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(NASA-CR-146396) JUPITER ORBITER LIFETIME: THE HAZARD OF GALILEAN SATELLITE COLLISION (Science Applications, Inc.) 79 p HC $5.00 CSCL 22C

N76-17173

Unclas

G3/13 15041

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REPORT NO. SAI 1-120-194-T2

JUPITER ORBITER LIFETIME

The Hazard of Galilean Satellite Collision

by

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for

Planetary Programs Division
Office of Space Science
NASA Headquarters
Washington, D.C.

Contract No. NASW-2613

February 14, 1975

FOREWORD

This study was performed between March and December 1974 as part of the work performed by Science Applications, Inc. for the Planetary Programs Division of OSS/NASA under Contract No. NASW-2613. The results are intended to assist NASA planners assess the hazard of Galilean satellite collision in the event that spacecraft quarantine requirements are imposed on the post-operational lifetime of a Jupiter orbiter.

The author expresses his appreciation to C. Uphoff of Vector Sciences, Inc. for useful conversations concerning the subject matter, and to M. Stancati, J. Niehoff and G. Adamek of the SAI-Chicago staff for their valuable assistance in computer programming and preparation of this report.

SUMMARY

The four Galilean satellites of Jupiter present a long-term collision hazard to an uncontrolled orbiting spacecraft that repeatedly enters the spatial region occupied by the satellites. An assessment of this risk and its implication for Jupiter mission planning becomes important if quarantine constraints, currently under review, are imposed on an unsterilized spacecraft. This report describes an analysis of satellite close encounters and the likelihood of collision over a wide range of initial orbit conditions with the effect of orbit inclination being of key interest. The scope of the analysis is restricted to orbital dynamic considerations alone, i.e. the question of biological contamination given the event of collision is not addressed here. A quarantine or orbiter lifetime of 50 years is assumed. This time period begins at spacecraft "shutdown" following completion of the science mission objectives.

A numerical approach is adopted wherein each initial orbit is propagated for 50 years, and satellite closest encounter distances are recorded on every revolution. The computer program developed for this purpose strikes a necessary compromise between orbit computation accuracy and speed. It includes approximations of the three major perturbation effects on the long-term motion of the orbiter: (1) Jupiter oblateness, (2) solar gravity, and (3) satellite gravity. Program execution time is about 1 minute to complete 600 orbit revolutions typical of a 50-year lifetime. The loss of definitive accuracy in favor of rapid simulation is compensated for by adopting a broad statistical viewpoint regarding the question of collision probability or likelihood. This requires the generation of a fairly large number of data samples, a method we refer to as "orbit flooding". It should be noted, however,

that this is not a Monte Carlo simulation, which even with the approximate numerical approach used would require a prohibitive amount of computer time.

Numerical data has been generated for 32 basic orbits comprised of 2 perijove distances (5 and 11 Jupiter radii), 2 orbit periods (21.3 and 60 days), and 8 inclinations between 0° and 90°. The initial epoch for each orbit is sampled over a 7-day interval defined by the characteristic phase resonance (syzygy) of the three inner Galilean satellites, Io, Europa and Ganymede. A sample size of 15 epochs, spaced uniformly 0.5 day apart, is used. All time samples are tacitly assumed to be equally likely. In total then, the Jupiter orbiter space is filled with 480 initial orbits each propagated for 50 years. Significant perturbation of the orbital elements during this time results in further permeation of the sampling space.

An overall summary of results is given by the collision record for all satellites presented in Table S-1. Of the 480 orbits, the total number of first collision occurences is 81 or 17%. This is of course biased by the equatorial orbit cases; if these are excluded then the first collisions number 34 of 420 orbits, or 8%. The equatorial orbits, representing a worst case upper bound, are physically unreasonable in that the Galilean satellites are not exactly in Jupiter's equatorial plane nor would a spacecraft be placed exactly in this plane. The uniqueness of $I = 0$ is seen by the total number of collisions when orbit continuation is allowed. For example, taking the $5R_J$, 21.3^d orbit, there are an average of 5 subsequent satellite impacts following the first collision. This does not happen when $I \neq 0$. Raising the orbit inclination reduces the risk of collision, yet collisions were recorded even at 60° and 90° inclination. The orbit class having a perijove of $5R_J$ and period of 21.3 days is most susceptible to collision because all satellite orbits

TABLE S-1 COLLISION RECORD

Nominal Orbit Lifetime = 50 years
Initial Epoch Samples/Case = 15
( ) = Total Collisions with Continuation

Number of First Collisions

Orbit Case	$i = 0^o$	$i = 0.5^o$	$i = 1^o$	$i = 5^o$	$i = 10^o$	$i = 30^o$	$i = 60^o$	$i = 90^o$
Perijove = 5 R_J Period = 21.33^d	14 (84)	5	2	4 (5)	2	1	1	1
5 R_J 60^d	14 (51)	4	2	0	0	0	0	0
11 R_J 21.33^d	13 (65)	2	2	2	0	0	0	0
11 R_J 60^d	6 (21)	1	1	2	0	1	1	0

Summary	Number of Initial Orbits	Number of First Collisions
Including Equatorial Orbits	480	81
Excluding Equatorial Orbits	420	34

are crossed with greater frequency. Io is the dominant body in this case accounting for 50% of the collision occurrences over all eight inclination samples.

Fig. S-1 summarizes the likelihood of close encounters and collisions taken as an average over all four orbit classes. Graphed as a function of inclination on linear scale, it clearly indicates the rapid decrease between 0° and 10° followed by a leveling off trend. The analytical prediction curve is based on Wetherill's asteroid collision theory applied to the present problem without modification. The comparison serves as corroborating evidence of the basic validity of the numerical data. Discussion of the analytical formula and further comparative results is given in the text. Another means of validation is to examine the ratio of close encounters to collisions. If, for example, this ratio is fractionally small then one would have greater confidence that the event of collision is statistically significant. This is found to be the case.

A general conclusion of this study follows from the summary data shown and other more specific results given in the text: for the types of crossing orbits investigated, the spacecraft should be placed in an orbit of at least 30° inclination to ensure a 50-year lifetime probability approaching 97-99%. However, if planet and satellite quarantine is imposed on a Jupiter orbiter mission, this lifetime probability may not be high enough. It will then be required to design the post-operational initial orbit specifically for collision avoidance. Among the possibilities mentioned in the text are (1) hyperbolic escape, (2) circular orbit, (3) critical inclination orbit, and (4) Callisto - resonant orbit beyond Ganymede. The question as to whether such collision avoidance orbits are compatible with the operational sequence and maneuver budget of the nominal mission design is beyond the scope of this study and left for for more detailed mission analysis.

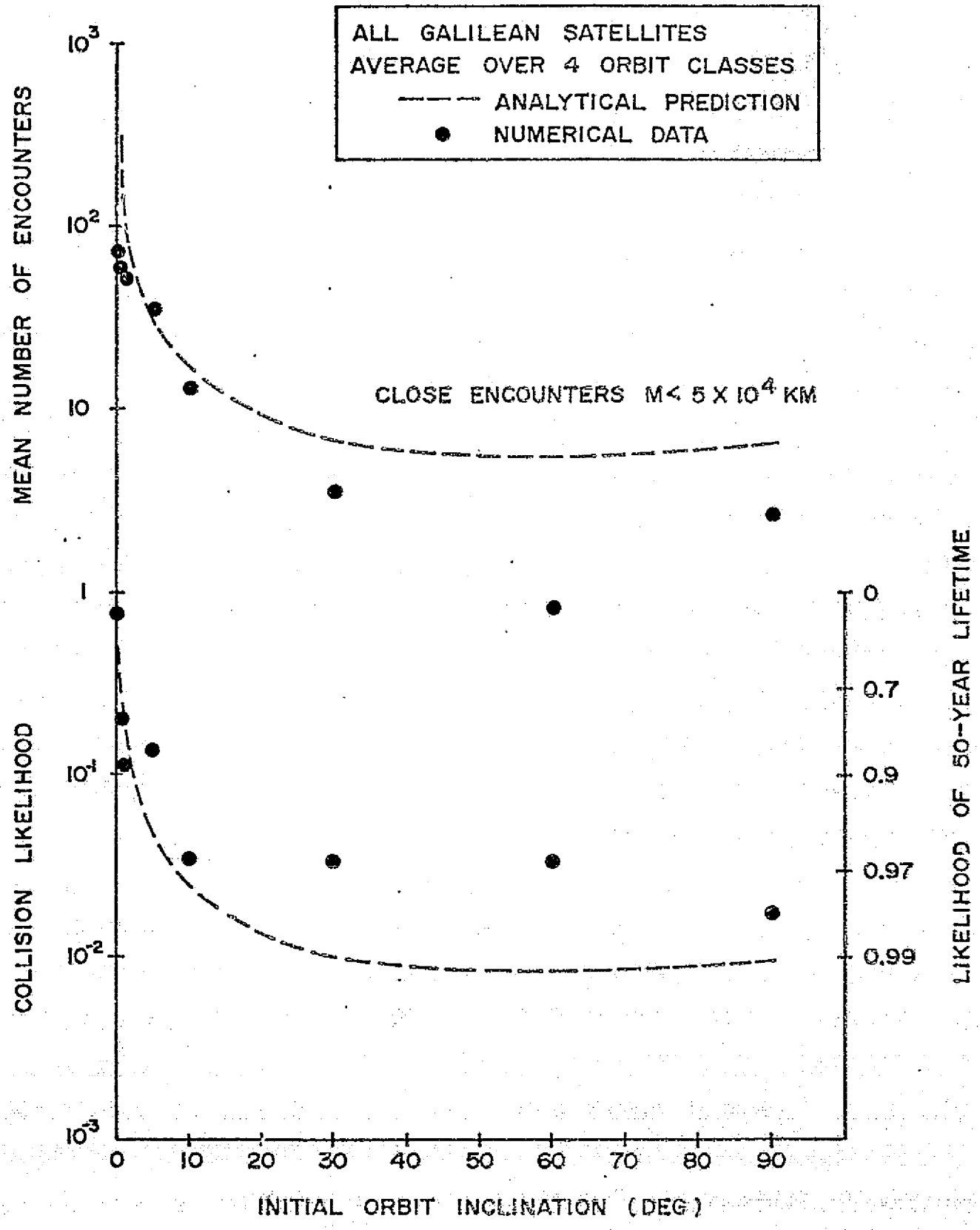

FIG. S-1 LIKELIHOOD OF CLOSE ENCOUNTERS AND COLLISION WITH THE GALILEAN SATELLITES FOR A 50-YEAR JUPITER ORBITER LIFETIME

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1. INTRODUCTION

Planning for Jupiter orbiter missions in the 1980 decade has reached the stage of detailed mission analysis and spacecraft design. Both Pioneer and Mariner-class orbiters are being considered. [1, 2] During the course of the nominal operational lifetime of such orbiters (1-2 years), some degree of active control based on real time adaptive orbit design will be in effect so as to avoid premature collision with Jupiter or with its natural satellites. In fact, current Jupiter Orbiter mission planning includes extensive use of the gravitational fields of the Galilean satellites for dynamic orbit shaping to enhance scientific observation and mission performance. The question of interest in this report concerns the post-operational, long-term motion of the orbiter and its relation to planet and satellite quarantine constraints that may be imposed on an unsterilized spacecraft.

Quarantine requirements for the Jovian system are currently under review. Although the necessity for satellite quarantine has not been established, the present inability to assess the implication of such a constraint, should it be imposed, is of concern to mission planning. The present study was undertaken to examine the orbital dynamic implications. An implicit assumption is therefore made that a 50-year quarantine period is in effect, and that some small value of the contamination probability is required for the Galilean satellites (Io, Europa, Ganymede and Callisto) as well as for Jupiter.

The contamination probability is comprised of two factors: (1) the probability of collision and (2) the probability of contamination given that collision occurs. By collision we mean entry into the Jupiter cloud tops or actual impact on the satellites. In what follows we will not be concerned with the probability of biological contamination, but only with the dynamic event of collision. In fact, to place the

problem in an even narrower sense, we will be concerned with the "likelihood" of collision over a wide range of initial orbit conditions. It is important to make a clear distinction between likelihood and definitive probability in order that the results of this study be understood in the proper context.

Suppose that a spacecraft is placed at a known initial condition in the Jupiter orbital space and that the dynamic force model affecting its subsequent motion is known exactly. If the question is then asked, will the spacecraft collide with Jupiter or its satellites over a 50-year period, the answer is either yes (probability = 1) or no (probability = 0). Unfortunately, it may not be possible to state the correct answer with absolute certainty because of the inability to predict the long-term orbit propagation without error. Even the best state-of-the-art integration program may have significant error build-up over several hundred orbiter revolutions about Jupiter. However, if the integration error bound is known and is small compared to the close encounter distances recorded, it would be reasonable in this case to state that the likelihood of collision is small.

The difficulty in the simple deterministic problem posed above is further compounded when we admit the real world of uncertainty. Included in the list of error sources are the initial conditions, Jupiter's gravitational field, the satellite ephemerides and gravitational fields, and other perturbative forces that may act on the spacecraft. If each error source could be described by a probability distribution, then the event of collision is a random process and it is valid to ask what is the probability of this event. The two standard methods of solution are linearized error propagation and Monte Carlo sampling. Both methods have serious drawbacks from a practical standpoint; the first because the linearity assumption will become invalid after a period of time well before 50 years, the second because of the large

number of samples needed. Furthermore, either method will be subject to the same numerical integration (or analytical theory) errors in predicting the long-term motion of the spacecraft.

An excellent review of the problems of Jupiter orbit prediction and collision hazard has been given recently by Uphoff.[3] It was found that the long-term avoidance of close approaches ($<5 \times 10^4$ km) to the Galilean satellites is virtually impossible for low and even moderate inclination orbits which cross the orbital distances of the satellites. The principal reason for this effect is the oblateness of Jupiter which causes precession of the orbital plane. Uphoff draws the reasonable conclusion that it is technically and economically unfeasible to predict the definitive probability of collision. This does not necessarily imply that the probability is high, but only that it is impractical to determine given the present state-of-the-art of orbit prediction methods. It was recommended that an approximate orbit propagation computer program be developed which accounts for the major perturbation forces and is rapid in execution. Such a program can be used to generate parametric data on the likelihood of collision thereby bounding the question of lifetime probability. It was this recommendation, in part, that motivated the present study.

Section 2 of this report describes the scope and method of analysis, and includes discussion of the dynamical model approximations, the JOL computer program characteristics, and the range of initial orbit conditions to be studied. Numerical results discussed in Section 3 are based on the tabulated statistics of satellite close encounters given in Appendix A. The Summary preceding this section is presented for the busy reader wishing only to abstract the basic results and conclusions of the study.

2. METHOD OF ANALYSIS

2.1 Galilean Satellite Motion

Jupiter's four great satellites move in nearly circular equatorial orbits in the region 6-26 Jupiter radii. These satellites might be called semi-planets as Ganymede's size approximates that of the planet Mercury, and Io and Callisto are both larger than the Earth's moon. Pertinent physical and orbital parameters of each body are listed in Table 1. To simplify the computation of satellite positions for purposes of this study, it is assumed that the orbits are exactly circular and lie in Jupiter's equatorial plane.

Perhaps the most interesting characteristic is the longitudinal phase relationship between Io, Europa and Ganymede. Laplace is credited with discovering that the mean longitudes very nearly obey the stable resonance relationship

$$L_I - 3L_E + 2L_G = 180^\circ \tag{1}$$

which results from the fact that the orbital periods of the three inner satellites are approximately in the ratio 1:2:4. The mutual gravitational interaction among these bodies is magnified by the resonance effect which in turn acts to maintain its stability. Fig. 1 shows the satellite orbits and positions on the date 1985 December 23.146. The X-axis reference is the projection of Earth's ecliptic vernal equinox onto Jupiter's equatorial plane. The particular orientation of the inner satellites depicted in the figure is referred to as syzygy and repeats every 7.15 days. One should also note that there is an anti-syzygy lineup every 3.55 days at which time Ganymede and Europa have equal longitudes and Io is in superior conjunction. The line of syzygy precesses in a retrograde sense relative to the Jupiter-Sun line with a period of 437 days. The assumption is made in this study that the

TABLE 1

PHYSICAL AND ORBITAL PARAMETERS OF THE GALILEAN SATELLITES

- JUPITER

Equatorial Radius	$R_J = 71422$ km
Gravitational Constant	$\mu_J = 1.267106 \times 10^8$ km^3/sec^2 $\equiv$ 2.596237×10^3 R_J^3/day^2
Oblateness	$J_2 = 0.01471$

- SATELLITES

Parameter	Io	Europa	Ganymede	Callisto
Radius, km	1800	1549	2621	2389
Gravitational Constant, km^3/sec^2	6000	3170	10300	6340
Inclination to Jup. Equator, deg.	~0	~0	~0	~0
Eccentricity	~0	~0	~0	~0
Mean Orbital Distance[a], R_J	5.904312	9.395288	14.987064	26.360204
Orbital Period, days	1.769138	3.551181	7.154553	16.689019
Reference Longitude[a,b], deg.	102.60777	348.61292	201.61550	89.14804
Mean Motion[a], deg./day	203.488955	101.374724	50.317609	21.57107
Sphere-of-Influence, km	7202	9643	24751	36070

a. Adjusted values used in JOL program to maintain Laplacian resonance relationship; does not imply knowledge accuracy

b. Epoch Julian Date = 2446422.0 $\equiv$ 1985 Dec. 22 (Noon)

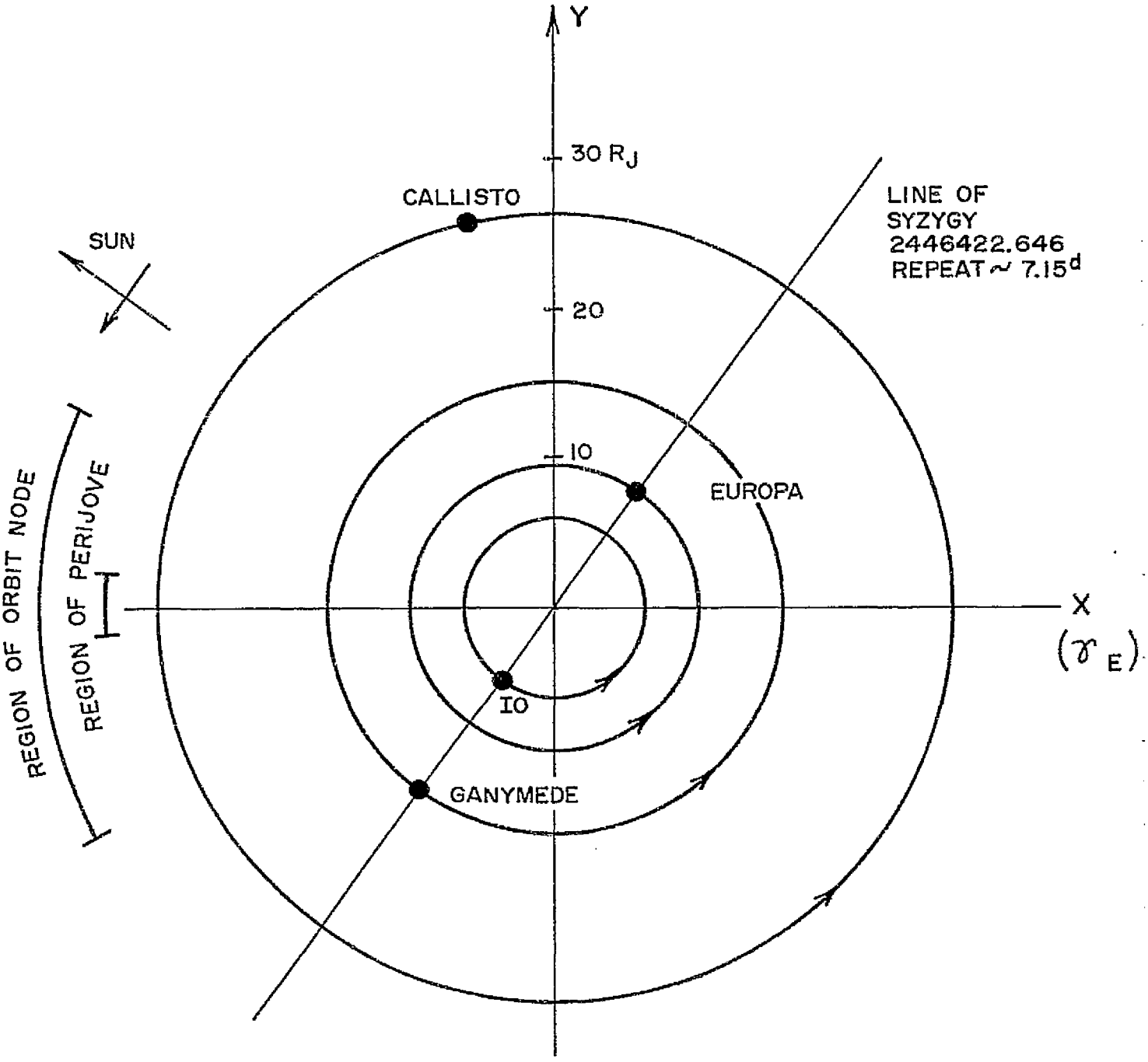

FIG. 1 GALILEAN SATELLITE AND ORBIT GEOMETRY

DEC. 23, 1985

longitudinal resonance described above holds exactly. For this purpose the orbital distances listed in Table 1 were adjusted so that the corresponding mean motion rates satisfy the necessary angular relationship as a function of time. Also shown in Fig. 1 are the spatial regions of the spacecraft's initial orbit node and apse lines which are assumed for the lifetime study (initial orbit parameters will be described later). This particular orientation places the orbit perijove (closest approach to Jupiter) near the equatorial plane crossing.

2.2 Gravitational Perturbations

There are three major perturbations that affect the long-term motion of orbiting spacecraft.

(1) Jupiter's oblateness
(2) Solar gravity
(3) Galilean satellite gravity

The relative strength of these perturbing forces depends, of course, on the size, shape and orientation of the spacecraft orbit. The gravitational field perturbation due to Jupiter's aspherical shape is largest for close orbits of low eccentricity. In contrast, the solar gravity effect increases with the orbit size and eccentricity. Disturbing forces due to the satellite fields would have little effect on the long-term motion of an orbiter, except for close encounters or resonance magnification of small forces. However, it is just this pervading action of the satellites which can change the orbit period by small amounts thereby upsetting the delicate phase relationship necessary to avoid close encounters. If the orbit evolves into such a situation, the satellite perturbation effects can become very significant in a relatively short time.

One of the important ground rules of this study is that an appropriate compromise be struck between the conflicting requirements of orbit computation accuracy and speed. The computer program should include approximations of the major perturbing forces in order to simulate the changing orbit elements over 50 years. Also, the program should be capable of direct comparison with accurate (and slow) integrating methods, and produce similar results over a limited time span of several orbits. The approximations are described below.

The main effect of Jupiter's oblateness term J_2 is precession of the orbit plane resulting from regression of the nodal longitude Ω and advancement of the argument of perijove ω. Expressed as an averaged secular change per revolution of the orbiter, the equations are (in units of deg/revolution)

$$\Delta\Omega = -\left[\frac{540\, J_2\, R_J^2}{a^2(1-e^2)^2}\right]\cos I \tag{2}$$

$$\Delta\omega = \left[\frac{540\, J_2\, R_J^2}{a^2(1-e^2)^2}\right]\left(\frac{5}{2}\cos^2 I - \frac{1}{2}\right) \tag{3}$$

where R_J is Jupiter's equatorial radius and a, e and I are, respectively, the orbit's semi-major axis, eccentricity and inclination. A typical magnitude of the precession term is 0.1 deg/revolution for an equatorial orbit of size $a = 31\ R_J$ and $e = 0.85$. The above expressions are used to rectify the orientation elements once per orbit as the spacecraft passes through perijove.

Solar gravity action on the orbit is approximated by the change in the elements (r_p, I, Ω, ω) averaged over an orbiter revolution. The average perturbation on orbit energy is zero (i.e., $\Delta a = 0$). The

most important effect of solar perturbations in the context of the orbiter lifetime study is the change in perijove distance given by the following expressions,

$$\Delta r_p = A \left[\sin 2\Gamma \cos 2\omega \cos I - \sin 2\omega \left(\cos^2 \Gamma - \sin^2 \Gamma \cos^2 I \right) \right] \tag{4}$$

$$A = 7.5\pi \left(\frac{\mu_{SUN}}{\mu_J} \right) \left(\frac{a^4}{a_J^3} \right) e \sqrt{1 - e^2} \tag{5}$$

where $\left(\mu_{SUN} / \mu_J \right)$ is the Sun-Jupiter mass ratio, a_J is Jupiter's mean orbital distance and Γ is the direction angle of the Sun relative to the orbit's ascending node. A typical value of the amplitude A lies in the range 0.01 - 0.1 Jupiter radii per revolution for the highly eccentric orbits considered in this report. The time history of perijove distance is determined by the accumulation of Δr_p increments, and depends strongly on the angle relationships in the bracketed term above. This term can be separated into a secular trend, $-1/2 A \sin 2\omega \sin^2 I$, and an oscillatory solution in Γ whose period is about 6 years (1/2 Jupiter's orbital period). It will be noted that oblateness and solar perturbations are coupled through the time variation of Ω and ω. The computer program accounts for the solar gravity effect by rectifying the elements (r_p, I, Ω and ω) once per orbit at the perijove point.

Gravitational perturbations due to the four Galilean satellites are accounted for in two different ways.

(1) Close Encounters (<5 SOI)

If the spacecraft comes within 5 spheres-of-influence of any satellite, then the perturbation is computed on the basis of a two-body, impulsive, gravity-assist formula. This condition is checked each time the spacecraft crosses the satellite orbit distance. At the nominal crossing time t*,

a relative position vector $\Delta \underline{r} = \underline{r} - \underline{r}_s$ and hyperbolic approach velocity vector $\underline{V}_h = \underline{V} - \underline{V}_s$ are calculated. The time to closest approach and the hyperbolic miss vector are approximated by

$$\Delta t_c = -\left(\underline{V}_h \bullet \Delta \underline{r}\right) / V_h^2 \tag{6}$$

$$\underline{b} = \Delta \underline{r} + \underline{V}_h \, \Delta t_c \tag{7}$$

Knowing the gravitational constant of the satellite μ_s, it is a simple matter to calculate the equivalent gravity-assist impulse vector

$$\Delta \underline{V}_{GA} = \left(\cos \Psi - 1\right) \underline{V}_h - \left(V_h \sin \Psi / b\right) \underline{b} \tag{8}$$

where Ψ is the asymptote turn angle given by

$$\cos \Psi = \frac{b^2 - \left(\mu_s / V_h^2\right)^2}{b^2 + \left(\mu_s / V_h^2\right)^2} \tag{9}$$

and the closest approach distance is

$$r_p = -\frac{\mu_s}{V_h^2} + \sqrt{b^2 + \left(\frac{\mu_s}{V_h^2}\right)^2} \tag{10}$$

Finally, the new velocity vector relative to Jupiter resulting from the close encounter is $\underline{V} + \Delta \underline{V}_{GA}$.

(2) Far Encounters

This calculation is made before applying the G-A formulas described above. It is based on a simple average acceleration due to all satellites, excluding that "close encounter"

satellite, if any, which will be accounted for by the G-A formula. The averaging takes place over several (≤ 8) subarcs on each orbit revolution within the region between perijove and Callisto's orbit distance. The subarcs are divided by radial distance from Jupiter rather than by time increments. Hence, if the nominal orbit crosses the radial distances of all four satellites, then there are 9 end points comprised of perijove, the four satellite distances on the outbound leg to apojove, and the four satellite distances on the inbound leg to perijove. Consider one such subarc along an unperturbed orbit between the endpoint positions $\underline{r}_1$ and $\underline{r}_2$. The time difference Δt_{12} is readily computed. The total satellite gravity perturbation at each end point is

$$\Delta \underline{g}_i = - \sum_{j=1}^{m \leq 4} \mu_{sj} \left[\frac{\underline{r}_i - \underline{r}_{sj}}{\left|\underline{r}_i - \underline{r}_{sj}\right|^3} + \frac{\underline{r}_{sj}}{\left|\underline{r}_{sj}\right|^3} \right] \quad \underline{i = 1, 2} \tag{11}$$

Velocity and position rectification at the second endpoint is then approximated by

$$\Delta \underline{V}_2 = \frac{1}{2} \left(\Delta \underline{g}_1 + \Delta \underline{g}_2 \right) \Delta t_{12} \tag{12}$$

$$\Delta \underline{r}_2 = \frac{1}{4} \left(\Delta \underline{g}_1 + \Delta \underline{g}_2 \right) \Delta t_{12}^2 \tag{13}$$

Treatment of satellite perturbation may be summarized as follows: (1) calculate the adjustment to position and velocity due to far encounter perturbations; (2) add the velocity adjustment due to a close encounter, if any; (3) use the rectified position and velocity to calculate new orbit elements; (4) continue orbit propagation and repeat procedure for the next subarc.

The general question of approximation accuracy is difficult to ascertain but a few remarks could be made. Numerical experience shows that the G-A impulse method for close encounters is fairly accurate in predicting the change in orbital elements, particularly the change in semi-major axis. The method of treating far encounter perturbations relies on the assumption of a relatively short time interval across each subarc so that the contained $\Delta \underline{g}(t)$ is a nearly linear segment of the total(oscillatory) variation of $\Delta \underline{g}(t)$. Another assumption is that the perturbations have a zero average over the Callisto - Callisto subarc. Limited numerical comparisons with integrated orbits over several revolutions showed reasonable agreement in orbit element variations. It seems likely, however, that the approximation accuracy is highly dependent on the nominal orbit conditions, and that for some orbits the long-term motion would be better predicted by omitting the far encounter approximation altogether.

2.3 JOL Program Characteristics

A computer program based on the above-mentioned approximations was written in the XBASIC language for execution on a Univac-1108 system. All program variables and constants are referred to distance units in Jupiter radius and time units in (Earth) days. The reference coordinate system is Jupiter's equatorial plane, but the X-axis in this plane is somewhat arbitrarily defined (for input purposes only) as the projection of Earth's ecliptic vernal equinox. Any initial orbit conditions may be input in terms of perijove distance, apojove distance, inclination, longitude of ascending node, and argument of perijove. The initial epoch is specified by the Julian date minus 2440000 and refers to the starting time at orbit perijove. Additional input quantities are the initial solar longitude, final time, and output option parameters.

Program execution rate is about 10 orbit revolutions per second of 1108 CPU time. A typical 50-year orbit propagation of 600 revolutions would then require about 1 minute of computer time. Table 2 is an example of a short-form output listing giving only summary data of the final orbit conditions and satellite encounter statistics. As the orbit is propagated, the program stores the closest encounter distance with each satellite for each revolution. The number of encounters are accumulated in 7 distance cells between 0 and 300,000 km, and a final open cell for all encounters beyond 300,000 km. Distance is measured from the satellite center. The number of revolutions (712 in the example) may be found by summing any column listed under a particular satellite, or by summing the totals column and dividing by 4. The last printout gives the cell frequency distribution in percent of all satellite encounters. For example, the frequency of all encounters between 50,000 and 100,000 km is $(45 \times 100) \div (4 \times 712) = 1.58\%$. The frequency of all encounters less than 100,000 km is simply the summation of the first five cells, or 1.76%.

In the example, a collision with Europa is recorded on the 640th revolution after 40 years of orbit propagation. The printout "END CURRENT COMPUTATION" is misleading since the program continues execution to the nominal 50-year lifetime in order to develop the full statistical record. There are, however, two conditions which can terminate execution before 50 years; (1) collision with Jupiter, and (2) evolution to a hyperbolic escape orbit which can result from very close satellite encounters or collisions.

Figures 2 and 3 show the history of orbit element changes for the above example. Perijove distance variations are due to the solar perturbation effect and show an oscillation of about $\pm 0.15\ R_J$ superimposed on a long-term secular trend of $3 \times 10^{-4}\ R_J$ per revolution.

TABLE 2

EXAMPLE OF JOL PROGRAM OUTPUT (SHORT FORM)

```
INITIAL EPOCH(J. D. )
6428

ORBIT ELEMENTS(RP, RA, I, N, W)
5, 57. 08095, 30, 200. 3, 342. 8

INITIAL SOLAR LONGITUDE
144

FINAL TIME(DAYS)
18250

OUTPUT STEP SIZE(REVS)
5000

CLOSE ENCOUNTER OUTPUT YES=1, NO=0
0

     DAYS        PERIAPSE  ECC     PERIOD      INCL       NODE        ARG
      . 000       5. 000  . 839    21. 326    30. 000   200. 300   34  800

COLLISION WITH SATELLITE 2 END CURRENT COMPUTATION
REV= 640 TIME= 14711. 2

   18253. 735     4. 996  . 912    53. 139    27. 202   101. 760   107. 944
              SUMMARY OF ENCOUNTER STATISTICS

     (KM. )          IO        EUROPA      GANYMEDE    CALLISTO       TOTALS
      0-  3000        0          1           0           0              1
   3000- 10000        1          0           0           0              1
  10000- 30000        1          0           0           0              1
  30000- 50000        1          1           0           0              2
  50000-100000       34         11           0           0             45
 100000-200000      108         26          11           4            149
 200000-300000      138         67          28           7            240
 300000-            429        606         673         701           2409
CELL FREQUENCIES(%)
 . 035112  . 035112  . 035112  . 070225  1. 58006  5. 23174  8. 42697
 84. 5857
```

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FIG. 2 ORBIT HISTORY (P, Rp)

INCLINATION = 30°
INITIAL EPOCH = DEC. 28, 1985

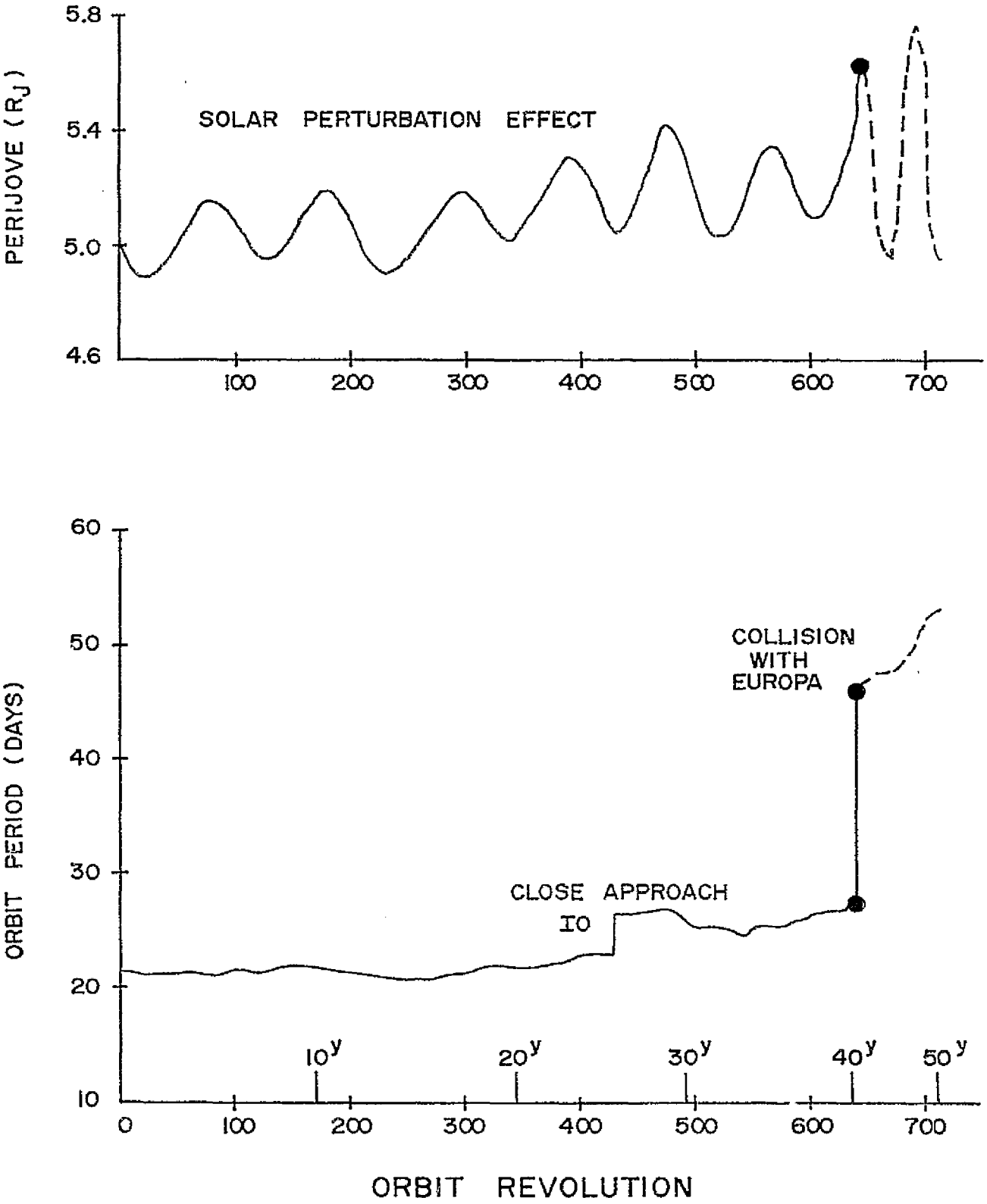
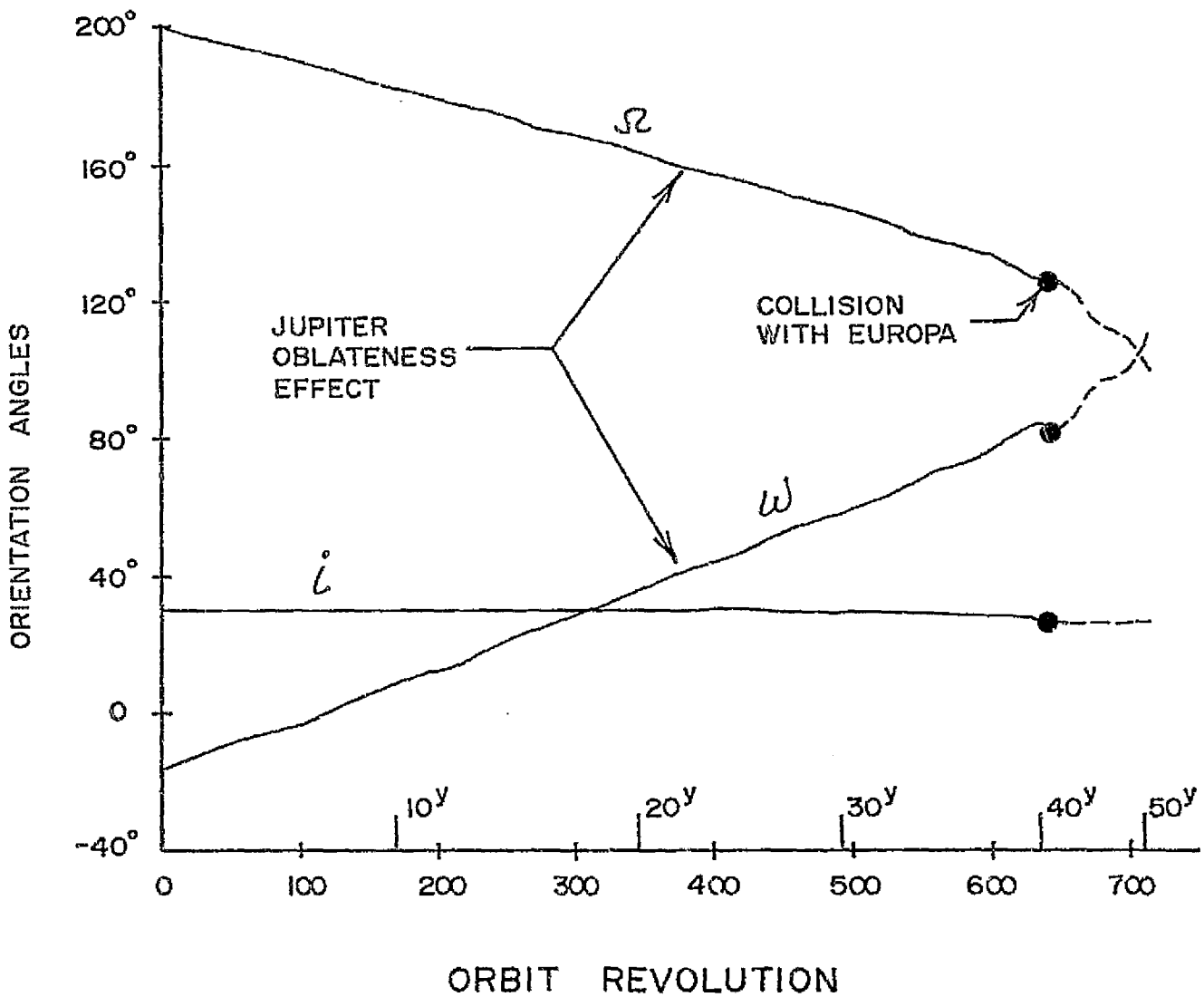


FIG. 3 ORBIT HISTORY (i, Ω, ω)

INITIAL PERIJOVE = 5 R_J
INITIAL PERIOD = 21.33 DAYS
INITIAL EPOCH = DEC. 28, 1985



Orbit period is nearly constant for the first 25 years until a close approach (7700 km) to Io. This results in a velocity magnitude change of 76 m/sec causing orbit period to increase by almost 4 days. The subsequent collision with Europa (CA = 896 km) effects a velocity increase of 381 m/sec assuming, of course, a "transparent" Europa. Figure 3 shows the orbit plane precession characteristic due to Jupiter's oblateness. Perijove longitude $\bar{\omega} = \Omega + \omega$ advances 37° from initial epoch to the time of Europa collision. The variation of inclination is negligible in this case.

2.4 Scope of Numerical Analysis

Application of the JOL program to the present study may be referred to as a method of "orbit flooding". By this we mean that the Jupiter orbit space will be sampled by a large number and variety of initial orbits each propagated for a 50-year time span. The statistical record of satellite encounter distances and collision occurrences should provide information on the likelihood of collision as a function of orbit perijove, period and inclination. The effect of inclination is of main concern, i.e. we wish to test the hypothesis that collision risk is reduced with higher orbit inclination. Table 3 lists the range of initial orbit conditions. A total of 32 basic orbits were studied; these are comprised of 2 perijove distances (5 and 11 R_J), 2 orbit periods (21.3 and 60 days), and 8 inclinations between 0° and 90°. The orientation elements Ω and ω are representative of 1984 Jupiter arrival conditions propagated 18 months forward to December 1985. For purposes of this study the latter date will be taken as the end of the operational Jupiter orbiter mission and hence the beginning of the 50-year lifetime investigation. More realistic values of Ω and ω would depend on specific orbital maneuvers made during the 18-month operational lifetime. Any assumption in this regard was avoided as being too mission dependent.

TABLE 3

INITIAL ORBIT CONDITIONS FOR LIFETIME STUDY

- IN-PLANE ELEMENTS

Orbit Class	Perijove, R_P (R_J)	Period, P (days)	Apojove, R_A (R_J)	Eccentricity, e
1	5	21.33	57.08	0.83892
2	5	60	118.72	0.91917
3	11	21.33	51.08	0.64562
4	11	60	112.72	0.82218

- ORIENTATION ANGLES

	Orbit Class 1 & 2		Orbit Class 3 & 4	
Inclination, I^o	Node, Ω^o	Argument, ω^o	Node, Ω^o	Argument, ω^o
0	182.3	0.0	171.8	0.0
0.5	182.3	0.0	171.8	0.0
1	182.3	0.0	171.8	0.0
5	158.1	24.0	158.1	13.7
10	184.9	357.4	184.9	347.0
30	200.3	342.8	200.3	332.4
60	204.6	339.6	204.6	329.2
90	206.8	339.0	206.8	328.6

The initial starting time for each of the 32 orbits is sampled over a 7-day (syzygy) time span from December 22-29. The tacit assumption is made that all initial epochs are equally likely. A total of 15 samples are used spaced uniformly 0.5 day apart. The choice of uniform rather than random Monte Carlo sampling is made because of the limited sample size. Statistical results compiled from the 15-time samples are presented in the next Section.

3. RESULTS AND CONCLUSIONS

Discussion of the study results is separated into four subsections. First, an analytical equation for predicting "order-of-magnitude" collision probability is given and applied to the satellite problem. Numerical results obtained from the JOL computer program are then described for a particular orbit example followed by parametric data for the full range of initial orbits considered. The last subsection contains a brief comment on some possible orbits which may be chosen specifically to avoid collision.

3.1 A Reference Analytical Prediction

It would be useful to have a simple analytical formula for estimating collision probability as a function of orbit parameters. Such a formula is available from the collision theory developed by Wetherill[4] in his study of collisions in the asteroid belt. Since we will apply the theory to the present problem without modification, it is important to note the inherent limitations in doing so. Wetherill derives a collision probability equation from fundamental geometrical considerations involving the evolution of crossing orbits into intersecting orbits. When applied directly to the satellite problem, the underlying assumptions are that the orbit elements (a, e, I) remain constant and that the orientation elements (Ω, ω) are uniformly distributed without preference. The first assumption is not strictly true in

in our case, but the variational effect can be understood given the numerical perturbation data. While the second assumption does not correspond to our more specific choices of Ω and ω initial values, there is a smoothing effect due to Jupiter oblateness perturbation of these elements and our method of initial epoch sampling. In any event, comparative agreement to within a factor of 2 or 3, or even an order of magnitude, would be considered satisfactory.

The collision probability per unit time for a circular satellite orbit in the equatorial plane is given by the expression

$$\dot{P} = \frac{R_s^2 \, U}{2 \pi^2 \, r_s \, a^2 \sqrt{1 - e^2} \quad \sin I \, \left| \operatorname{ctn} \alpha \right|} \tag{14}$$

where R_s is the satellite body radius, r_s is the satellite orbital distance, U is the relative velocity magnitude between the orbits at the intersecting distance r_s, and α is the co-path angle between the spacecraft velocity direction and the radial direction to Jupiter at the distance r_s. The singularities at $I = 0^o$, 180° and $\alpha = \pm 90^o$ need not cause too much concern since it is not physically reasonable to expect these conditions to hold exactly. The auxiliary expressions are

$$U^2 = \frac{\mu_J}{r_s} \left[3 - \frac{r_s}{a} - 2 \sqrt{a (1 - e^2)} \cos I \right] \tag{15}$$

$$\operatorname{ctn}^2 \alpha = \frac{(a e)^2 - (a - r_s)^2}{a^2 (1 - e^2)} \tag{16}$$

Equation (14) needs to be evaluated separately for each of the Galilean satellites; $\dot{P} = 0$ if the spacecraft and satellite orbits do not cross. The collision probability or likelihood for each satellite is then

$P_c = \dot{P}\, T_L$ where T_L is the lifetime period of interest. Note that the same equation can also estimate the mean number of close encounters by simply replacing the body radius R by a miss distance M.

Numerical results obtained from the analytical formula are graphed in Fig's. 4 and 5 for the spacecraft orbits considered in this study. Fig. 4 is for the orbit ($R_P = 5\,R_J$, $P = 21.33$ days) and shows the likelihood of collision with each satellite. In general, the satellite having the shortest orbital period (Io) is more likely to produce close encounters and collisions; the reversal of this characteristic between Europa and Ganymede is due to Ganymede's larger size. The upper curve represents the overall likelihood of colliding with at least one of the four satellites assuming that the events of non-collision are independent. The combining expression is

$$P_c = 1 - \prod_{i=1}^{4} (1 - P_{ci})$$

Fig. 5 shows the overall collision likelihood for each of the four orbit classes. The 11 R_J, 60^d orbit is least likely to produce collision because Io and Europa are not intersected and because the orbital period of 60^d results in fewer revolutions over the 50-year lifetime.

We will refrain at this point from drawing further conclusions based on the analytical prediction results until a comparison is made with the numerical data which accounts for perturbation effects. However, the reader will certainly not ignore two apparent characteristics: (1) the likelihood of collision may be significantly high, and (2) the strong influence of orbit inclination on this result.

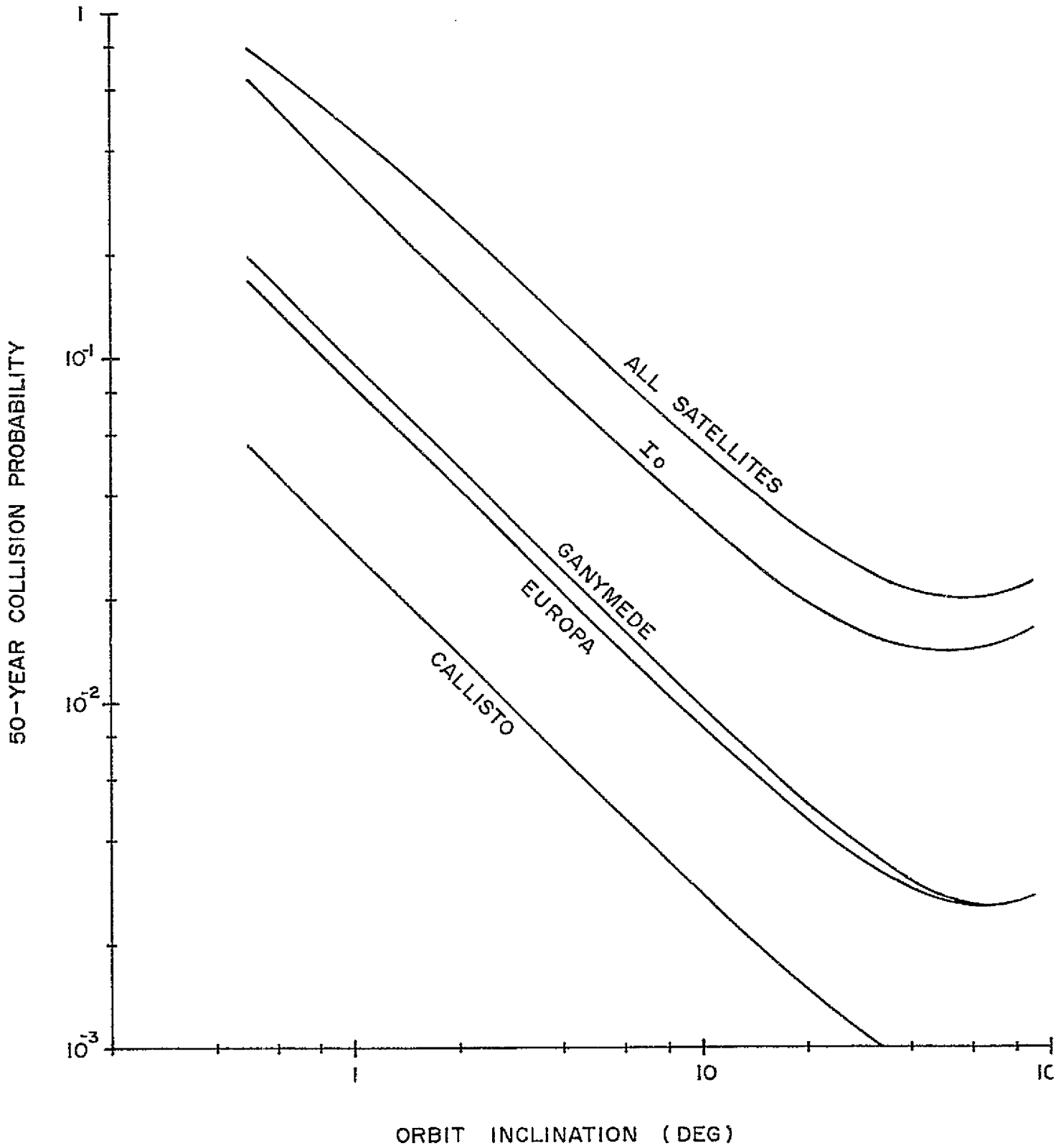


FIG. 4 ANALYTICAL PREDICTION OF GALILEAN SATELLITE COLLISION FOR A JUPITER ORBITER $R_p = 5R_J$, P=21.33 DAY

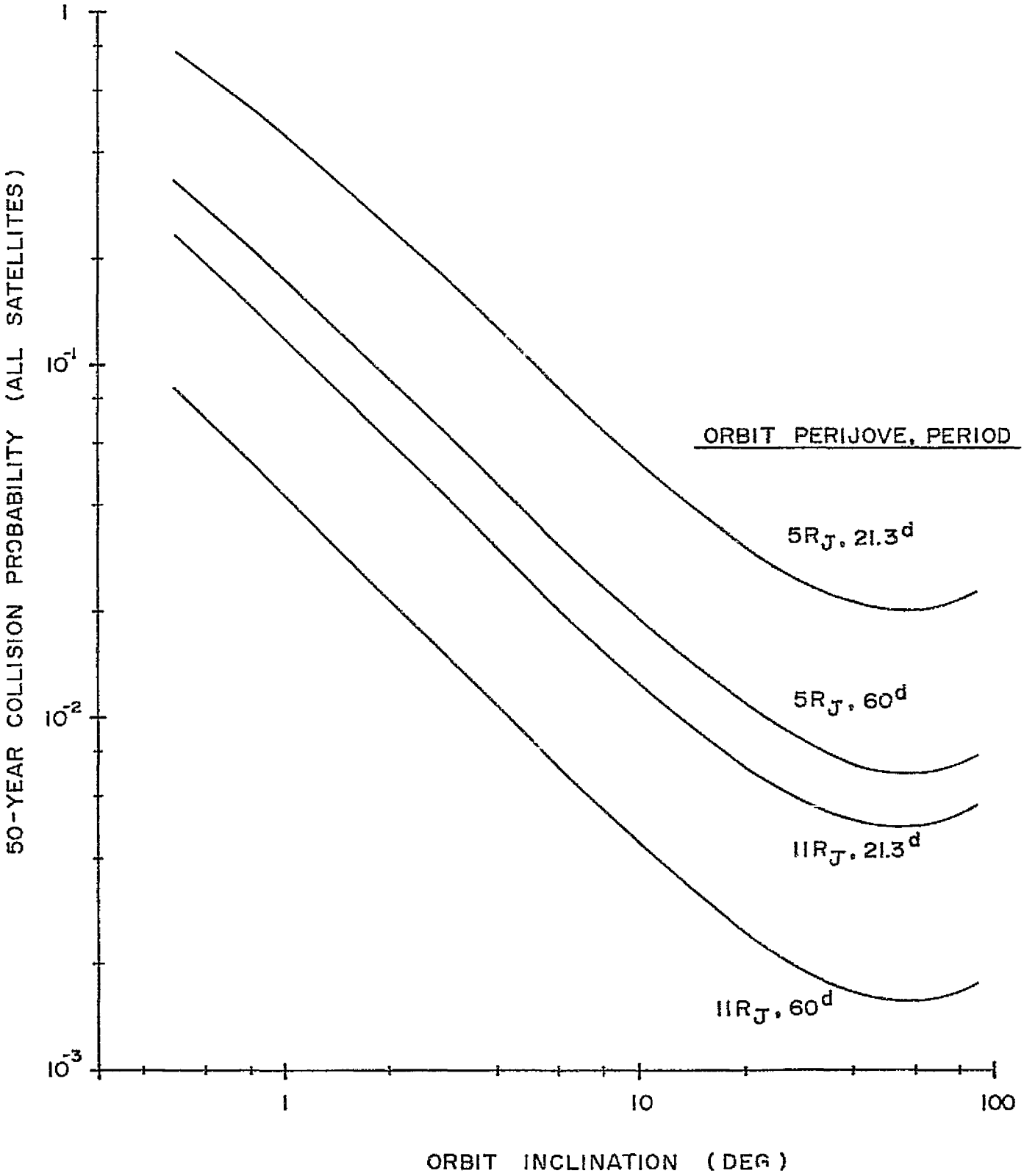


FIG. 5 ANALYTICAL PREDICTION OF GALILEAN SATELLITE COLLISION FOR FOUR CLASSES OF JUPITER ORBITS

3.2 Case Study of an Example Orbit

We will examine the orbit given by the initial elements: perijove distance = $5 R_J$, period = 21.33 days, and inclination = 0.5°. Frequent close encounters may be expected in this case as the spacecraft will cross the orbital distance of each Galelian satellite close to the equatorial plane. Table 4, taken from Appendix A, summarizes the encounter statistics compiled over the 15 initial epoch samples. The first block of output data shows orbit elements at the 50-year time point in terms of mean (average) value, standard deviation, and min-max spread. This provides a measure of the orbit variability due to perturbations. The second data block presents statistical information on the cumulative frequency of encounters within a given miss distance taken over all four satellites. Note that the maximum possible number of encounters on any orbit propagation is 4 x the number of revolutions. For example, using mean values, 8.135% of all satellite encounters have a miss distance within 100,000 km while 0.255% pass as close as 10,000 km. Actual number of encounters are presented in the third data block in terms of mean values for each satellite, and mean and standard deviation values for all satellites. The final data block shows the number of collisions recorded for each of the satellites and Jupiter, and gives a measure of overall collision likelihood computed as the fraction = no. of collisions ÷ 15.

Distribution of the number of close encounters (within 50,000 km) over the initial epoch samples is shown in Fig. 6. Straight line segments connecting the data points are used to illustrate the general trend only, and do not imply linear variation between points. The satellite Io is seen to be the dominant factor in this case with number of encounters varying between 37 and 107; the mean value as indicated in Table 4 is 66. When comparing the variation with initial epoch there is an apparent correlation among the four satellites,

TABLE 4

GALILEAN SATELLITE ENCOUNTER STATISTICS

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 5.000	NUMBER OF EPOCHS = 15
PERIOD(DAYS)	= 21.330	EPOCH INTERVAL = 7 DAYS
INCLINATION(DEG)	= 0.500	DEC. 22-29, 1985
NODE(DEG)	= 182.300	
ARG(DEG)	= 0.000	

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	5.0	1.4	2.9	7.9
PERIOD(DAYS)	22.3	14.7	5.8	65.3
INCLINATION(DEG)	4.3	2.8	1.4	12.6
NODE(DEG)	162.9	104.0	31.4	316.2
ARGUMENT(DEG)	178.6	126.4	11.5	351.5
REVOLUTIONS	1058.6	378.6	600.0	1737.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.023	0.021	0.000	0.083
< 10,000 KM	0.255	0.137	0.068	0.542
< 30,000 KM	1.673	0.496	0.921	2.875
< 50,000 KM	3.291	0.659	1.713	4.208
< 100,000 KM	8.135	1.257	4.706	9.642

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL MEAN	TOTAL SD
< 3000 KM	0.7	0.1	0.1	0.0	0.9	0.7
< 10,000 KM	6.1	2.4	1.3	0.4	10.3	5.1
< 30,000 KM	36.1	18.5	9.4	2.7	66.7	19.4
< 50,000 KM	66.0	39.2	20.3	8.2	133.7	39.0
< 100,000 KM	156.5	90.3	55.8	29.0	331.7	90.7

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 4 EUROPA = 0 GANYMEDE = 1 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.33

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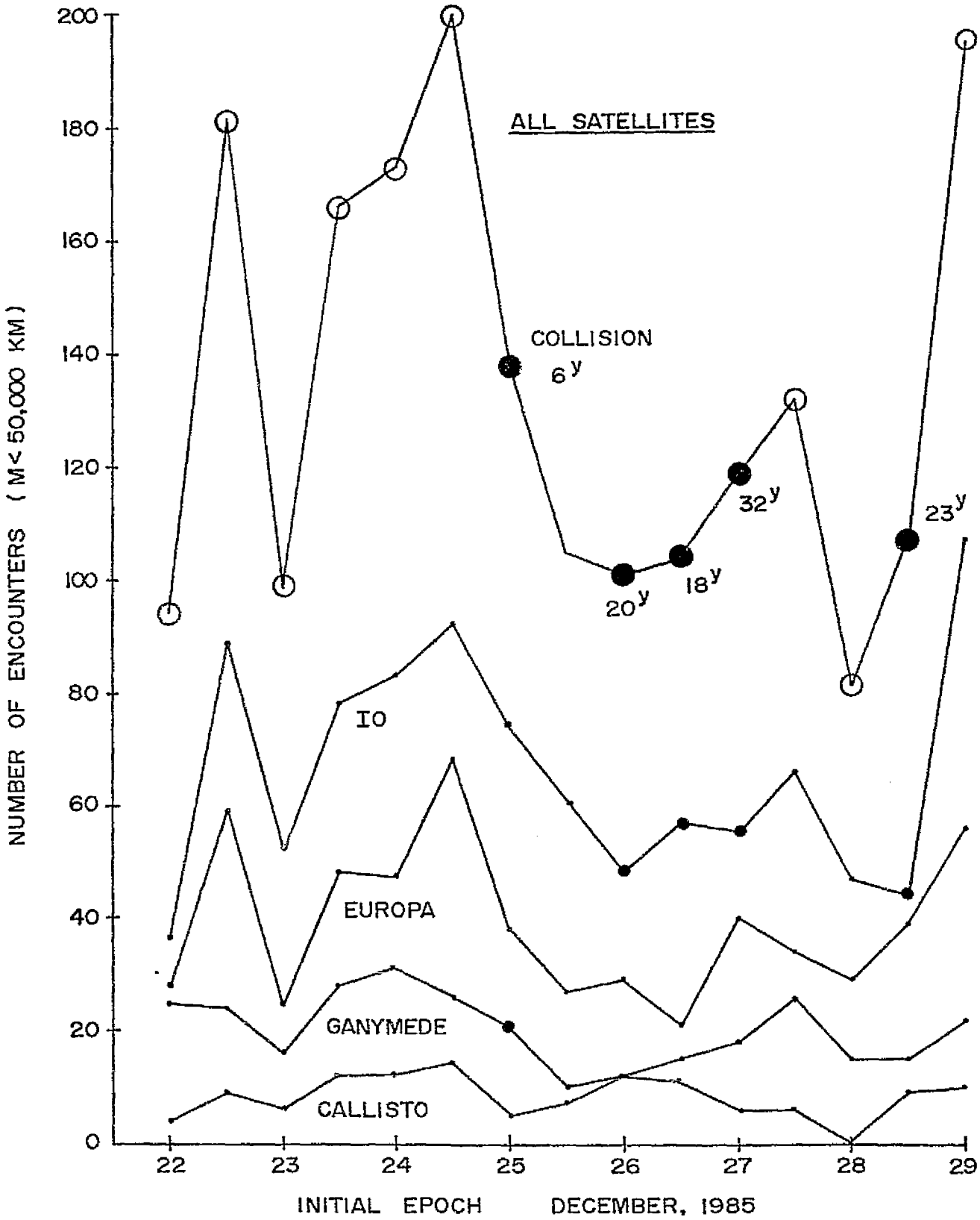

FIG. 6 CLOSE ENCOUNTERS OVER 50^y LIFETIME
$R_p = 5R_J$, $P = 21.33^d$, $I = 0.5°$

particularly Io and Europa. This is likely a result of the unique phase relationship between the three inner satellites. The additive number of close encounters for all satellites varies between 81 and 200 with a mean value of 134. The sample points for which collisions occurred are noted as well as the year of collision. Collision grouping between initial epochs of Dec. 25-28 is not particularly relevant since other orbit cases showed considerable variability in which epochs resulted in collision events. Additional data on very close encounters is shown in Fig. 7.

The likelihood of collision for this case was found to be about 33%. One way to test the validity of this result is to compare the statistics of close encounters ($<5 \times 10^4$ km) in relation to the collision record. If, for example, the ratio of the number of collisions to close encounters is fractionally small then one would have some confidence that the event of collision is statistically significant rather than being a chance occurrence due to a small sample size. From Table 4, the mean value of this ratio is $0.33/133.7 = 0.0025$, i.e., about 0.25% of all close encounters under 50,000 km may be expected to result in collision. The same ratio calculated for very close encounters ($< 10^4$ km) is $0.33/10.3 = 0.032$.

Another means of corroborating the numerical data is to use the analytical prediction formula given in Section 3.1. From Fig. 4 we see that the predicted collision likelihood for all satellites is 0.76, or slightly more than twice the numerical result. However, it will be recalled that the basic collision theory assumes constant orbit elements, and this is certainly not the case as noted from the end-of-life elements in Table 4. In particular, the mean final value of inclination is 4.3° compared to the initial value of 0.5°. We would therefore expect Eq. (14) to predict higher encounter and collision rates. We may adjust the results obtained from Eq. (14) by using

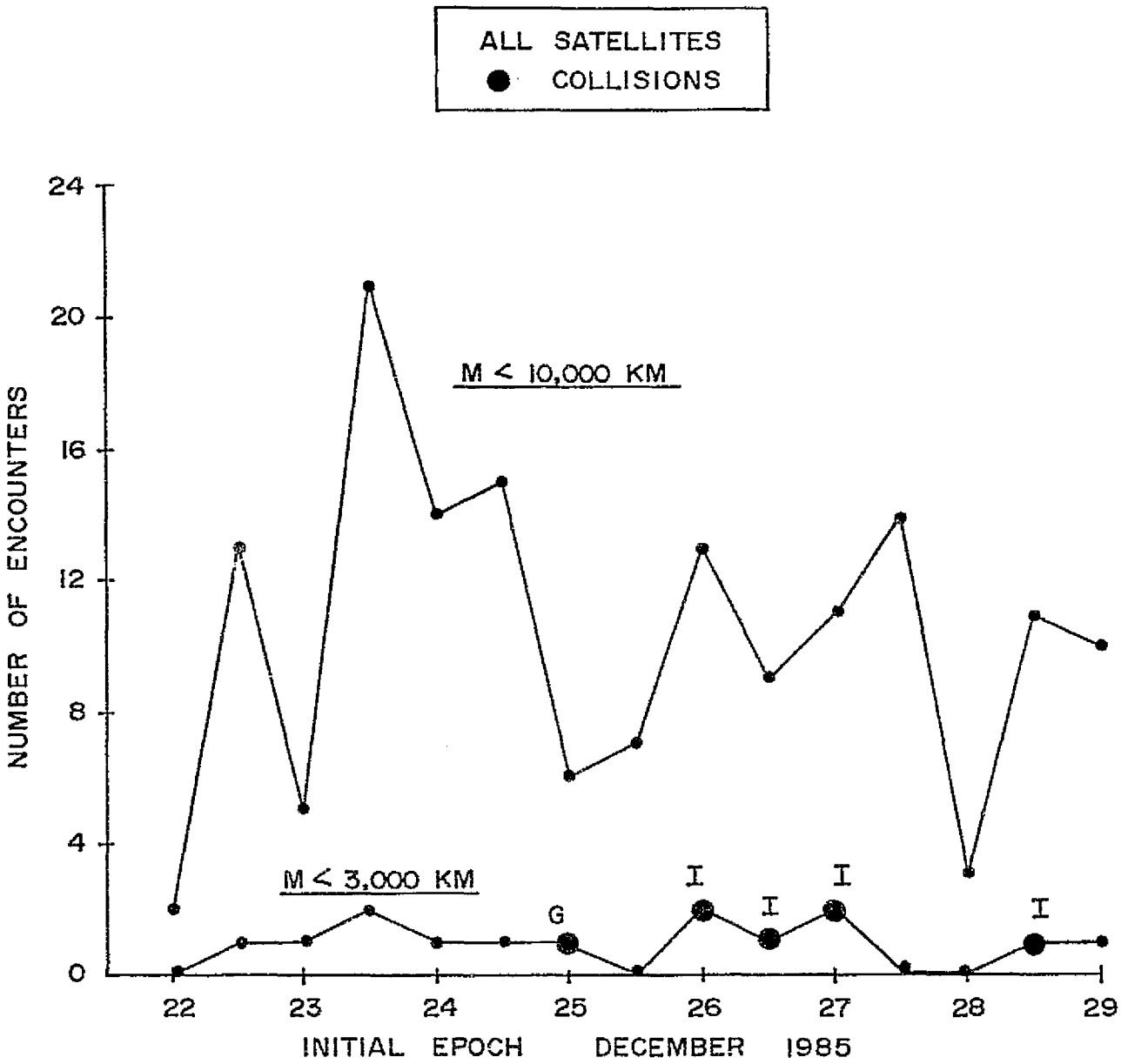

FIG. 7 VERY CLOSE ENCOUNTERS OVER 50^y LIFETIME

$R_p = 5R_J$, $P = 21.33^d$, $I = 0.5°$

average values for the elements (a, e, I). A simplified approximation of the average elements is one-half the sum of initial and final values; e.g., $\bar{I} = 2.4^{o}$. When this is done the predicted collision likelihood reduces to 0.25 which compares even more favorably with the numerical result of 0.33. To carry the validation test one step further, Fig. 8 compares analytical and numerical results for each satellite in terms of mean number of encounters over a range of miss distances. Agreement to within a factor of 2 is obtained. We conclude therefore that acceptable confidence may be placed in the numeral results of this study.

3.3 Summary of Parametric Data

Appendix A contains the tabulated statistical results for each of the 32 basic orbits. A graphical summary of this data is presented in Fig's. 9-12 for each of the four orbit classes and shown parametrically as a function of initial orbit inclination. Inclination is seen to be a major parameter influencing the number of close encounters and collision likelihood. Results are reasonably well correlated with the analytical prediction, i.e., the magnitude of collision likelihood is very significant at low inclination for the type of crossing orbits considered in this study. Inclinations of 0° - 10° are considerably more at risk than orbits above 10°, but collision likelihood cannot be ignored even for highly inclined orbits. The orbit class having a perijove distance at 5 R_J is most susceptible to close encounter and collision because all satellite orbits are intersected - particularly Io. Within this class the shorter period orbit is generally at greater risk because of the larger number of revolutions completed in 50 years time.

An overall summary of results is given by the collision record of Table 5. Of the 480 initial orbits, the total number of first collision occurrences is 81 or 17%. This is of course biased by the equatorial

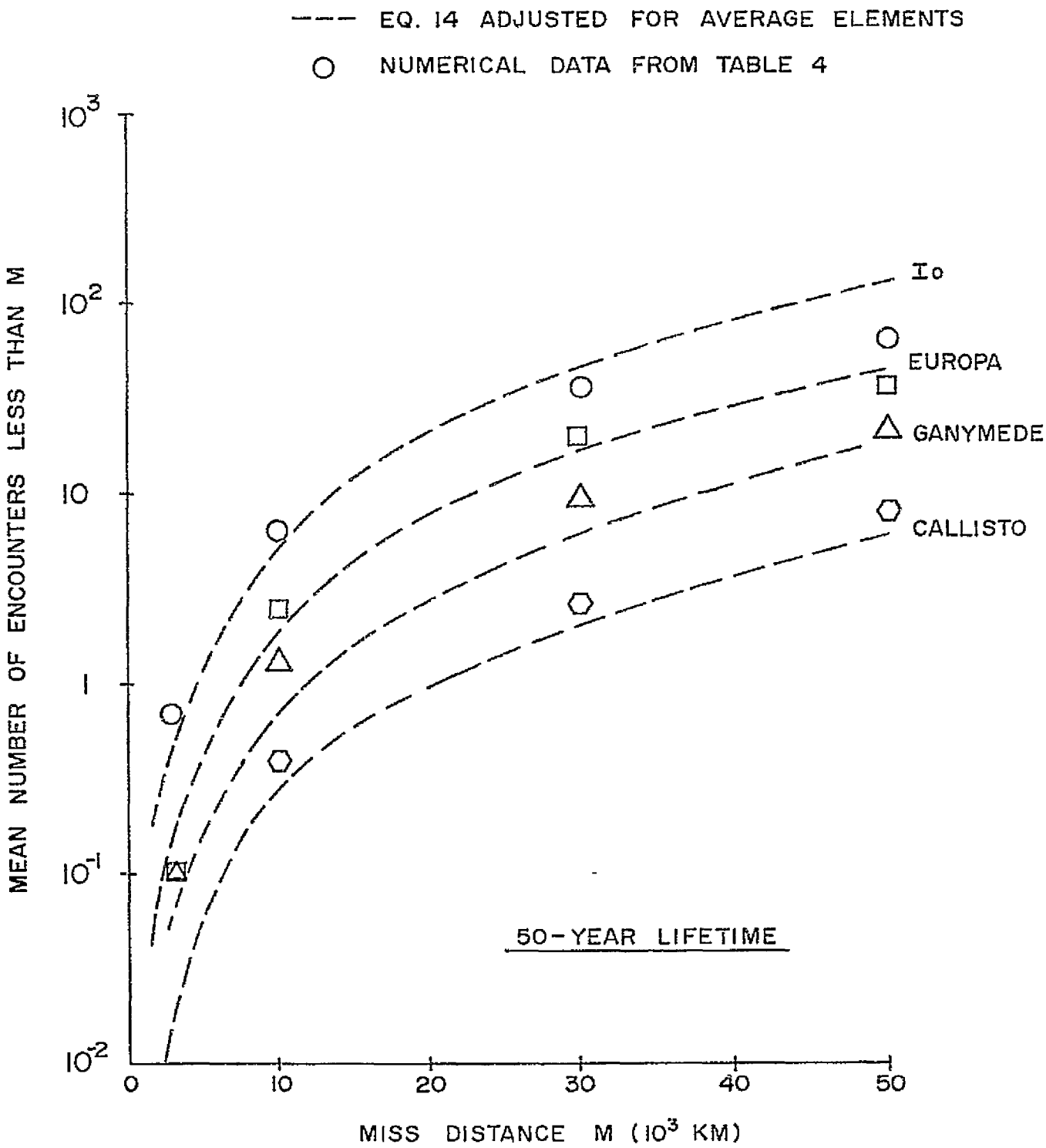

FIG. 8 COMPARISON OF NUMERICAL AND ANALYTICAL RESULTS

INITIAL ORBIT $R_p = 5R_J$, $P = 21.33^d$, $I = 0.5°$

TABLE 5 COLLISION RECORD

Nominal Orbit Lifetime = 50 years
Initial Epoch Samples/Case = 15
( ) = Total Collisions with Continuation

Number of First Collisions

Orbit Case	$i = 0^o$	$i = 0.5^o$	$i = 1^o$	$i = 5^o$	$i = 10^o$	$i = 30^o$	$i = 60^o$	$i = 90^o$
Perijove = 5 R_J Period = 21.33^d	14 (84)	5	2	4 (5)	2	1	1	1
5 R_J 60^d	14 (51)	4	2	0	0	0	0	0
11 R_J 21.33^d	13 (65)	2	2	2	0	0	0	0
11 R_J 60^d	6 (21)	1	1	2	0	1	1	0

Summary	Number of Initial Orbits	Number of First Collisions
Including Equatorial Orbits	480	81
Excluding Equatorial Orbits	420	34

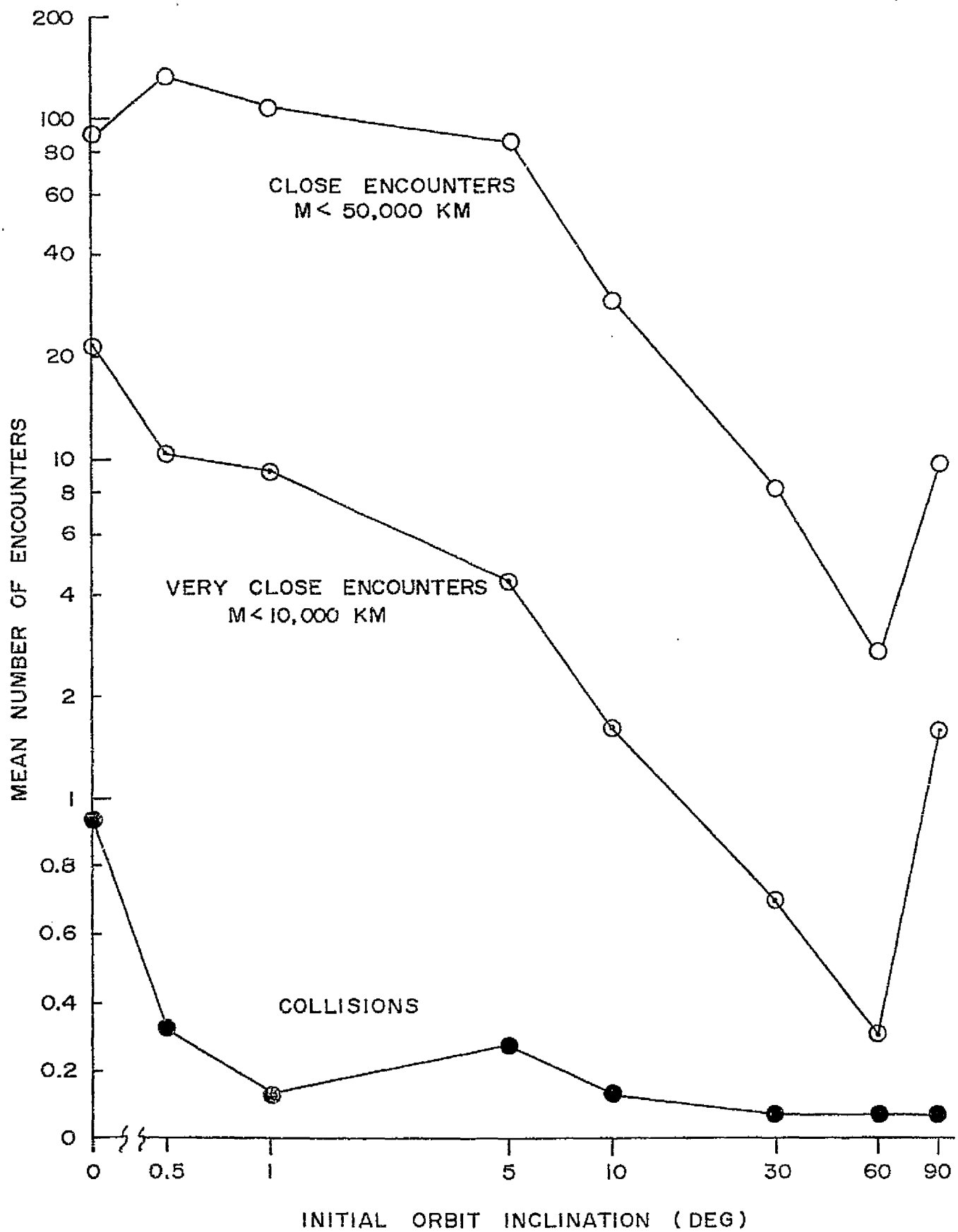

FIG. 9 EFFECT OF INCLINATION ON NUMBER OF ENCOUNTERS OVER 50^y LIFETIME FOR $R_p=5R_J$, $P=21.33^d$

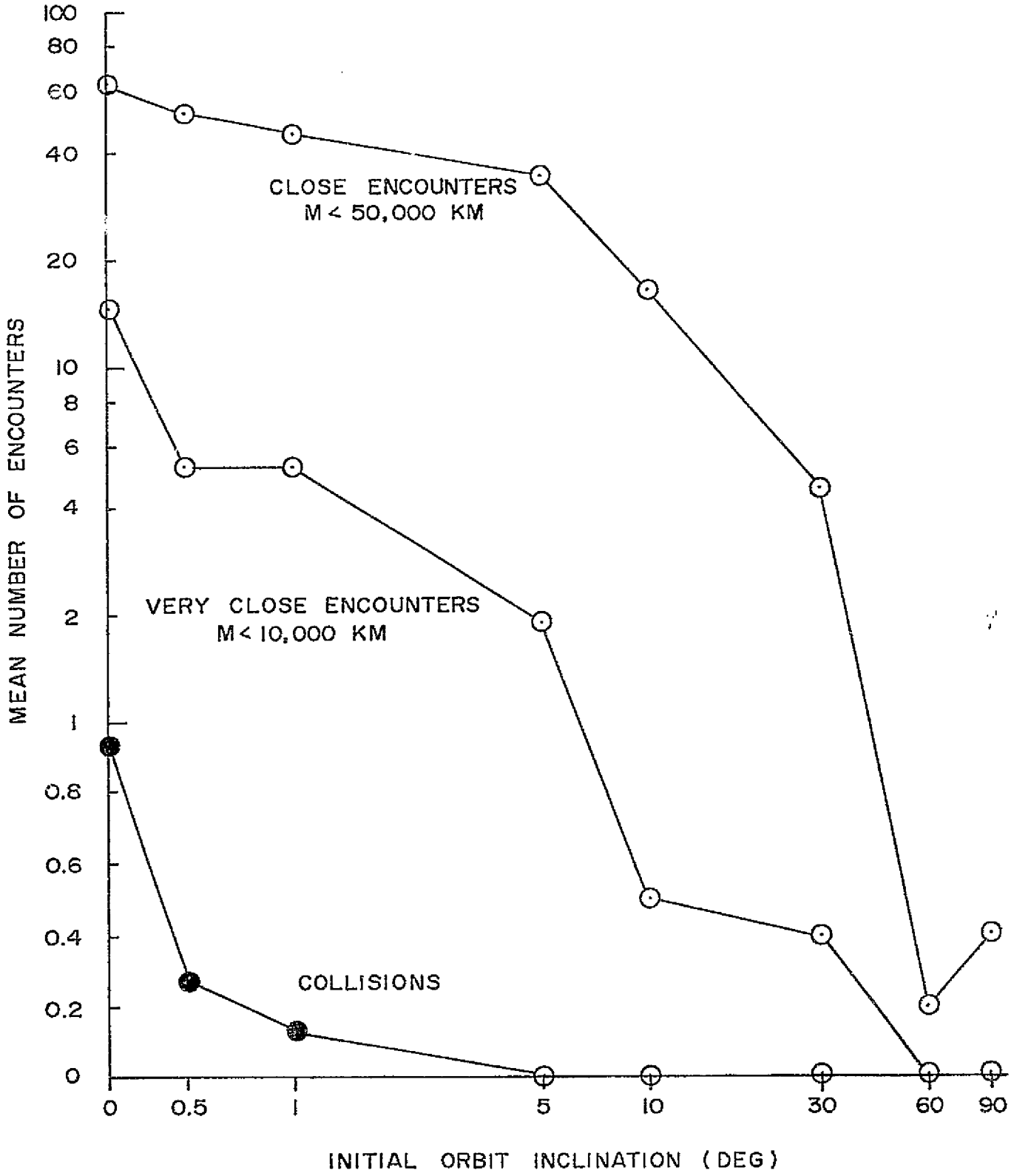

FIG. 10 EFFECT OF INCLINATION ON NUMBER OF ENCOUNTERS OVER 50^y LIFETIME FOR $R_p = 5R_J$, $P = 60^d$

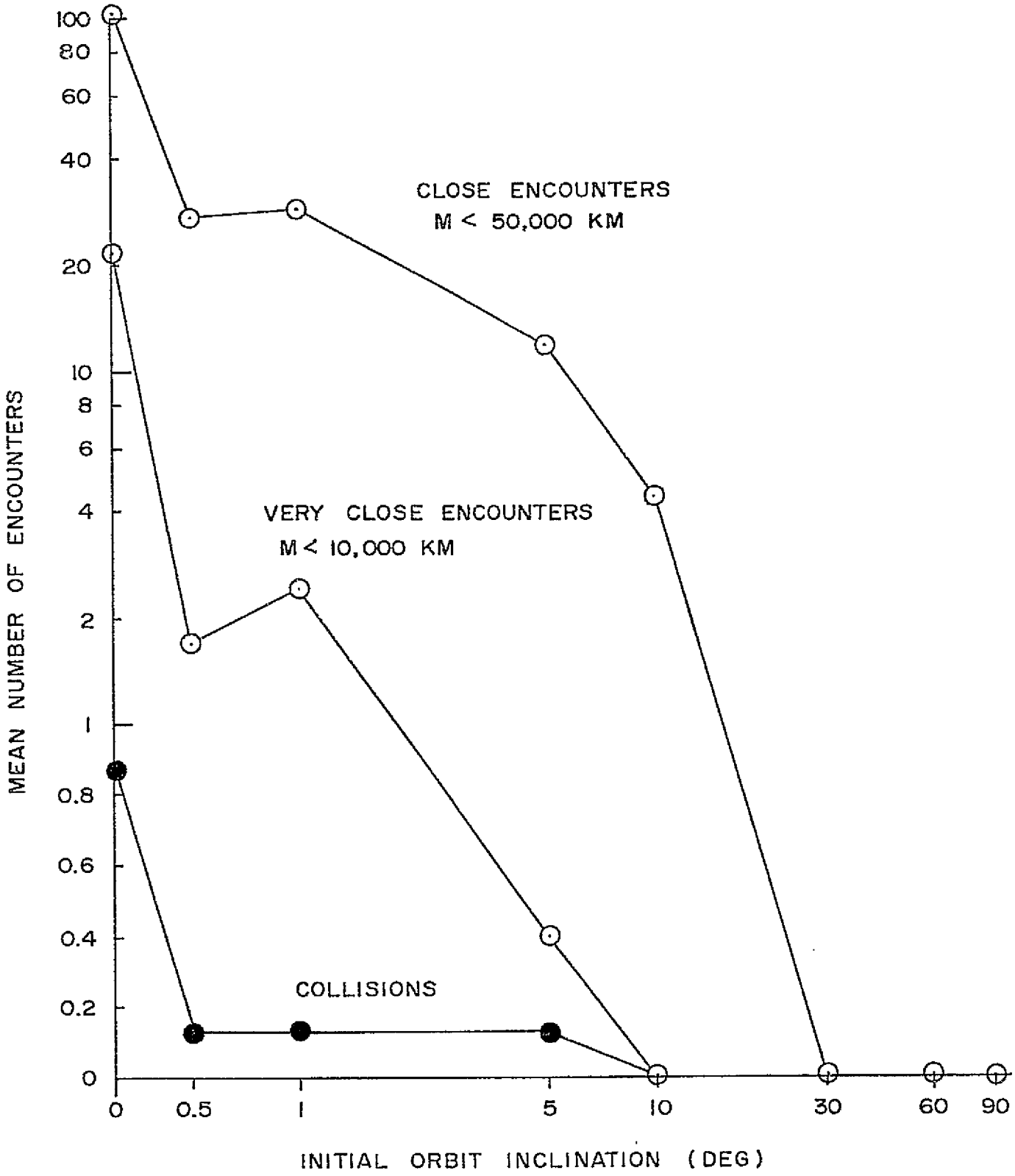

FIG. 11 EFFECT OF INCLINATION ON NUMBER OF ENCOUNTERS OVER 50^y LIFETIME FOR $R_p = 11 R_J$, $P = 21.33^d$

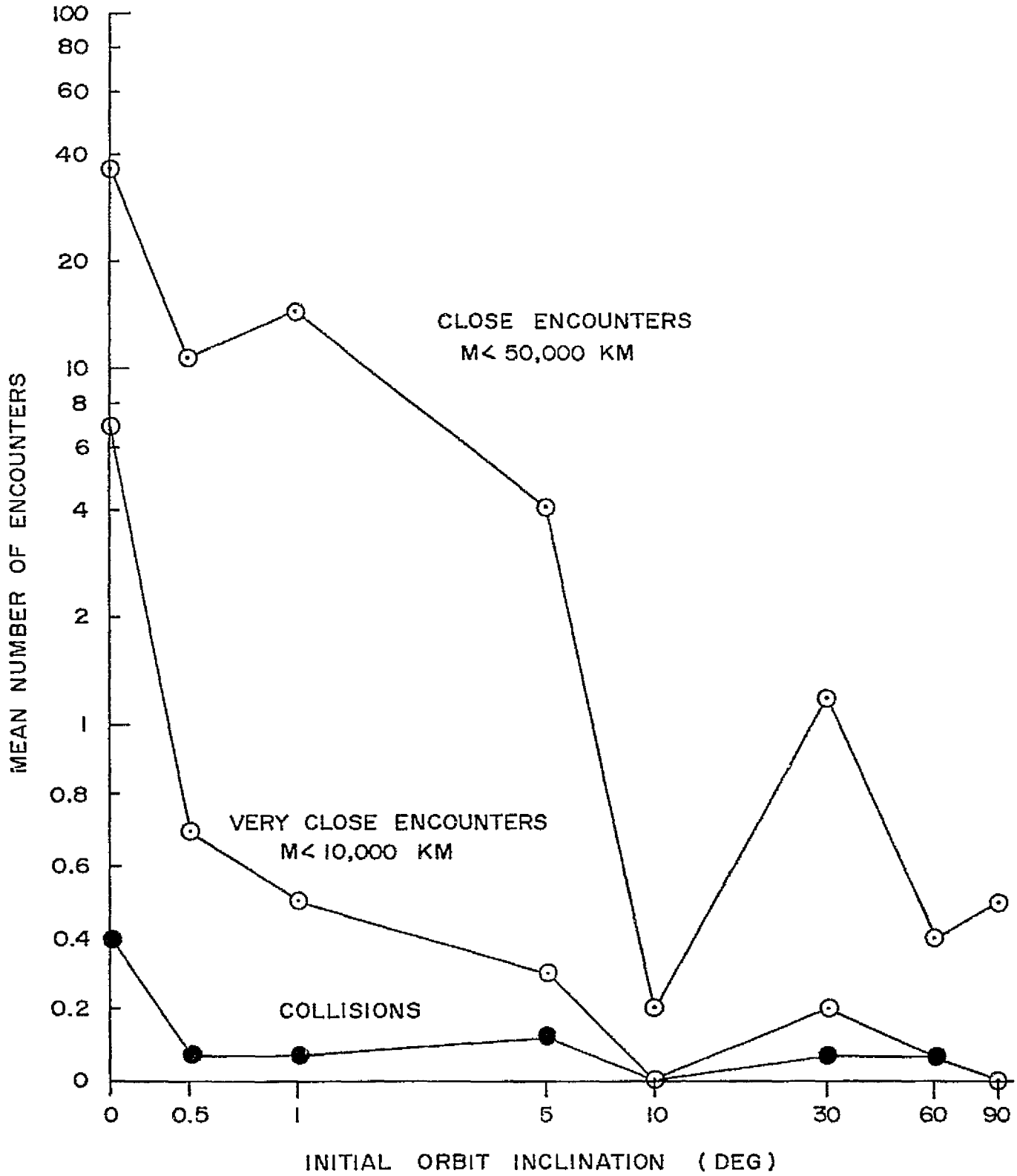

FIG. 12 EFFECT OF INCLINATION ON NUMBER OF ENCOUNTERS OVER 50^y LIFETIME FOR $R_p = 11 R_J$, $P = 60^d$

orbit cases; if these are excluded then the first collisions number 34 of 420 orbits, or 8%. The equatorial orbits, representing a worst case upper bound, are physically unreasonable in that the Galilean satellites are not exactly in the equatorial plane nor would a spacecraft be placed exactly in this plane. The uniqueness of $I = 0^{\circ}$ is seen by the total number of collisions with continuation allowed. For example, taking the 5 R_J, 21.3^d orbit, there are an average of 5 subsequent satellite impacts following the first collision. This does not happen when $I \neq 0$.

The final illustration, Fig. 13, summarizes the collision likelihood and number of close encounters taken as an average over all four orbit classes. Graphed as a function of orbit inclination on linear scale, it clearly indicates the rapid decrease between 0° and 10° followed by a leveling off trend. For the types of crossing orbits investigated here, the spacecraft should be placed in an orbit of at least 30° inclination to ensure a 50-year lifetime probability approaching 97%.

3.4 Orbit Design for Collision Avoidance

If planet and satellite quarantine constraints are imposed on a Jupiter orbiter mission, a lifetime probability of 97-99% may not be sufficient. We have restricted this study to initial conditions representative of operational-type orbits. Results have confirmed our a priori expectations that such orbits cannot be assured of extremely high lifetime probability. However, there are orbits which may be designed specifically for collision avoidance. Several possibilities are listed below.

(1) Hyperbolic escape trajectory

(2) Circular orbit at least 1 R_J removed from any satellite orbital distance

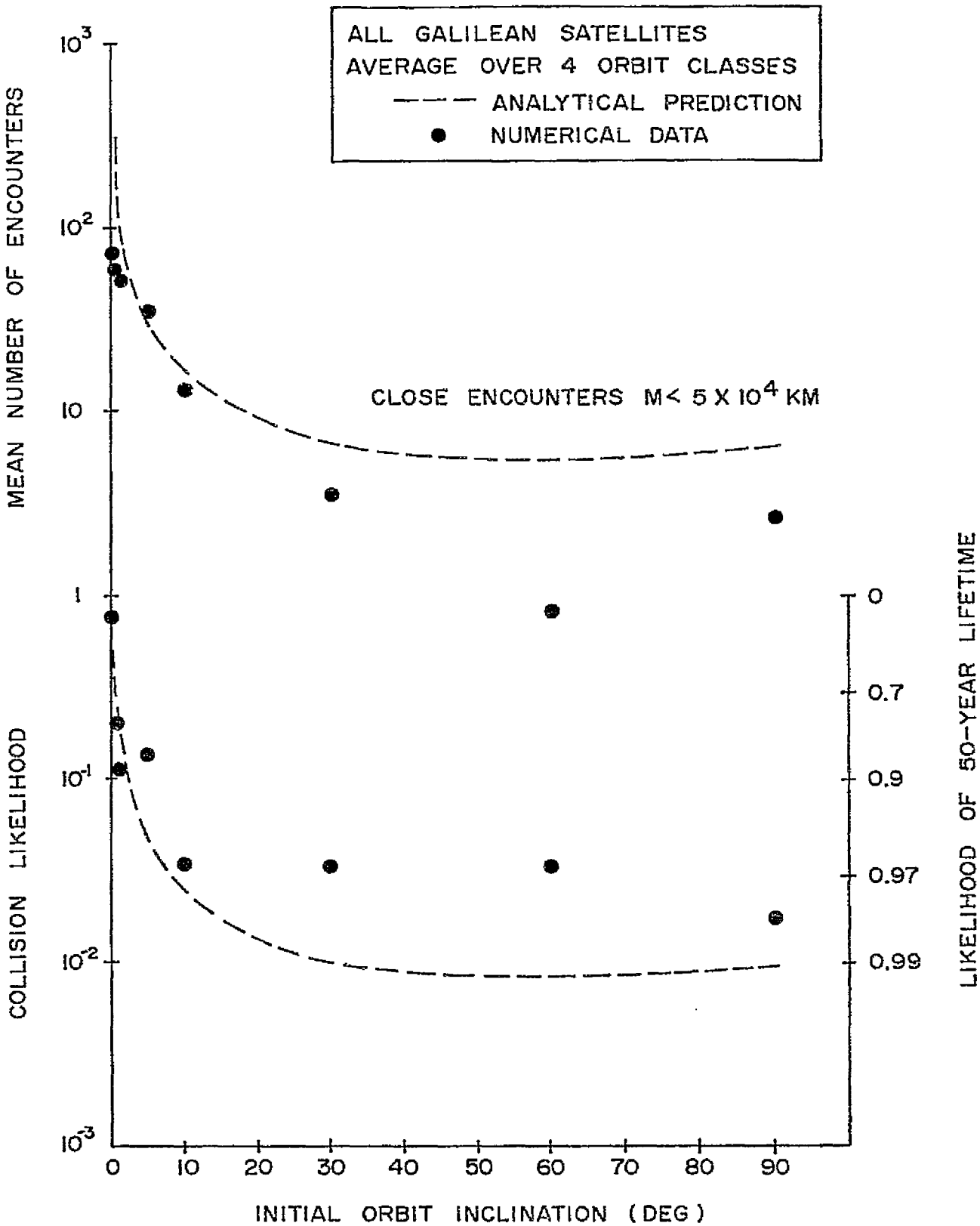

FIG. 13 LIKELIHOOD OF CLOSE ENCOUNTERS AND COLLISION WITH THE GALILEAN SATELLITES FOR A 50-YEAR JUPITER ORBITER LIFETIME

(3) "Critical inclination" orbit ($I \approx 63^{\circ}$)

(4) Callisto - resonant orbit beyond Ganymede

The first suggestion is perhaps simplest in concept in that a ΔV maneuver of sufficient magnitude would cause the spacecraft to escape the Jovian system and thereby assure collision avoidance. This might be achieved for a maneuver of a few hundred meters per second possibly assisted by a final, controlled, close swingby of one of the Galilean satellites. A circular orbit should be stable for 50 years or more even in the equatorial plane. Again, a ΔV maneuver combined with several satellite gravity-assists could achieve a circular orbit. The third possibility was suggested by Uphoff[3]. At an inclination near 63° the effect of Jupiter's oblateness on the argument of perijove is very small. Hence, by placing perijove in the equatorial plane at a distance within Io's orbit (e.g. $3 R_J$), and by setting the orbital period short enough so as to avoid significant solar perturbations on perijove distance, the result should be a fairly stable collision avoidance orbit. The last suggestion has been proposed for study by T. Heppenheimer. Perijove distance would be placed between Ganymede and Callisto (e.g. $20 R_J$) and the orbital period would be a multiple of Callisto's period. The initial time phasing would require the spacecraft and Callisto to be in superior conjunction (180° apart on opposite sides of Jupiter) at the initial perijove epoch. Acceptability of this approach depends on how accurate the orbit period can be set to resonance, and also on the strength of perturbation effects due to Jupiter oblateness and solar gravity. The question as to whether the collision avoidance orbits described above are compatible with the operational sequence and maneuver budget of the nominal mission design is beyond the scope of this study and left for more detailed mission analysis.

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2. Hyde, J. R. et al, "Mariner Jupiter Orbiter Study Report - Vol. II, Science Objectives and Mission Analysis", Jet Propulsion Laboratory, In Press.

3. Uphoff, C., "The Long-Term Motion of Artificial Jovian Satellites", Analytical Mechanics Associates, Inc. Report No. 72-52, November 1972.

4. Wetherill, G.W., "Collisions in the Asteroid Belt", Journal of Geophysical Research, Vol. 72, No. 9, May 1967, pp. 2429-2444.

APPENDIX A

Galilean Satellite Encounter Statistics

GALILEAN SATELLITE ENCOUNTER STATISTICS

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 5.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 21.330	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 0.000	DEC. 22-29, 1985	
NODE(DEG)	= 182.300		
ARG(DEG)	= 0.000		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	6.1	12.0	0.0	48.5
PERIOD(DAYS)	144.5	257.3	1.3	945.4
INCLINATION(DEG)	0.0	0.0	0.0	0.0
NODE(DEG)	0.4	6.5	-8.6	21.8
ARGUMENT(DEG)	190.2	103.4	25.3	357.9
REVOLUTIONS	564.3	691.6	59.0	2748.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.391	0.193	0.105	0.904
< 10,000 KM	1.118	0.457	0.637	2.486
< 30,000 KM	2.946	0.833	2.070	4.420
< 50,000 KM	4.371	0.980	2.934	6.077
< 100,000 KM	8.673	1.949	5.751	11.464

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL	
					MEAN	SD
< 3000 KM	2.6	2.8	1.7	0.6	7.7	8.9
< 10,000 KM	8.9	6.3	4.9	1.4	21.5	22.3
< 30,000 KM	26.0	17.1	11.7	3.7	58.5	65.1
< 50,000 KM	40.5	25.1	17.9	5.9	89.5	104.7
< 100,000 KM	81.7	50.3	32.1	12.0	176.1	205.9

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 5 EUROPA = 4 GANYMEDE = 3 CALLISTO = 2 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.93

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OF POOR QUALITY

GALILEAN SATELLITE ENCOUNTER STATISTICS

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 5.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 21.330	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 0.500	DEC. 22-29, 1985	
NODE(DEG)	= 182.300		
ARG(DEG)	= 0.000		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	5.0	1.4	2.9	7.9
PERIOD(DAYS)	22.3	14.7	5.8	65.3
INCLINATION(DEG)	4.3	2.8	1.4	12.6
NODE(DEG)	162.9	104.0	31.4	316.2
ARGUMENT(DEG)	178.6	126.4	11.5	351.5
REVOLUTIONS	1058.6	378.6	600.0	1737.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.023	0.021	0.000	0.083
< 10,000 KM	0.255	0.137	0.068	0.542
< 30,000 KM	1.673	0.496	0.921	2.875
< 50,000 KM	3.291	0.659	1.713	4.208
< 100,000 KM	8.135	1.257	4.706	9.642

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL	
					MEAN	SD
< 3000 KM	0.7	0.1	0.1	0.0	0.9	0.7
< 10,000 KM	6.1	2.4	1.3	0.4	10.3	5.1
< 30,000 KM	36.1	18.5	9.4	2.7	66.7	19.4
< 50,000 KM	66.0	39.2	20.3	8.2	133.7	39.0
< 100,000 KM	156.5	90.3	55.8	29.0	331.7	90.7

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 4 EUROPA = 0 GANYMEDE = 1 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.33

GALILEAN SATELLITE ENCOUNTER STATISTICS

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	=	5.000
PERIOD(DAYS)	=	21.330
INCLINATION(DEG)	=	1.000
NODE(DEG)	=	182.300
ARG(DEG)	=	0.000

NUMBER OF EPOCHS = 15
EPOCH INTERVAL = 7 DAYS
DEC. 22-29, 1985

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	5.5	1.8	3.9	10.7
PERIOD(DAYS)	36.1	30.3	8.2	111.7
INCLINATION(DEG)	4.7	5.9	0.3	25.3
NODE(DEG)	231.2	98.1	58.3	352.2
ARGUMENT(DEG)	215.2	88.1	36.7	356.1
REVOLUTIONS	845.0	451.0	368.0	2029.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.017	0.025	0.000	0.068
< 10,000 KM	0.318	0.167	0.114	0.669
< 30,000 KM	1.967	0.611	0.554	2.759
< 50,000 KM	3.660	0.872	1.244	4.891
< 100,000 KM	8.361	1.522	3.450	9.908

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL MEAN	TOTAL SD
< 3000 KM	0.3	0.1	0.0	0.1	0.5	0.6
< 10,000 KM	5.9	2.0	0.9	0.3	9.1	3.5
< 30,000 KM	31.9	15.5	8.2	2.7	58.3	19.7
< 50,000 KM	55.9	32.4	17.7	6.0	111.9	40.7
< 100,000 KM	128.0	66.8	45.5	22.9	263.2	104.5

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 1 EUROPA = 0 GANYMEDE = 0 CALLISTO = 1 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.13

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GALILEAN SATELLITE ENCOUNTER STATISTIC

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	=	5.000
PERIOD(DAYS)	=	21.330
INCLINATION(DEG)	=	3.000
NODE(DEG)	=	158.100
ARG(DEG)	=	24.000

NUMBER OF EPOCHS = 15
EPOCH INTERVAL = 7 DAYS
DEC. 22-29, 1985

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	5.3	0.6	4.5	6.5
PERIOD(DAYS)	22.2	15.8	9.3	75.6
INCLINATION(DEG)	7.8	6.9	1.4	31.4
NODE(DEG)	165.2	77.5	42.4	268.8
ARGUMENT(DEG)	170.3	111.8	3.2	356.3
REVOLUTIONS	934.8	195.9	581.0	1341.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.020	0.035	0.000	0.110
< 10,000 KM	0.118	0.122	0.000	0.497
< 30,000 KM	0.911	0.462	0.483	2.099
< 50,000 KM	2.293	0.683	1.275	3.702
< 100,000 KM	7.083	1.084	5.340	8.650

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL MEAN	TOTAL SD
< 3000 KM	0.5	0.2	0.0	0.1	0.7	1.3
< 10,000 KM	2.8	1.0	0.4	0.2	4.4	4.6
< 30,000 KM	20.5	9.1	3.4	1.5	34.5	22.1
< 50,000 KM	50.9	23.1	8.5	3.4	85.9	35.8
< 100,000 KM	140.1	76.2	36.1	11.9	264.2	71.8

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 1 EUROPA = 2 GANYMEDE = 0 CALLISTO = 1 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.27

GALILEAN SATELLITE ENCOUNTER STATISTICS

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 5.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 21.330	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 10.000	DEC. 22-29, 1985	
NODE(DEG)	= 184.900		
ARG(DEG)	= 357.400		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	4.9	1.4	0.0	6.4
PERIOD(DAYS)	154.7	505.7	16.6	1982.5
INCLINATION(DEG)	11.5	1.3	7.6	13.0
NODE(DEG)	339.7	72.7	84.6	380.4
ARGUMENT(DEG)	244.0	35.7	143.6	296.2
REVOLUTIONS	808.2	119.7	483.0	1000.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.006	0.016	0.000	0.052
< 10,000 KM	0.049	0.028	0.000	0.090
< 30,000 KM	0.345	0.086	0.207	0.475
< 50,000 KM	0.893	0.145	0.518	1.075
< 100,000 KM	4.995	0.516	4.362	5.961

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL MEAN	TOTAL SD
< 3000 KM	0.1	0.0	0.0	0.0	0.1	0.4
< 10,000 KM	1.3	0.1	0.1	0.1	1.6	1.0
< 30,000 KM	7.8	2.4	0.5	0.7	11.4	3.9
< 50,000 KM	19.1	6.5	2.2	1.4	29.2	6.9
< 100,000 KM	114.3	31.4	11.0	4.2	160.9	26.5

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 2 EUROPA = 0 GANYMEDE = 0 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.13

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GALILEAN SATELLITE ENCOUNTER STATISTIC

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 5.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 21.330	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 30.000	DEC. 22-29, 1985	
NODE(DEG)	= 200.300		
ARG(DEG)	= 342.800		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	5.2	0.7	4.5	7.5
PERIOD(DAYS)	24.0	8.7	15.8	53.1
INCLINATION(DEG)	29.6	1.6	26.2	32.4
NODE(DEG)	107.0	11.4	88.7	140.5
ARGUMENT(DEG)	109.4	12.0	76.7	132.6
REVOLUTIONS	828.3	68.3	712.0	941.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.002	0.009	0.000	0.035
< 10,000 KM	0.022	0.024	0.000	0.070
< 30,000 KM	0.113	0.056	0.000	0.207
< 50,000 KM	0.251	0.089	0.087	0.395
< 100,000 KM	1.662	0.525	0.233	2.138

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL MEAN	TOTAL SD
< 3000 KM	0.0	0.1	0.0	0.0	0.1	0.3
< 10,000 KM	0.4	0.2	0.1	0.0	0.7	0.8
< 30,000 KM	2.1	1.2	0.3	0.1	3.7	1.9
< 50,000 KM	3.9	3.6	0.5	0.3	8.3	3.0
< 100,000 KM	35.9	13.8	3.5	1.5	54.6	16.9

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 0 EUROPA = 1 GANYMEDE = 0 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.07

GALILEAN SATELLITE ENCOUNTER STATISTICS

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 5.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 21.330	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 60.000	DEC. 22-29, 1985	
NODE(DEG)	= 204.600		
ARG(DEG)	= 339.600		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	6.0	0.3	5.8	6.9
PERIOD(DAYS)	26.5	12.2	16.6	63.0
INCLINATION(DEG)	62.2	0.7	61.6	64.1
NODE(DEG)	168.5	4.7	164.1	177.2
ARGUMENT(DEG)	352.7	2.3	350.5	360.4
REVOLUTIONS	857.9	56.4	760.0	947.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.002	0.008	0.000	0.033
< 10,000 KM	0.010	0.020	0.000	0.066
< 30,000 KM	0.031	0.044	0.000	0.132
< 50,000 KM	0.083	0.069	0.000	0.263
< 100,000 KM	1.155	0.354	0.227	1.686

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL	
					MEAN	SD
< 3000 KM	0.1	0.0	0.0	0.0	0.1	0.3
< 10,000 KM	0.3	0.0	0.0	0.0	0.3	0.6
< 30,000 KM	1.0	0.0	0.0	0.0	1.0	1.4
< 50,000 KM	2.7	0.0	0.0	0.0	2.7	2.1
< 100,000 KM	39.7	0.0	0.0	0.0	39.7	13.2

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 1 EUROPA = 0 GANYMEDE = 0 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.07

GALILEAN SATELLITE ENCOUNTER STATISTIC

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 5.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 21.330	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 90.000	DEC. 22-29, 1985	
NODE(DEG)	= 206.800		
ARG(DEG)	= 339.000		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	6.5	0.5	5.4	7.4
PERIOD(DAYS)	17.7	3.2	10.5	23.0
INCLINATION(DEG)	90.6	1.3	89.0	94.3
NODE(DEG)	208.6	2.3	205.0	215.3
ARGUMENT(DEG)	306.0	12.2	265.4	315.6
REVOLUTIONS	988.5	144.6	820.0	1426.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.006	0.013	0.000	0.035
< 10,000 KM	0.040	0.033	0.000	0.111
< 30,000 KM	0.109	0.062	0.048	0.298
< 50,000 KM	0.240	0.096	0.091	0.438
< 100,000 KM	0.789	0.218	0.396	1.280

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL MEAN	TOTAL SD
< 3000 KM	0.3	0.0	0.0	0.0	0.3	0.6
< 10,000 KM	1.5	0.0	0.1	0.1	1.6	1.4
< 30,000 KM	3.5	0.5	0.1	0.4	4.5	3.7
< 50,000 KM	7.4	0.7	0.2	1.5	9.8	5.3
< 100,000 KM	24.6	1.7	0.5	5.1	31.9	13.5

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 1 EUROPA = 0 GANYMEDE = 0 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.07

GALILEAN SATELLITE ENCOUNTER STATISTICS

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 5.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 60.000	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 0.000	DEC. 22-29, 1985	
NODE(DEG)	= 182.300		
ARG(DEG)	= 0.000		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	3.7	3.0	0.0	10.4
PERIOD(DAYS)	133.4	148.6	4.8	412.0
INCLINATION(DEG)	0.0	0.0	0.0	0.0
NODE(DEG)	-0.1	0.2	-0.6	0.3
ARGUMENT(DEG)	208.1	73.2	36.6	348.1
REVOLUTIONS	434.3	489.9	7.0	1777.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.538	0.881	0.000	3.571
< 10,000 KM	1.165	0.822	0.338	3.571
< 30,000 KM	3.039	1.368	1.471	7.143
< 50,000 KM	4.382	1.405	1.681	7.143
< 100,000 KM	8.001	1.423	4.615	10.174

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL MEAN	TOTAL SD
< 3000 KM	2.7	0.9	0.5	0.5	4.5	5.3
< 10,000 KM	7.5	3.9	2.0	1.1	14.5	13.8
< 30,000 KM	20.3	10.9	6.0	3.8	41.0	37.4
< 50,000 KM	29.5	16.9	9.6	5.9	61.9	55.1
< 100,000 KM	58.7	33.8	19.9	10.5	122.9	111.7

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 9 EUROPA = 1 GANYMEDE = 2 CALLISTO = 2 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.93

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GALILEAN SATELLITE ENCOUNTER STATISTIC

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 5.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 60.000	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 0.500	DEC. 22-29, 1985	
NODE(DEG)	= 182.300		
ARG(DEG)	= 0.000		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	4.5	1.4	0.4	5.9
PERIOD(DAYS)	72.0	48.7	21.5	224.5
INCLINATION(DEG)	2.6	2.0	0.5	6.9
NODE(DEG)	115.8	104.5	3.2	337.5
ARGUMENT(DEG)	174.1	76.5	34.8	319.7
REVOLUTIONS	333.5	155.3	93.0	790.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.042	0.072	0.000	0.213
< 10,000 KM	0.422	0.153	0.127	0.633
< 30,000 KM	2.125	0.459	1.116	2.769
< 50,000 KM	3.781	0.747	1.897	4.747
< 100,000 KM	8.416	0.962	6.473	9.814

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL MEAN	TOTAL SD
< 3000 KM	0.3	0.1	0.0	0.1	0.5	0.7
< 10,000 KM	2.8	1.4	0.6	0.4	5.2	2.2
< 30,000 KM	13.8	8.2	3.9	2.2	28.1	12.2
< 50,000 KM	23.2	15.7	8.4	4.3	51.6	25.9
< 100,000 KM	53.0	32.1	18.3	10.7	114.0	59.2

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 2 EUROPA = 1 GANYMEDE = 0 CALLISTO = 0 JUPITER = 1

OVERALL COLLISION LIKELIHOOD = 0.27

GALILEAN SATELLITE ENCOUNTER STATISTICS

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	=	5.000
PERIOD(DAYS)	=	60.000
INCLINATION(DEG)	=	1.000
NODE(DEG)	=	182.300
ARG(DEG)	=	0.000

NUMBER OF EPOCHS = 15
EPOCH INTERVAL = 7 DAYS
DEC. 22-29, 1985

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	4.5	0.6	3.2	5.2
PERIOD(DAYS)	73.1	52.3	15.4	153.3
INCLINATION(DEG)	2.6	1.9	1.0	8.1
NODE(DEG)	184.1	111.9	14.2	355.9
ARGUMENT(DEG)	200.3	105.3	34.8	356.2
REVOLUTIONS	335.3	141.7	149.0	587.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.012	0.027	0.000	0.089
< 10,000 KM	0.367	0.209	0.128	0.714
< 30,000 KM	1.761	0.560	0.893	2.768
< 50,000 KM	3.290	0.667	1.913	4.464
< 100,000 KM	8.319	0.867	6.757	9.467

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL	
					MEAN	SD
< 3000 KM	0.1	0.1	0.0	0.0	0.2	0.4
< 10,000 KM	3.3	1.0	0.7	0.2	5.2	3.7
< 30,000 KM	13.1	7.9	2.9	1.0	24.9	14.0
< 50,000 KM	21.1	14.2	7.2	3.1	45.6	23.0
< 100,000 KM	53.3	32.0	18.3	10.1	113.8	53.7

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 2 EUROPA = 0 GANYMEDE = 0 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.13

GALILEAN SATELLITE ENCOUNTER STATISTIC

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 5.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 60.000	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 5.000	DEC. 22-29, 1985	
NODE(DEG)	= 158.100		
ARG(DEG)	= 24.000		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	4.4	0.7	2.6	5.3
PERIOD(DAYS)	69.1	28.5	31.5	127.1
INCLINATION(DEG)	6.8	6.1	2.5	26.2
NODE(DEG)	219.5	144.6	13.4	354.6
ARGUMENT(DEG)	236.0	47.4	170.4	312.6
REVOLUTIONS	331.9	110.3	198.0	568.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.000	0.000	0.000	0.000
< 10,000 KM	0.137	0.081	0.000	0.320
< 30,000 KM	0.913	0.339	0.474	1.563
< 50,000 KM	2.464	0.621	1.303	3.627
< 100,000 KM	7.249	1.016	4.976	8.643

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL	
					MEAN	SD
< 3000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 10,000 KM	1.1	0.4	0.3	0.1	1.9	1.3
< 30,000 KM	8.4	2.9	0.9	0.6	12.7	7.2
< 50,000 KM	21.3	9.5	2.5	0.9	34.3	17.5
< 100,000 KM	54.1	26.9	13.7	4.3	99.1	43.1

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 0 EUROPA = 0 GANYMEDE = 0 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.00

GALILEAN SATELLITE ENCOUNTER STATISTICS

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 5.000	NUMBER OF EPOCHS = 15
PERIOD(DAYS)	= 60.000	EPOCH INTERVAL = 7 DAYS
INCLINATION(DEG)	= 10.000	DEC. 22-29, 1985
NODE(DEG)	= 184.900	
ARG(DEG)	= 357.400	

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	4.5	0.4	3.4	4.9
PERIOD(DAYS)	67.0	31.1	26.4	145.0
INCLINATION(DEG)	10.1	3.2	6.5	16.8
NODE(DEG)	56.2	8.5	43.8	72.2
ARGUMENT(DEG)	155.8	8.0	142.4	173.4
REVOLUTIONS	310.7	74.7	232.0	472.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.000	0.000	0.000	0.000
< 10,000 KM	0.032	0.048	0.000	0.111
< 30,000 KM	0.511	0.216	0.262	0.920
< 50,000 KM	1.297	0.313	0.542	1.815
< 100,000 KM	5.400	0.645	4.203	6.354

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL MEAN	TOTAL SD
< 3000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 10,000 KM	0.3	0.2	0.0	0.0	0.5	0.7
< 30,000 KM	4.3	1.5	0.5	0.2	6.5	3.4
< 50,000 KM	11.7	3.1	1.1	0.5	16.3	5.9
< 100,000 KM	45.9	14.1	6.1	2.0	68.0	22.0

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 0 EUROPA = 0 GANYMEDE = 0 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.00

ORIGINAL PAGE IS
OF POOR QUALITY

GALILEAN SATELLITE ENCOUNTER STATISTIC

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 5.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 60.000	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 30.000	DEC. 22-29, 1985	
NODE(DEG)	= 200.300		
ARG(DEG)	= 342.800		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	6.7	1.3	5.2	9.1
PERIOD(DAYS)	94.4	27.6	42.0	135.1
INCLINATION(DEG)	47.2	7.9	33.7	58.1
NODE(DEG)	207.0	8.4	189.6	215.7
ARGUMENT(DEG)	357.6	7.2	351.5	372.6
REVOLUTIONS	258.4	46.7	208.0	356.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.000	0.000	0.000	0.000
< 10,000 KM	0.040	0.063	0.000	0.196
< 30,000 KM	0.147	0.120	0.000	0.294
< 50,000 KM	0.420	0.190	0.118	0.937
< 100,000 KM	1.892	0.500	0.948	2.738

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL MEAN	TOTAL SD
< 3000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 10,000 KM	0.3	0.1	0.0	0.0	0.4	0.6
< 30,000 KM	1.5	0 1	0.0	0.0	1.6	1.4
< 50,000 KM	4.		0.0	0.0	4.5	2.8
< 100,000 KM	19		0.0	0.0	19.7	7.0

FIRST COLLISION R[illegible]D (NUMBER OF SAMPLES)

IO = 0 EUROPA = 0 GANYMEDE = 0 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.00

GALILEAN SATELLITE ENCOUNTER STATISTICS

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 5.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 60.000	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 60.000	DEC. 22-29, 1985	
NODE(DEG)	= 204.600		
ARG(DEG)	= 339.600		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	13.7	0.5	12.5	14.5
PERIOD(DAYS)	78.2	6.4	67.8	87.7
INCLINATION(DEG)	74.0	0.5	73.3	74.9
NODE(DEG)	205.1	1.1	203.1	206.6
ARGUMENT(DEG)	354.7	0.8	353.2	355.7
REVOLUTIONS	271.5	13.9	252.0	298.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.000	0.000	0.000	0.000
< 10,000 KM	0.000	0.000	0.000	0.000
< 30,000 KM	0.006	0.024	0.000	0.093
< 50,000 KM	0.018	0.037	0.000	0.093
< 100,000 KM	0.129	0.105	0.000	0.298

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL MEAN	TOTAL SD
< 3000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 10,000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 30,000 KM	0.0	0.1	0.0	0.0	0.1	0.3
< 50,000 KM	0.1	0.1	0.0	0.0	0.2	0.4
< 100,000 KM	0.8	0.5	0.1	0.0	1.4	1.1

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 0 EUROPA = 0 GANYMEDE = 0 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.00

GALILEAN SATELLITE ENCOUNTER STATISTICS

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 5.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 60.000	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 90.000	DEC. 22-29, 1985	
NODE(DEG)	= 206.800		
ARG(DEG)	= 339.000		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	16.6	0.5	15.4	17.9
PERIOD(DAYS)	81.3	8.9	61.4	97.8
INCLINATION(DEG)	92.6	0.3	91.9	93.0
NODE(DEG)	205.8	0.6	204.9	206.8
ARGUMENT(DEG)	355.1	2.6	352.6	361.1
REVOLUTIONS	276.5	12.9	254.0	297.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.000	0.000	0.000	0.000
< 10,000 KM	0.000	0.000	0.000	0.000
< 30,000 KM	0.031	0.059	0.000	0.197
< 50,000 KM	0.038	0.061	0.000	0.197
< 100,000 KM	0.151	0.080	0.000	0.261

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL MEAN	TOTAL SD
< 3000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 10,000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 30,000 KM	0.1	0.2	0.1	0.0	0.3	0.6
< 50,000 KM	0.1	0.3	0.1	0.0	0.4	0.6
< 100,000 KM	0.5	0.8	0.3	0.0	1.7	0.9

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 0 EUROPA = 0 GANYMEDE = 0 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.00

GALILEAN SATELLITE ENCOUNTER STATISTICS

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 11.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 21.330	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 0.000	DEC. 22-29, 1985	
NODE(DEG)	= 171.800		
ARG(DEG)	= 0.000		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	7.7	8.8	0.0	33.5
PERIOD(DAYS)	113.8	194.3	0.9	602.7
INCLINATION(DEG)	0.0	0.0	0.0	0.0
NODE(DEG)	0.2	0.9	-0.8	3.4
ARGUMENT(DEG)	198.5	94.0	12.8	345.7
REVOLUTIONS	1125.4	1221.3	80.0	4736.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.184	0.150	0.000	0.625
< 10,000 KM	0.524	0.276	0.131	1.250
< 30,000 KM	1.427	0.641	0.447	2.813
< 50,000 KM	2.206	0.914	1.044	3.512
< 100,000 KM	4.224	1.740	2.187	6.931

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL	
					MEAN	SD
< 3000 KM	2.3	1.7	1.7	0.7	6.5	6.3
< 10,000 KM	9.0	5.0	5.9	1.7	21.5	23.0
< 30,000 KM	28.7	13.3	14.8	5.8	62.6	71.2
< 50,000 KM	45.4	20.1	25.7	9.7	101.0	115.0
< 100,000 KM	89.6	40.9	43.5	18.5	192.5	216.9

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 0 EUROPA = 1 GANYMEDE = 8 CALLISTO = 4 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.87

GALILEAN SATELLITE ENCOUNTER STATISTICS

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 11.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 21.330	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 0.500	DEC. 22-29, 1985	
NODE(DEG)	= 171.800		
ARG(DEG)	= 0.000		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	11.5	0.5	10.6	12.6
PERIOD(DAYS)	31.0	18.9	14.8	91.7
INCLINATION(DEG)	[illegible]	1.3	1.4	5.8
NODE(DEG)	1[illegible]	131.1	0.4	343.8
ARGUMENT(DEG)	19[illegible].8	84.8	9.7	322.9
REVOLUTIONS	786.8	188.1	331.0	1121.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.008	0.022	0.000	0.076
< 10,000 KM	0.067	0.078	0.000	0.248
< 30,000 KM	0.429	0.171	0.243	0.826
< 50,000 KM	0.879	0.237	0.493	1.405
< 100,000 KM	2.189	0.414	1.252	2.934

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL MEAN	TOTAL SD
< 3000 KM	0.0	0.0	0.1	0.0	0.1	0.4
< 10,000 KM	0.0	0.0	1.3	0.5	1.7	1.7
< 30,000 KM	0.0	0.0	9.9	3.3	13.1	5.4
< 50,000 KM	0.0	0.1	19.3	7.9	27.2	8.3
< 100,000 KM	0.0	1.5	44.7	23.4	69.7	23.5

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 0 EUROPA = 0 GANYMEDE = 2 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.13

GALILEAN SATELLITE ENCOUNTER STATISTICS

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 11.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 21.330	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 1.000	DEC. 22-29, 1985	
NODE(DEG)	= 171.800		
ARG(DEG)	= 0.000		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	11.4	1.0	8.5	12.8
PERIOD(DAYS)	30.8	17.4	10.0	65.0
INCLINATION(DEG)	2.3	1.5	0.2	6.3
NODE(DEG)	211.3	91.5	59.7	324.3
ARGUMENT(DEG)	191.7	112.8	3.7	344.4
REVOLUTIONS	804.1	204.6	506.0	1277.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.004	0.010	0.000	0.033
< 10,000 KM	0.074	0.050	0.000	0.175
< 30,000 KM	0.387	0.146	0.183	0.783
< 50,000 KM	0.863	0.248	0.554	1.488
< 100,000 KM	2.264	0.579	1.448	3.622

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL	
					MEAN	SD
< 3000 KM	0.0	0.0	0.1	0.1	0.1	0.4
< 10,000 KM	0.0	0.3	1.4	0.7	2.4	1.8
< 30,000 KM	0.0	1.3	8.7	2.9	12.9	8.3
< 50,000 KM	0.0	2.1	18.5	8.1	28.7	15.1
< 100,000 KM	0.0	7.2	45.5	23.0	75.7	36.8

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 0 EUROPA = 0 GANYMEDE = 1 CALLISTO = 1 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.13

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GALILEAN SATELLITE ENCOUNTER STATISTIC

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 11.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 21.330	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 5.000	DEC. 22-29, 1985	
NODE(DEG)	= 158.100		
ARG(DEG)	= 13.700		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	11.4	0.8	9.7	13.0
PERIOD(DAYS)	20.7	3.9	13.7	25.2
INCLINATION(DEG)	6.2	1.3	4.6	8.8
NODE(DEG)	344.9	81.4	147.1	419.5
ARGUMENT(DEG)	182.4	57.2	59.8	253.6
REVOLUTIONS	888.9	173.5	645.0	1352.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.003	0.008	0.000	0.026
< 10,000 KM	0.009	0.019	0.000	0.069
< 30,000 KM	0.093	0.105	0.000	0.416
< 50,000 KM	0.328	0.208	0.117	0.994
< 100,000 KM	1.256	0.494	0.627	2.657

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL	
					MEAN	SD
< 3000 KM	0.0	0.0	0.1	0.0	0.1	0.4
< 10,000 KM	0.0	0.0	0.3	0.1	0.4	0.8
< 30,000 KM	0.0	0.6	2.0	1.1	3.7	4.8
< 50,000 KM	0.0	0.9	8.2	2.9	11.9	9.3
< 100,000 KM	0.0	4.6	31.3	10.3	46.3	26.5

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 0 EUROPA = 0 GANYMEDE = 2 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.13

GALILEAN SATELLITE ENCOUNTER STATISTICS

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 11.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 21.330	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 10.000	DEC. 22-29, 1985	
NODE(DEG)	= 184.900		
ARG(DEG)	= 347.000		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	11.4	1.0	10.5	14.4
PERIOD(DAYS)	22.6	4.8	16.2	31.9
INCLINATION(DEG)	13.3	1.7	9.7	16.0
NODE(DEG)	100.9	10.0	84.4	116.3
ARGUMENT(DEG)	112.8	10.5	93.9	136.8
REVOLUTIONS	831.3	47.3	736.0	918.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.000	0.000	0.000	0.000
< 10,000 KM	0.000	0.000	0.000	0.000
< 30,000 KM	0.053	0.049	0.000	0.148
< 50,000 KM	0.132	0.066	0.000	0.229
< 100,000 KM	0.597	0.148	0.328	0.854

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL	
					MEAN	SD
< 3000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 10,000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 30,000 KM	0.0	0.0	1.5	0.3	1.8	1.7
< 50,000 KM	0.0	0.0	3.5	0.9	4.4	2.2
< 100,000 KM	0.0	0.1	15.5	4.2	19.9	4.9

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 0 EUROPA = 0 GANYMEDE = 0 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.00

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GALILEAN SATELLITE ENCOUNTER STATISTIC

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 11.000	NUMBER OF EPOCHS = 15
PERIOD(DAYS)	= 21.330	EPOCH INTERVAL = 7 DAYS
INCLINATION(DEG)	= 30.000	DEC. 22-29, 1985
NODE(DEG)	= 200.300	
ARG(DEG)	= 332.400	

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	11.1	0.3	10.5	11.4
PERIOD(DAYS)	21.5	0.5	20.6	22.3
INCLINATION(DEG)	30.4	0.2	29.9	30.9
NODE(DEG)	167.9	1.3	165.1	169.8
ARGUMENT(DEG)	31.4	4.9	18.7	38.1
REVOLUTIONS	835.9	14.7	815.0	861.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.000	0.000	0.000	0.000
< 10,000 KM	0.000	0.000	0.000	0.000
< 30,000 KM	0.000	0.000	0.000	0.000
< 50,000 KM	0.000	0.000	0.000	0.000
< 100,000 KM	0.000	0.000	0.000	0 000

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL	
					MEAN	SD
< 3000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 10,000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 30,000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 50,000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 100,000 KM	0.0	0.0	0.0	0.0	0.0	0.0

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 0 EUROPA = 0 GANYMEDE = 0 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.00

GALILEAN SATELLITE ENCOUNTER STATISTICS

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 11.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 21.330	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 60.000	DEC. 22-29, 1985	
NODE(DEG)	= 204.600		
ARG(DEG)	= 329.200		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	12.7	0.9	9.6	13.3
PERIOD(DAYS)	26.8	2.0	22.9	29.7
INCLINATION(DEG)	62.9	1.6	61.7	68.3
NODE(DEG)	193.5	2.0	191.7	198.9
ARGUMENT(DEG)	348.5	9.9	317.8	357.0
REVOLUTIONS	779.7	20.5	746.0	813.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.000	0.000	0.000	0.000
< 10,000 KM	0.000	0.000	0.000	0.000
< 30,000 KM	0.000	0.000	0.000	0.000
< 50,000 KM	0.000	0.000	0.000	0.000
< 100,000 KM	0.000	0.000	0.000	0.000

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL	
					MEAN	SD
< 3000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 10,000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 30,000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 50,000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 100,000 KM	0.0	0.0	0.0	0.0	0.0	0.0

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 0 EUROPA = 0 GANYMEDE = 0 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.00

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GALILEAN SATELLITE ENCOUNTER STATISTIC

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 11.000	NUMBER OF EPOCHS = 15
PERIOD(DAYS)	= 21.330	EPOCH INTERVAL = 7 DAYS
INCLINATION(DEG)	= 90.000	DEC. 22-29, 1985
NODE(DEG)	= 206.800	
ARG(DEG)	= 328.600	

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	13.4	0.7	11.7	14.3
PERIOD(DAYS)	19.9	2.2	16.6	23.5
INCLINATION(DEG)	91.1	1.3	89.6	93.8
NODE(DEG)	207.5	2.4	204.0	211.2
ARGUMENT(DEG)	333.1	10.9	311.6	349.0
REVOLUTIONS	868.3	38.3	812.0	919.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.000	0.000	0.000	0.000
< 10,000 KM	0.000	0.000	0.000	0.000
< 30,000 KM	0.000	0.000	0.000	0.000
< 50,000 KM	0.000	0.000	0.000	0.000
< 100,000 KM	0.000	0.000	0.000	0.000

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL	
					MEAN	SD
< 3000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 10,000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 30,000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 50,000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 100,000 KM	0.0	0.0	0.0	0.0	0.0	0.0

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 0 EUROPA = 0 GANYMEDE = 0 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.00

GALILEAN SATELLITE ENCOUNTER STATISTICS

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 11.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 60.000	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 0.000	DEC. 22-29, 1985	
NODE(DEG)	= 171.800		
ARG(DEG)	= 0.000		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	13.6	9.0	0.3	34.4
PERIOD(DAYS)	130.1	161.7	0.9	567.3
INCLINATION(DEG)	0.0	0.0	0.0	0.0
NODE(DEG)	0.1	2.0	-4.2	6.1
ARGUMENT(DEG)	182.7	48.9	35.9	284.2
REVOLUTIONS	387.9	418.5	63.0	1640.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.091	0.125	0.000	0.397
< 10,000 KM	0.304	0.244	0.000	0.777
< 30,000 KM	0.974	0.644	0.270	2.271
< 50,000 KM	1.690	0.973	0.621	3.634
< 100,000 KM	3.423	1.729	2.149	7.585

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL	
					MEAN	SD
< 3000 KM	0.4	0.7	0.6	0.2	1.9	3.8
< 10,000 KM	2.0	1.9	2.0	1.0	6.9	13.9
< 30,000 KM	6.5	5.3	6.7	3.0	21.5	40.5
< 50,000 KM	10.5	8.3	11.9	5.7	36.5	66.3
< 100,000 KM	21.5	19.8	23.5	11.5	76.3	135.7

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 0 EUROPA = 0 GANYMEDE = 5 CALLISTO = 1 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.40

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GALILEAN SATELLITE ENCOUNTER STATISTICS

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 11.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 60.000	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 0.500	DEC. 22-29, 1985	
NODE(DEG)	= 171.800		
ARG(DEG)	= 0.000		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	11.1	0.8	10.1	12.6
PERIOD(DAYS)	98.6	87.8	33.7	356.0
INCLINATION(DEG)	2.3	2.7	0.0	10.3
NODE(DEG)	305.1	66.3	205.9	413.8
ARGUMENT(DEG)	246.4	63.9	136.7	338.8
REVOLUTIONS	298.7	83.4	188.0	466.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.009	0.034	0.000	0.133
< 10,000 KM	0.063	0.089	0.000	0.336
< 30,000 KM	0.517	0.152	0.258	0.754
< 50,000 KM	0.901	0.241	0.568	1.256
< 100,000 KM	2.246	0.466	1.624	3.141

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL MEAN	TOTAL SD
< 3000 KM	0.0	0.0	0.1	0.0	0.1	0.3
< 10,000 KM	0.0	0.1	0.6	0.1	0.7	0.9
< 30,000 KM	0.0	0.1	4.1	1.9	6.1	2.2
< 50,000 KM	0.1	0.1	7.3	3.3	10.7	4.3
< 100,000 KM	0.1	1.5	16.4	8.3	26.3	7.4

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 0 EUROPA = 0 GANYMEDE = 1 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.07

GALILEAN SATELLITE ENCOUNTER STATISTICS

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 11.000	NUMBER OF EPOCHS = 15
PERIOD(DAYS)	= 60.000	EPOCH INTERVAL = 7 DAYS
INCLINATION(DEG)	= 1.000	DEC. 22-29, 1985
NODE(DEG)	= 171.800	
ARG(DEG)	= 0.000	

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	11.4	0.7	10.2	12.4
PERIOD(DAYS)	69.5	22.0	34.5	105.2
INCLINATION(DEG)	1.6	0.7	0.5	3.1
NODE(DEG)	258.0	110.3	71.1	379.5
ARGUMENT(DEG)	177.4	83.0	4.5	295.5
REVOLUTIONS	326.2	80.1	225.0	453.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.004	0.014	0.000	0.055
< 10,000 KM	0.037	0.059	0.000	0.174
< 30,000 KM	0.545	0.202	0.238	0.815
< 50,000 KM	1.086	0.243	0.519	1.450
< 100,000 KM	2.457	0.325	1.903	3.080

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL MEAN	TOTAL SD
< 3000 KM	0.0	0.0	0.1	0.0	0.1	0.3
< 10,000 KM	0.0	0.0	0.5	0.1	0.5	0.8
< 30,000 KM	0.0	0.0	5.3	1.9	7.3	3.5
< 50,000 KM	0.0	0.2	9.7	4.6	14.5	5.6
< 100,000 KM	0.0	1.3	20.3	10.7	32.3	9.6

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 0 EUROPA = 0 GANYMEDE = 1 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.07

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GALILEAN SATELLITE ENCOUNTER STATISTIC

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 11.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 60.000	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 5.000	DEC. 22-29, 1985	
NODE(DEG)	= 158.100		
ARG(DEG)	= 13.700		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	11.3	0.5	10.6	12.2
PERIOD(DAYS)	77.2	31.7	27.3	133.6
INCLINATION(DEG)	5.3	1.3	3.9	8.2
NODE(DEG)	62.9	20.9	33.5	114.4
ARGUMENT(DEG)	130.5	21.7	63.4	161.8
REVOLUTIONS	287.7	79.3	139.0	472.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.016	0.047	0.000	0.180
< 10,000 KM	0.034	0.065	0.000	0.180
< 30,000 KM	0.150	0.110	0.000	0.310
< 50,000 KM	0.364	0.148	0.081	0.620
< 100,000 KM	1.642	0.374	1.147	2.169

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL	
					MEAN	SD
< 3000 KM	0.0	0.0	0.1	0.0	0.1	0.4
< 10,000 KM	0.0	0.0	0.3	0.1	0.3	0.6
< 30,000 KM	0.0	0.0	1.3	0.3	1.7	1.2
< 50,000 KM	0.0	0.0	3.3	0.8	4.1	1.9
< 100,000 KM	0.0	0.2	14.3	3.9	18.5	4.8

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 0 EUROPA = 0 GANYMEDE = 2 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.13

GALILEAN SATELLITE ENCOUNTER STATISTICS

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 11.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 60.000	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 10.000	DEC. 22-29, 1985	
NODE(DEG)	= 184.900		
ARG(DEG)	= 347.000		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	11.1	0.2	10.8	11.5
PERIOD(DAYS)	63.2	7.4	52.5	83.8
INCLINATION(DEG)	8.6	0.5	7.6	9.4
NODE(DEG)	153.6	10.1	128.6	166.9
ARGUMENT(DEG)	38.2	10.6	23.9	65.3
REVOLUTIONS	303.1	16.7	255.0	324.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.000	0.000	0.000	0.000
< 10,000 KM	0.000	0.000	0.000	0.000
< 30,000 KM	0.005	0.020	0.000	0.077
< 50,000 KM	0.015	0.060	0.000	0.231
< 100,000 KM	0.052	0.110	0.000	0.318

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL MEAN	TOTAL SD
< 3000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 10,000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 30,000 KM	0.0	0.0	0.1	0.0	0.1	0.3
< 50,000 KM	0.0	0.0	0.2	0.0	0.2	0.8
< 100,000 KM	0.0	0.1	0.6	0.0	0.7	1.4

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 0 EUROPA = 0 GANYMEDE = 0 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.00

GALILEAN SATELLITE ENCOUNTER STATISTIC

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 11.000	NUMBER OF EPOCHS = 15
PERIOD(DAYS)	= 60.000	EPOCH INTERVAL = 7 DAYS
INCLINATION(DEG)	= 30.000	DEC. 22-29, 1985
NODE(DEG)	= 200.300	
ARG(DEG)	= 332.400	

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	15.1	0.3	14.6	15.8
PERIOD(DAYS)	68.1	9.5	52.6	82.7
INCLINATION(DEG)	41.3	1.4	37.9	43.2
NODE(DEG)	198.6	1.1	196.7	200.2
ARGUMENT(DEG)	352.9	1.6	349.4	355.0
REVOLUTIONS	291.5	19.2	247.0	329.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.007	0.026	0.000	0.101
< 10,000 KM	0.019	0.055	0.000	0.202
< 30,000 KM	0.086	0.087	0.000	0.202
< 50,000 KM	0.102	0.109	0.000	0.304
< 100,000 KM	0.142	0.103	0.000	0.304

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL	
					MEAN	SD
< 3000 KM	0.0	0.0	0.1	0.0	0.1	0.3
< 10,000 KM	0.0	0.0	0.2	0.0	0.2	0.6
< 30,000 KM	0.0	0.0	1.0	0.0	1.0	1.0
< 50,000 KM	0.0	0.0	1.2	0.0	1.2	1.3
< 100,000 KM	0.0	0.0	1.7	0.0	1.7	1.2

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 0 EUROPA = 0 GANYMEDE = 1 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.07

GALILEAN SATELLITE ENCOUNTER STATISTICS

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 11.000	NUMBER OF EPOCHS	= 15
PERIOD(DAYS)	= 60.[illegible]	EPOCH INTERVAL	= 7 DAYS
INCLINATION(DEG)	= 60.[illegible]	DEC. 22-29, 1985	
NODE(DEG)	= 204.600		
ARG(DEG)	= 329.200		

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	24.6	1.7	22.3	28.4
PERIOD(DAYS)	84.2	31.4	68.6	178.8
INCLINATION(DEG)	69.7	1.0	67.0	71.3
NODE(DEG)	202.0	6.1	180.4	205.8
ARGUMENT(DEG)	350.4	5.5	333.0	356.3
REVOLUTIONS	266.9	47.0	100.0	291.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.017	0.065	0.000	0.250
< 10,000 KM	0.017	0.065	0.000	0.250
< 30,000 KM	0.017	0.065	0.000	0.250
< 50,000 KM	0.046	0.071	0.000	0.250
< 100,000 KM	0.070	0.073	0.000	0.250

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL MEAN	TOTAL SD
< 3000 KM	0.0	0.0	0.1	0.0	0.1	0.3
< 10,000 KM	0.0	0.0	0.1	0.0	0.1	0.3
< 30,000 KM	0.0	0.0	0.1	0.0	0.1	0.3
< 50,000 KM	0.0	0.0	0.4	0.0	0.4	0.5
< 100,000 KM	0.0	0.0	0.7	0.0	0.7	0.6

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 0 EUROPA = 0 GANYMEDE = 1 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.07

GALILEAN SATELLITE ENCOUNTER STATISTIC

INITIAL ORBIT CONDITIONS

PERIJOVE(RJ)	= 11.000	NUMBER OF EPOCHS = 15
PERIOD(DAYS)	= 60.000	EPOCH INTERVAL = 7 DAYS
INCLINATION(DEG)	= 90.000	DEC. 22-29, 1985
NODE(DEG)	= 206.800	
ARG(DEG)	= 328.600	

NOMINAL ORBIT LIFETIME = 50 YEARS

END-OF-LIFE ORBIT CONDITIONS

	MEAN	SD	MIN	MAX
PERIJOVE(RJ)	23.0	7.4	13.2	42.9
PERIOD(DAYS)	64.6	101.5	7.0	404.1
INCLINATION(DEG)	92.3	3.9	85.4	102.9
NODE(DEG)	207.8	11.2	187.4	227.2
ARGUMENT(DEG)	323.4	49.7	179.1	371.4
REVOLUTIONS	360.1	147.7	202.0	784.0

ENCOUNTER FREQUENCY DISTRIBUTION - ALL SATELLITES
(% OF ALL ENCOUNTERS)

	MEAN	SD	MIN	MAX
< 3000 KM	0.000	0.000	0.000	0.000
< 10,000 KM	0.000	0.000	0.000	0.000
< 30,000 KM	0.030	0.054	0.000	0.163
< 50,000 KM	0.035	0.053	0.000	0.163
< 100,000 KM	0.057	0.064	0.000	0.163

ENCOUNTER NUMBER DISTRIBUTION (MEAN VALUES)

	IO	EUROPA	GANYMEDE	CALLISTO	TOTAL	
					MEAN	SD
< 3000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 10,000 KM	0.0	0.0	0.0	0.0	0.0	0.0
< 30,000 KM	0.0	0.0	0.3	0.1	0.3	0.6
< 50,000 KM	0.0	0.0	0.4	0.1	0.5	0.6
< 100,000 KM	0.0	0.0	0.6	0.3	0.9	1.0

FIRST COLLISION RECORD (NUMBER OF SAMPLES)

IO = 0 EUROPA = 0 GANYMEDE = 0 CALLISTO = 0 JUPITER = 0

OVERALL COLLISION LIKELIHOOD = 0.00