0					
	Number		Probability		Number		Probability		Number			Probability		
Part.	Ell	Hyp	Ell	Hyp	Ell	Hyp	Ell	Hyp	Ell	Hyp	HR	Ell	Hyp	HR
1	243	0	1.	0.					243	0		1.	0.	
2	243	0	1.	0.					243	0		1.	0.	
3	241	2	1.	0.					219	24		1.	0.	
4	235	8	1.	0.					180	63		.94	.06	
5	243	0	1.	0.					243	0		1.	0.	
6	243	0	1.	0.					243	0		1.	0.	
7	243	0	1.	0.					243	0		1.	0.	
8	243	0	1.	0.					243	0		1.	0.	
9	19	224	.02	.98	51	192	.11	.89	0	243		0.	1.	
10	230	13	1.	0.					175	68		.92	.08	
11	0	243	0.	1.	21	222	.21	.79	0	90	153*	0.	.45	.55*
12	239	4	1.	0.					67	176		.45	.55	
13	237	6	1.	0.					186	57		.95	.05	
14	144	99	.66	.34	171	72	.79	.21	69	174		.26	.74	
15	243	0	1.	0.					241	2		1.	0.	
16	52	191	.24	.76	77	166	.38	.62	0	243		0.	1.	
17	237	6	1.	0.					130	113		.69	.31	
18	27	213	.09	.91	40	203	.20	.80	1	242		.005	.995	

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Table II (continued)

	ρ = 3.0				ρ = 8.0				ρ = 1.0					
	Number		Probability		Number		Probability		Number			Probability		
Part.	Ell	Hyp	Ell	Hyp	Ell	Hyp	Ell	Hyp	Ell	Hyp	HR	Ell	Hyp	HR
19	240	3	1.	0.					97	133	13*	.41	.59	0.*
20	0	243	0.	1.	0	243	0.	1.	0	90	153*	0.	45.	.55*

The last column headed "HR" stands for hyperbolic repulsive, i.e., cases where the radiation pressure exceeds the gravitational attraction.

CONCLUSIONS

(1) The statistical analysis confirms that the character of the nominal trajectory is essentially correct. The most probable elements are very close to the nominal ones (Case B, nominal velocity).

(2) The elliptic or hyperbolic character of most orbits is not usually affected by reasonable density assumptions (between 8. and 1.).

(3) Most particles are elliptic but particles 9, 11, 18 are most probably hyperbolic. Particle 20 is and remains hyperbolic under all reasonable assumptions and without resort to statistical or probabilistic arguments.

(4) The incoming asymptote of the hyperbolic orbits is consistent with the particles arriving from the apex of the solar motion.

(5) The perihelion of particle 20 is about .5 AU. This precludes evaporative and indicates interstellar origin.

REFERENCES

(1) Berg, O. E. and Richardson, F. F., "The Pioneer * Cosmic Dust Experiment", Rev. Sci. Inst. 40, October 1969.

(2) Private communication to O. E. Berg and H. Wolf.