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An Interstellar Precursor Mission

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NOTICE

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PREFACE

The work described in this report was performed by the Earth and Space Sciences, Systems, Telecommunications Science and Engineering, Control and Energy Conversion, Applied Mechanics, and Information Systems Divisions of the Jet Propulsion Laboratory for NASA Ames Research Center under NASA OAST Program 790, "Space Systems Studies," Stanley R. Sadin, sponsor.

ABSTRACT

A mission out of the planetary system, with launch about the year 2000, could provide valuable scientific data as well as test some of the technology for a later mission to another star. A mission to a star is not expected to be practical around 2000 because the flight time with the technology then available is expected to exceed 10,000 yr.

Primary scientific objectives for the precursor mission concern characteristics of the heliopause, the interstellar medium, stellar distances (by parallax measurements), low energy cosmic rays, interplanetary gas distribution, and mass of the solar system. Secondary objectives include investigation of Pluto. Candidate science instruments are suggested.

The mission should extend to 500-1000 AU from the sun. A heliocentric hyperbolic escape velocity of 50-100 km/s or more is needed to attain this distance within a reasonable mission duration. The trajectory should be toward the incoming interstellar wind. For a year 2000 launch, a Pluto encounter can be included. A second mission targeted parallel to the solar axis would also be worthwhile.

The mission duration is 20 years, with an extended mission to a total of 50 years. A system using 1 or 2 stages of nuclear electric propulsion was selected as a possible baseline. The most promising alternatives are ultralight solar sails or laser sailing, with the lasers in Earth orbit, for example. The NEP baseline design allows the option of carrying a Pluto orbiter as a daughter spacecraft.

Within the limited depth of this study, individual spacecraft systems for the mission are considered, technology requirements and problem areas noted, and a number of recommendations made for technology study and advanced development. The most critical technology needs include attainment of 50-yr spacecraft lifetime and development of a long-life NEP system.

RECOMMENDATIONS FOR TECHNOLOGY DEVELOPMENT

FOR EXTRAPLANETARY MISSION

To permit an extraplanetary mission, such as that described in this report, to commence about the year 2000, efforts are recommended on the following topics. In general, a study should be initiated first, followed by development effort as indicated by the study.

First priority

Starting work on the following topics is considered of first priority, in view of their importance to the mission and the time required for the advance development.

1) Design and fabrication techniques that will provide 50-year spacecraft lifetime.

2) Nuclear electric propulsion with operating times of 10 years or more at full power and able to operate at low power levels for attitude control and spacecraft power to a total of 50 years.

3) Ultralight solar sails, including their impact upon spacecraft and mission design.

4) Laser sailing systems, including their impact upon spacecraft and mission design.

5) Detailing and application of spacecraft quality assurance and reliability methods utilizing test times much shorter than the intended lifetime.

Second priority

Other topics that will require advance effort beyond that likely without special attention include:

6) Spacecraft bearings and moving parts with 50-yr lifetime.

7) Neutral gas mass spectrometer for measuring concentrations of 10^{-2} -10^{-10} atom/cm^3, with 50-yr lifetime.

8) Techniques to predict long-time behavior of spacecraft materials from short-time tests.

9) Compatibility of science instruments with NEP.

10) Methods of calibrating science instruments for 50-yr lifetime.

11) Optical vs. microwave telecommunications with orbiting DSN.

12) Stellar parallax measurements in deep-space.

FOR STAR MISSION

For a star mission, topics which warrant early study include:

13) Antimatter propulsion.

14) Propulsion alternatives for a star mission.

15) Cryogenic spacecraft.

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INTRODUCTION

BACKGROUND

Even before the first earth satellites were launched in 1957, there was popular interest in the possibility of spacecraft missions to other stars and their planetary systems. As space exploration has progressed to the outer planets of the solar system, it becomes appropriate to begin to consider the scientific promise and engineering difficulties of mission to the stars and, hopefully, their accompanying planets.

In a conference on "Missions Beyond the Solar System", organized by L. D. Friedman and held at JPL in August 1976, the idea of a precursor mission out beyond the planets, but not nearly to another star, was suggested as a means of bringing out and solving the engineering problems that would be faced in a mission to a star. At the same time, it was recognized that such a precursor mission, even though aimed primarily at engineering objectives, should also have significant scientific objectives.

Subsequently, in November 1976, this small study was initiated to examine a precursor mission and identify long lead-time technology development which should be initiated to permit such a mission. This study was funded by the Study, Analysis, and Planning Office (Code RX) of the NASA Office of Aeronautics and Space Technology.

STUDY OBJECTIVE

The objective of the study was to establish probable science goals, mission concepts and technology requirements for a mission extending from outer regions of the solar system to interstellar flight. An unmanned mission was intended.

STUDY SCOPE

The study was intended to address science goals, mission concepts, and technology requirements for the portion of the mission outward from the outer portion of the planetary system.

Because of the limited funding available for this study, it was originally planned that the portion of the mission between the earth and the outer portion of the planetary system would not be specifically addressed; likewise, propulsion concepts and technology would not be included. Problems encountered at speeds approaching that of light were excluded for the same reason. In the course of the study, it became clear that these constraints were not critical, and they were relaxed, as indicated later in this report.

STUDY APPROACH

The study effort consisted of two tasks. Task 1 concerned science goals and mission concepts, Task 2 technology requirements.

TASK 1

In Task 1, science goals for the mission were to be examined, and the scientific measurements to be made. Possible relation of the mission to the separate effort on Search for Extraterrestrial Intelligence was also to be considered. Another possibility to be examined was that of using the data, in reverse time sequence, to examine a star and its surroundings (in this case, the solar system) as might be done from an approaching spacecraft.

Possible trajectories would be evaluated with respect to the interaction of the direction of the outward asymptote and the speed with the science goals. A very limited examination might be made of trajectories within the solar system and accompanying propulsion concepts to assess the feasibility of the outward velocities considered.

During the study, science goals and objectives were derived by series of conversations and small meetings with a large number of scientists. Most of these were from JPL, a few elsewhere. Appendix B gives their names.

The trajectory information was obtained by examination of pertinent work done in other studies and a small amount of computation carried out specifically for this study.

TASK 2

In this task, technology requirements that appear to differ significantly from those of missions within the solar system were to be identified. These would be compared with the projected state-of-the-art for the year 2000 ± 15. It was originally planned that requirements associated with propulsion would be addressed only insofar as they interact with power or other systems.

This task was carried out by bringing together study team participants from each of the technical divisions of the Laboratory. (Participants are listed in Appendix A.) Overall concepts were developed and discussed at study team meetings. Each participant obtained inputs from other members of his division on projected capabilities and development needed for individual subsystems. These were iterated at team meetings. In particular, several iterations were needed between propulsion and trajectory calculations.

STAR MISSION

Many of the contributors to this study, both scientific and engineering, felt an actual star mission should be considered. Preliminary examination indicated, however, that the hyperbolic velocity attainable for solar system escape during the time period of interest (year 2000 ± 15) was of the order of 10^2 km/s or 3×10^9 km/year. Since the nearest star is at a distance of 4.3 light years or about 4×10^{13} km, the mission duration would exceed 10,000 years. This did not seem worth considering for two reasons.

First, attaining, and especially establishing, a spacecraft lifetime of 10,000 years by the year 2000 is not considered feasible. Secondly, propulsion capability and hence hyperbolic velocity attainable is expected to increase with time. Doubling the velocity should take not more than another 25 years of work, and would reduce the mission duration to only 5000 years. Thus, a spacecraft launched later would be expected to arrive earlier. Accordingly, launch to a star by 2000 ± 15 does not seem reasonable.

For this reason, a star mission is not considered further in the body of this report. A few thoughts which arose during this study and pertain to a star mission are recorded in Appendix C. It is recommended that a subsequent study address the possibility of a star mission starting in 2025, 2050, or later, and the long lead-time technology developments that will be needed to permit this mission.

SCIENTIFIC OBJECTIVES AND REQUIREMENTS

Preliminary examination of trajectory and propulsion possibilities indicated that a mission extending to distances of some hundred or perhaps a few thousand AU from the sun with a launch around the year 2000 was reasonable. The following science objectives and requirements are considered appropriate for such a mission.

SCIENTIFIC OBJECTIVES

Primary Objectives

1) Determination of the characteristics of the heliopause, where the solar wind presumably terminates against the incoming interstellar medium.
2) Determination of the characteristics of the interstellar medium.
3) Determination of the stellar and galactic distance scale, through measurements of the distance to nearby stars.
4) Determination of the characteristics of cosmic rays at energies excluded by the heliosphere.
5) Determination of characteristics of the solar system as a whole, such as its interplanetary gas distribution and total mass.

Secondary Objectives

1) Determination of the characteristics of Pluto and its satellites and rings, if any. If there had been a previous mission to Pluto, this objective would be modified.
2) Determination of the characteristics of distant galactic and extragalactic objects.
3) Evaluation of problems of scientific observations of another solar system from a spacecraft.

TRAJECTORY REQUIREMENTS

The primary science objectives necessitate passing through the heliopause, preferably in a relatively few years after launch to increase the reliability of data return. Most of the scientists interviewed preferred a mission directed toward the incoming interstellar gas, where the heliopause is expected to be closest and most well defined. The "upwind" direction with respect to neutral interstellar gas is approximately R.A. 250°, Decl - 16° (Weller and Meier, 1974; Ajello, 1977). (See Fig. 1. The sun's motion with respect to interstellar charged particles and magnetic fields is not known.) Presumably any direction within, say, 40° of this would be satisfactory. A few scientists preferred a mission parallel to the sun's axis (perpendicular to the ecliptic), believing that interstellar magnetic field and perhaps particles may leak inward further along this axis. Some planetary scientists would like the mission to include a flyby or orbiter of Pluto, depending on the extent to which Pluto might have been explored by an earlier mission. Although a Pluto flyby is incompatible with a direction perpendicular to the ecliptic, it happens that in the period of interest (arrival around the year 2005) Pluto will lie almost exactly in the "upwind" direction mentioned, so an "upwind" trajectory could include a Pluto encounter.

The great majority of scientists consulted preferred a trajectory that would take the spacecraft out as fast as possible. This would minimize time to reach the heliopause and the interstellar medium. Also, it would, at any time, provide maximum earth-S/C separation as a base for optical measurements of stellar parallax. A few scientists would like to have the S/C go out and then return to the solar system to permit evaluating and testing methods of obtaining scientific data with a future S/C encountering another solar system. Such a return would, roughly, halve the duration of the outward portion of the flight for any fixed mission duration. Also, since considerable propulsive energy would be required to "stop and turn around", this approach would considerably reduce the outward hyperbolic velocity attainable. These two effects would greatly reduce the maximum distance that could be reached for a given mission duration.

As a "strawman mission", it is recommended that a no-return trajectory with an asymptote near R.A. 250°, Decl -15° and a flyby of Pluto be

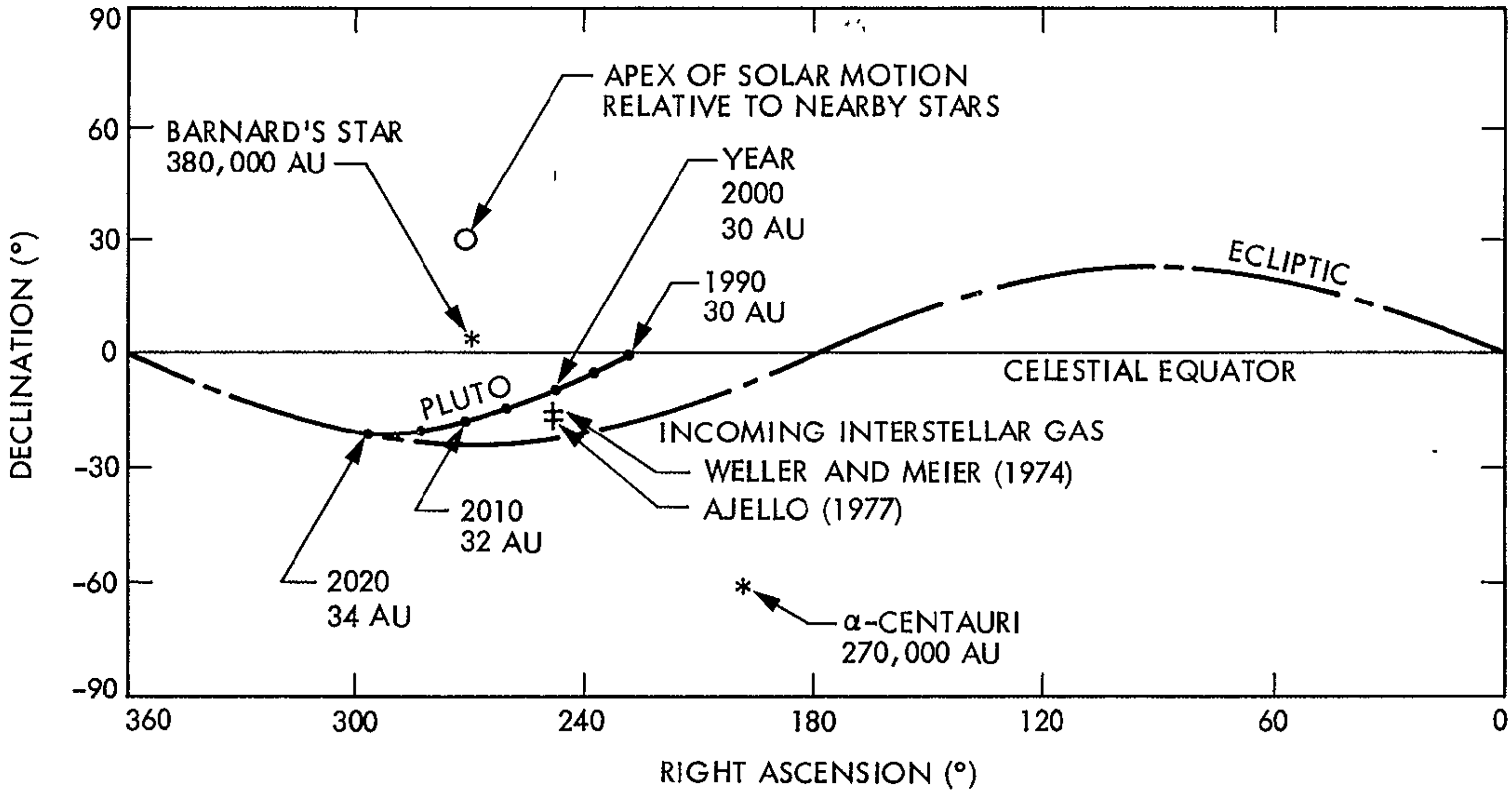

Fig. 1 Some Points of Interest on the Celestial Map.
From Sergeyevsky (1971) modified.

considered, with a hyperbolic excess velocity of 40-90 km/s or more. Higher velocities should be used if practical. Propulsion should be designed to avoid interference with scientific measurements and should be off when mass measurements are to be made.

A number of scientific observations (discussed below) would be considerably improved if two spacecraft, operating simultaneously, were used, with asymptotic trajectories at approximately right angles to each other. Thus, use of a second spacecraft, with an asymptotic trajectory approximately parallel to the solar axis, is worthwhile scientifically.

SCIENTIFIC MEASUREMENTS

Heliopause and Interstellar Medium

Determination is needed of the characteristics of the solar wind just inside the heliopause, of the heliopause itself, of the accompanying shock (if one exists), and of the region between the heliopause and the shock. The location of the heliopause is not known; estimates now tend to center at about 100 AU from the sun. (As an indication of the uncertainty, estimates a few years ago ran as low as 5 AU.)

Key measurements to be made include magnetic field, plasma properties (density, velocity, temperature, composition, plasma waves) and electric field. Similar measurements, extending to low energy levels, are needed in the interstellar medium, together with measurements of the properties of the neutral gas (density, temperature, composition of atomic and molecular species, velocity) and of the interstellar dust (particle concentration, particle mass distribution, composition, velocity). The radiation temperature should also be measured.

The magnetic, electric, and plasma measurements would require only conventional instrumentation, but high sensitivity would be needed. Plasma blobs could be detected by radio scintillation of small sources at a wavelength near 1 m. Radiation temperature could be measured with a radiometer at wavelengths of 1 cm to 1 m, using a detector cooled to a few Kelvins. Both in-situ and remote measurements of gas and dust properties are desirable. In-situ measurements of dust composition could be made by an updated version of an impact-ionization mass spectrometer. In-situ measurements of ions could be made by a mass spectrometer and by a plasma analyzer. In-situ measurements of neutral gas composition would probably require development of a mass spectrometer with greater sensitivity and signal/noise ratio than present instruments. Remote measurements of gas composition could be made by absorption spectroscopy, looking back toward the sun. Of particular interest in the gas measurements are the ratios D/H, $H/H_2/H^+$, He/H, He^3/He^4; the contents of C, N, O, and if possible of Li, Be, B; and the flow velocity. Dust within some size range could be observed remotely by changes in the continuum intensity.

Stellar and Galactic Distance Scale

Present scales of stellar and galactic distance are probably uncertain by 20%. This in turn leads to uncertainties of 40% in the absolute luminosity (energy production), the quantity which serves as the fundamental input data for stellar model calculations. Uncertainties in galactic distances make it difficult to provide good input data for cosmological models.

The basic problem is that all longer-range scales depend ultimately on the distances to Cepheid variables in nearby clusters, such as the Hyades and Pleiades. Distances to these clusters are determined by statistical analysis of relative motions of stars within the clusters, and the accuracy of this analysis is not good. With a baseline of a few hundred AU between S/C and earth, triangulation would provide the distance to nearby Cepheids with high accuracy. This will require a camera with resolution of a fraction of an arc second, implying an objective diameter of 30 cm to 1 m. Star position angles need not be measured relative to the sun or earth line, but only with respect to distant stars in the same image frame. To reduce the communications load, only the pixel coordinates of a few selected objects need be transmitted to earth.

Cosmic Rays

Measurements should be made of low energy cosmic rays, which the solar magnetic field excludes from the heliosphere. Properties to be measured include flux, spectrum, composition, and direction. Measurements should be made at energies below 10 MeV and perhaps down to 10 keV or lower. Conventional instrumentation should be satisfactory.

Solar System as a Whole

Determinations of the characteristics of the solar system as a whole include measurements of neutral and ionized gas and of dust. Quantities to be measured include spatial distribution and the other properties mentioned above.

Column densities of ionized material can be observed by low frequency radio dispersion. Nature, distribution and velocity of neutral gas components and some ions can be observed spectroscopically by fluorescence under solar radiation. To provide adequate sensitivity, a large objective will be needed. Continuum observation should show the dust distribution.

The total mass of the solar system should be measured. This could be done through dual frequency radio doppler tracking.

Observations of Distant Objects

Observations of more distant objects should include radio astronomy observations at frequencies below 1 kHz, below the plasma frequency of the interplanetary medium. This will require a VLF receiver with a very long dipole or monopole antenna.

Also, both radio and gamma-ray events should be observed and timed. Comparison of event times on the S/C and at earth will indicate the direction of the source.

In addition, the galactic hydrogen distribution should be observed by UV spectrophotometry, outside any local concentration due to the sun.

Pluto

If a Pluto flyby is contemplated, measurements should include optical observations of the planet to determine its diameter, surface and atmosphere features, and an optical search for and observations of any satellites or rings. Atmospheric density, temperature and composition should be measured, and nearby charged particles and magnetic fields. Surface temperature and composition should also be observed. Suitable instruments include a TV camera, infrared radiometer, ultraviolet/visible spectrometer, particles and fields instruments, infrared spectrometer.

For atmospheric properties, UV observations during solar occultation (especially for H and He) and radio observations of earth occultation should be useful.

The mass of Pluto should be measured: radio tracking should provide this.

If a Pluto orbiter is included in the mission, measurements should also include surface composition, variable features, rotation axis, shape, and gravity field. Additional instruments should include a gamma-ray spectrometer and an altimeter.

Simulated Stellar Encounter

If return to the solar system is contemplated, as a simulation of a stellar encounter, observations should be made, during approach, of the existence of possible stellar companions and planets, and later of satellites, asteroids, and comets, and of their characteristics. Observations of neutral gas, dust, plasma, and energetic emissions associated with the star should be made, and any emissions from planets and satellites. Choice(s) should be made of a trajectory through the approaching solar system (recognizing the time-delays inherent in a real stellar mission), the choice(s) should be implemented, and flyby measurements made.

The approach measurements could probably be made using instruments aboard for other purposes. For flyby, it would probably be adequate to use data recorded on earlier missions rather than carry additional instruments.

An alternative considered was simulating a stellar encounter by "looking backwards while leaving the solar system and later replaying the data backwards". This was not looked on with favor by the scientists contacted because the technique would not permit making the operational decisions that would be key in encountering a "new" solar system: locating and flying by planets, for example. "Looking backwards" at the solar system is desired to give solar system data per se, as mentioned above. Stellar encounter operations are discussed briefly in Appendix C.

Gravity Waves

A spacecraft at a distance of several hundred AU offers an opportunity for a sensitive technique for detecting gravity waves. All that is needed is precision 2-way radio doppler measurements between S/C and earth.

Measurements Not Planned

Observations not contemplated include:

1) Detecting the Oort cloud of comets, if it exists. No method of detecting a previously unknown comet far out from the sun is recognized unless there is an accidental encounter. Finding a previously seen comet when far out would be very difficult because the orbits of long-period comets are irregular and their aphelia are hard to determine accurately; moreover, a flyby, far from the sun, would tell little about the comet and nothing about the Oort cloud. The mass of the entire Oort cloud might be detectable from outside, but the mission is not expected to extend the estimated 50,000 AU out. If Lyttleton's comet model is correct, a comet accidentally encountered would be revealed by the dust detector.

2) VLBI using an earth-S/C baseline. This would require very high rates of data transmission to earth, rates which do not appear reasonable. Moreover, it is doubtful that sources of the size resolved with this baseline are intense enough to be detected and that the required coherence would be maintained after passage through inhomogeneities in the intervening medium. Also, with only 2 widely separated receivers and a time-varying baseline, there would be serious ambiguity in the measured direction of each source.

Advantages of Using Two Spacecraft

Use of two spacecraft, with asymptotic trajectories at roughly right angles to each other, would permit exploring two regions of the heliopause (upwind and parallel to the solar axis) and provide significantly greater understanding of its character, including the phenomena occurring near the magnetic pole direction of the sun. Observations of transient distant radio and gamma-ray events from two spacecraft plus the earth would permit location of the source with respect to two axes, instead of the one axis determinable with a single S/C plus earth.

CANDIDATE SCIENCE PAYLOAD

1) Vector magnetometer
2) Plasma spectrometer
3) Ultraviolet/visible spectrometers
4) Dust impact detector and analyzer
5) Low energy cosmic ray analyzer
6) Dual-frequency radio tracking (including low frequency with high frequency uplink)
7) Radio astronomy/plasma wave receiver (including VLF; long antenna)
8) Mass spectrometer
9) Microwave radiometer
10) Electric field meter
11) Camera (aperture 30 cm to 1 m)
12) Gamma-ray transient detector

If Pluto flyby or orbiter is planned:

13) Infrared radiometer
14) Infrared spectrometer

If Pluto orbiter is planned:

15) Gamma-ray spectrometer
16) Altimeter

TRAJECTORIES

UNITS AND COORDINATE SYSTEMS

Units

Some useful approximate relations in considering an extraplanetary mission are:

1 AU	$= 1.5 \times 10^{8}$ km
1 light year	$= 9.5 \times 10^{12}$ km $= 6.3 \times 10^{4}$ AU
1 parsec	$= 3.1 \times 10^{13}$ km $= 2.1 \times 10^{5}$ AU $= 3.3$ light years
1 year	$= 3.2 \times 10^{7}$ s
1 km/s	$= 0.21$ AU/yr $= 3.3 \times 10^{-6}$ c

where c = velocity of light

Coordinate Systems

For objects out of the planetary system, the equatorial coordinate system using right ascension (α) and declination (δ) is often more convenient than the ecliptic coordinates, celestial longitude (λ) and celestial latitude (β). Conversion relations are:

$$\sin\beta = \cos\varepsilon \sin\delta - \sin\varepsilon \cos\delta \sin\alpha$$

$$\cos\beta \sin\lambda = \sin\varepsilon \sin\delta + \cos\varepsilon \cos\delta \sin\alpha$$

$$\cos\beta \cos\lambda = \cos\delta \cos\alpha$$

where ε = obliquity of ecliptic $\simeq 23.5°$

DIRECTIONS OF INTEREST

Extraplanetary

Most recent data for the direction of the incoming interstellar neutral gas are:

Weller & Meier (1974):

Right ascension	$\alpha = 252°$
Declination	$\delta = -15°$

Ajello (1977):

Right ascension	$\alpha = 252°$
Declination	$\delta = -17°$

Thus, these 2 data sources are in excellent agreement.

At α = 250° the ecliptic is about 20°S of the equator, so the wind comes in at celestial latitude of about 4°. Presumably, it is only a coincidence that this direction lies close to the ecliptic plane.

The direction of the incoming gas is sometimes referred to as the "apex of the sun's way", since it is the direction toward which the sun is moving with respect to the interstellar gas. The term "apex", however, conventionally refers to the direction the sun is moving relative to nearby stars, rather than relative to interstellar gas. These two directions differ by about 45° in declination and about 20° in right ascension. The direction of the solar motion with respect to nearby stars, and some other directions of possible interest, are shown in Fig. 1.

Pluto

Table 1 gives the position of Pluto for the years 1990 to 2030. Note that, by coincidence, during 2000 to 2005 Pluto is within a few degrees of the direction toward the incoming interstellar gas (see Fig. 1). At the same time it is near its perihelion distance, only 30-31 AU from the sun.

SOLAR SYSTEM ESCAPE TRAJECTORIES

As a step in studying trajectories for extraplanetary missions, a series of listings giving distance and velocity vs. time for parabolic and hyperbolic solar system escape trajectories has been generated. These are given in Appendix D and a few pertinent values extracted in Table 2. Note, for example, that with a hyperbolic heliocentric excess velocity V_∞ = 50 km/s, a distance of 213 AU is reached in 20 years and a distance of 529 AU in 50 years. With V_∞ = 100 km/s, these distances would be doubled approximately.

LAUNCHABLE MASS

Solar system escape missions typically require high launch energies, referred to as C_3, to achieve either direct escape or high flyby velocity

TABLE 1

Position of Pluto, 1990-2030

Year	Position on 1 January: Distance from sun, AU	Right ascension, °	Declination, °
1990	29.58	227.03	-1.37
1995	29.72	238.51	-6.30
2000	30.12	249.98	-10.89
2005	30.78	261.39	-14.92
2010	31.64	272.61	-18.20
2015	32.67	283.53	-20.69
2020	33.81	294.02	-22.37
2025	35.04	304.00	-23.32
2030	36.31	313.37	-23.63

TABLE 2

Summary of Solar System Ballistic Escape Trajectories

Initial Condition: Circular Orbit at 1 AU

V_∞ km/s	Distance (RAD), AU, for Time (T) = 10 yrs.	20 yrs.	50 yrs.	Velocity (VEL), km/s for Time (T) = 10 yrs.	20 yrs.	50 yrs.
0	25.1	40.4	75.3	8.4	6.6	4.9
1	25.2	40.6	76.0	8.4	6.7	4.9
5	27.0	45.1	90.4	9.5	8.0	6.7
10	32.1	57.0	126.	12.5	11.4	10.7
20	47.7	91.2	220.	20.9	20.5	20.2
30	66.5	130.	321.	30.4	30.2	30.1
40	86.5	171.	424.	40.3	40.1	40.1
50	107.	213.	529.	50.2	50.1	50.0
60	128.	254.	634.	60.1	60.1	60.0

(See Appendix D for detail)

at a gravity assist planet. Table 3 gives projected C_3 capabilities in $(km/s)^2$ for the three versions of the Shuttle/Interim Upper Stage assuming net payloads of 300, 400, and 500 kg. It can be seen that as launched mass increases the maximum launch energy possible decreases. Conceivably higher C_3's are possible through the use of in-orbit assembly of larger IUS versions, or development of more powerful upper stages such as the Tug. The range of C_3 values found here will be used in the study of possible escape trajectories given below.

DIRECT LAUNCH FROM EARTH

Direct launch from the Earth to a ballistic solar system escape trajectory requires a minimum launch energy of 152.2 $(km/s)^2$. Table 4 gives the maximum solar system V_∞ obtainable (in the ecliptic plane) and maximum ecliptic latitude obtainable (for a parabolic escape trajectory) for a range of possible C_3.

The relatively low V_∞ and inclination values obtainable with direct launch make it an undesirable choice for launching of extra-solar probes as compared with those techniques discussed below.

JUPITER ASSIST

Jupiter Gravity Assist

Of all the planets, Jupiter is by far the best to use for gravity assisted solar system escape trajectories because of its intense gravity field. The geometry of the Jupiter flyby is shown in Figure 2. Assume that the planet is in a circular orbit about the Sun with orbital velocity V_{Jh} = 13.06 km/s.

The spacecraft approaches the planet with some relative velocity, V_{in}, directed at an angle β to V_{Jh}, and departs along V_{out} after having been bent through an angle α. The total bend angle

$$\alpha = 2 \arcsin [1/(1 + V_{in}^2 r_p/\mu)]$$

where r_p is the closest approach radius to Jupiter and $\mu = GM_J$, the gravitational mass of Jupiter. Note that V_{Jh}, V_{in} and V_{out} need not all

TABLE 3

Capabilities of Shuttle with Interim Upper Stage

Launch Vehicle	Launch energy C_3, $(km/s)^2$ for indicated payload (kg)		
	300	400	500
Shuttle/2-stage IUS	95.5	91.9	88.2
Shuttle/3-stage IUS	137.9	131.0	124.4
Shuttle/4-stage IUS	178.4	161.5	148.2

TABLE 4

Solar System Escape Using Direct Ballistic Launch from Earth

Launch energy, C_3, $(km/s)^2$	Maximum hyperbolic excess velocity, V_∞, in ecliptic plane (km/s)	Maximum ecliptic latitude, λ_{max}, for parabolic trajectory (°)
152.2	0.00	0.00
155.	3.11	2.73
160.	5.15	4.53
165.	6.57	5.80
170.	7.73	6.84
175.	8.72	7.74

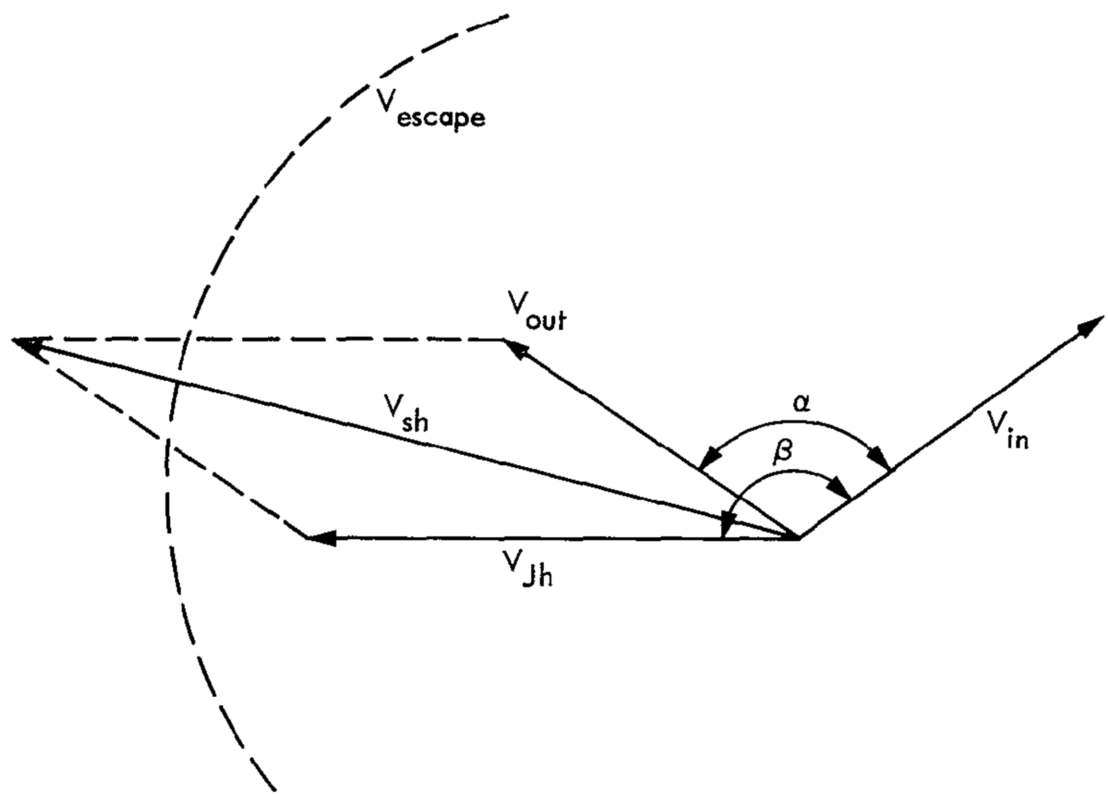

Fig. 2   Geometry of Jupiter Flyby

be in the same plane, so the spacecraft can approach Jupiter in the ecliptic plane and be ejected on a high inclination orbit. The heliocentric velocity of the spacecraft after the flyby, V_{sh}, is given by the vector sum of V_{Jh} and V_{out}. If this velocity exceeds approximately 1.414 V_{Jh}, shown by the dashed circle in Figure 2, the spacecraft achieves by hyperbolic orbit and will escape the solar system. The hyperbolic excess velocity is given by $V^2_{sh} - 2\mu/r$ where μ here is GM_S, the gravitation mass for the Sun, and r is the distance from the Sun, 5.2 astronomical units. The maximum solar system escape velocity will be obtained when the angle between V_{Jh} and V_{out} is zero. This will necessarily result in a near-zero inclination for the outgoing orbit. Around this vector will be a cone of possible outgoing escape trajectories. As the angle from the central vector increases the hyperbolic excess velocity relative to the Sun will decrease. The excess velocity reaches zero (parabolic escape orbit) when the angle between V_{Jh} and V_{sh} is equal to arc cos $[(3 - V^2_{in}/V^2_{Jh})/2\sqrt{2}]$. This defines then the maximum inclination escape orbit that can be obtained for a given V_{in} at Jupiter. Table 5 gives the dependence of solar system hyperbolic escape velocity on V_{in} and the angle between V_{Jh} and V_{sh}. The maximum angle possible for a given V_{in} is also shown.

For example, for a V_{in} at Jupiter of 10. km/s the maximum inclination obtainable is 31.41°, and the solar system escape speed will be 13.03 km/s for an inclination of 10°, 10.45 km/s for an inclination of 20°. Note that for V_{in}'s greater than 20 km/s it is possible to eject along retrograde orbits. This is an undesirable waste of energy however. It is preferable to wait for Jupiter to move 180° around its orbit when one could use a direct outgoing trajectory and achieve a higher escape speed in the same direction.

To consider in more detail the opportunities possible with Jupiter gravity assist, trajectories have been found assuming the Earth and Jupiter in circular, co-planar orbits, for a range of possible launch energy values. These results are summarized in Table 6. Note that the orbits with C_3 = 180 $(km/s)^2$ have negative semi-major axes indicating that they are hyperbolic. With the spacecraft masses and launch vehicles discussed above it is thus possible to get solar system escape velocities

TABLE 5

Solar System Escape Using Jupiter Gravity Assist

Approach velocity relative to Jupiter, V_{in} (km/s):	6.0	10.0	15.0	20.0	25.0	30.0
Angle between outbound heliocentric velocity of S/C, V_{sh}, and of Jupiter, J_{sh} (°)	Solar system hyperbolic excess velocity, V_{∞}, (km/s), for above approach velocity					
0.0	4.70	13.81	21.12	27.42	33.28	38.90
5.0	4.01	13.61	21.00	27.32	33.19	38.82
10.0	*****	13.03	20.63	27.02	32.93	38.58
15.0	*****	12.00	20.01	26.53	32.50	38.19
20.0	*****	10.45	19.13	25.85	31.91	37.65
25.0	*****	8.12	17.99	24.97	31.16	36.97
30.0	*****	3.93	16.57	23.91	30.25	36.15
40.0	*****	*****	12.73	21.25	28.01	34.13
50.0	*****	*****	6.47	17.89	25.28	31.69
60.0	*****	*****	*****	13.75	22.13	28.92
70.0	*****	*****	*****	8.32	18.65	25.94
80.0	*****	*****	*****	*****	14.86	22.83
90.0	*****	*****	*****	*****	10.65	19.70
	Maximum angle between outbound heliocentric velocity of S/C, V_{sh}, and of Jupiter, V_{Jh}, (°), for above approach velocity					
	9.58	31.41	53.53	76.60	103.57	143.56

Note: ***** indicates unobtainable combination of V_{in} and angle.

TABLE 6

Jupiter Gravity Assist versus Launch Energy

Launch Energy, C3 $(km/s)^2$	Transfer orbit semi-major axis, a (AU)	Approach velocity relative to Jupiter, V_{in} (km/s)	Angle between approach velocity and Jupiter heliocentric velocity, β, (°)	Maximum bend angle relative to Jupiter, α, for flyby at 1.1 R (°)	Maximum heliocentric hyperbolic escape velocity, V_∞, for flyby at 1.1 R (°)	Maximum inclination to ecliptic for parabolic trajectory, λ_{max}, for flyby at 1.1 R (°)
80.0	3.23	6.55	148.96	153.85	6.59	13.66
90.0	3.82	9.08	127.34	144.10	12.22	27.17
100.0	4.63	10.98	119.53	137.02	15.38	35.81
110.0	5.82	12.54	115.10	131.35	17.72	42.69
120.0	7.74	13.88	112.13	126.59	19.61	48.58
130.0	11.38	15.07	109.95	122.48	21.21	53.82
140.0	20.98	16.14	108.27	118.86	22.61	58.61
150.0	117.43	17.12	106.91	115.61	23.87	63.05
160.0	-33.64	18.03	105.78	112.67	25.01	67.22
180.0	-9.63	19.67	103.99	107.52	27.02	74.99
200.0	-5.71	21.13	102.61	103.11	28.77	82.22

on the order of 25 km/s in the ecliptic plane and inclinations up to about 67° above the ecliptic plane using simple ballistic flybys of Jupiter. Thus a large fraction of the celestial sphere is available to solar system escape trajectories using this method.

Jupiter Powered Flyby

One means of improving the performance of the Jupiter flyby is to perform a maneuver as the spacecraft passes through periapsis at Jupiter. The application of this ΔV deep in the planet's gravitational potential well results in a substantial increase in the outgoing V_{out} and thus the solar system hyperbolic excess velocity V_{∞}. This technique is particularly useful in raising relatively low V_{in} values incoming to high outgoing V_{out}'s. Table 7 gives the outgoing V_{out} values at Jupiter obtainable as a function of V_{in} and ΔV applied at periapsis. A flyby at 1.1 R_J is assumed. The actual V_{out} might be fractionally smaller because of gravity losses and pointing errors but the table gives a good idea of the degrees of performance improvement possible.

Carrying the necessary propulsion to perform the ΔV maneuver would require an increase in launched payload and thus a decrease in maximum launch energy and V_{in} possible at Jupiter. Table 8 gives the required launched mass for a net payload of 300 kg after the Jupiter flyby, using a space storable propulsion system with I_{sp} of 370 seconds, and the maximum C_3 possible with a Shuttle/4-stage IUS launch vehicle, as a function of ΔV capability at Jupiter. These numbers may be combined with the two previous tables to find the approximate V_{in} at Jupiter and the resulting V_{out}.

Launch Opportunities to Jupiter

Launch opportunities to Jupiter occur approximately every 13 months. Precise calculations of such opportunities would be inappropriate at this stage in a study of extra-solar probe possibilities. Because Jupiter moves about 33° in ecliptic longitude in a 13 month period, and because the cone of possible escape trajectories exceeds 30° in half-width for V_{out} above about 10 km/s, it should be possible to launch to any ecliptic longitude over a 12 year period by properly choosing the launch date and flyby date at Jupiter. With sufficient V_{out} the

TABLE 7

Jupiter Powered Flyby

Approach velocity relative to Jupiter, V_{in}, (km/s)	Outbound velocity relative to Jupiter, V_{out}, (km/s), for indicated ΔV (km/s) applied at periapsis of 1.1 R_j				
	.50	1.00	1.50	2.00	2.50
6.0	9.66	12.30	14.48	16.38	18.11
8.0	11.03	13.41	15.44	17.25	18.90
10.0	12.57	14.71	16.59	18.29	19.86
12.0	14.22	16.16	17.00	19.50	20.99
14.0	15.96	17.72	19.33	20.83	22.24
16.0	17.76	19.37	20.86	22.37	23.61
18.0	19.59	21.08	22.47	23.80	25.06
20.0	21.46	22.83	24.14	25.39	26.00

TABLE 8

Launched Mass for 300 kg Net Payload

after Jupiter Powered Flyby

ΔV at Jupiter (km/s)	Required launched mass for S/C I_{sp} = 370 s (kg)	Maximum launch energy, C_3, attainable with shuttle/4-stage IUS $(km/s)^2$
.0	300.	178.4
.5	428.	157.4
1.0	506.	147.4
1.5	602.	137.0
2.0	720.	127.2
2.5	869.	114.9

high ecliptic latitudes would be available as described in an earlier section. Flight times to Jupiter will typically be 2 years or less.

Venus-Earth Gravity Assist

One means of enhancing payload to Jupiter is to launch by way of a Venus-Earth Gravity Assist (VEGA) trajectory. These trajectories launch at relatively low C_3's, 15 - 30 $(km/s)^2$, and incorporate gravity assist and ΔV maneuvers at Venus and Earth to send large payloads to the outer planets. The necessary maneuvers add about 2 years to the total flight time before reaching Jupiter. The extra payload could then be used as propulsion system mass to perform the powered flyby at Jupiter. An alternate approach is that VEGA trajectories allow use of a smaller launch vehicle to achieve the same mission as a direct trajectory.

POWERED SOLAR FLYBY

The effect of an impulsive delta-V maneuver when the spacecraft is close to the Sun has been calculated for an extra-solar spacecraft. The calculations are done for a burn at the perihelion distance of 0.1 AU, for orbits whose V_∞ value before the burn is 0, 5, and 10 km/s respectively. Results are shown in Table 9. It can be seen that the delta-V maneuver deep in the Sun's potential well can result in a significant increase in V_∞ after the burn, having its greatest effect when the pre-burn V_∞ is small.

The only practical means to get 0.1 from the Sun (other than with a "super sail", discussed below) is a Jupiter flyby at a V_∞ relative to Jupiter of 12 km/s or greater. The flyby is used to remove angular momentum from the spacecraft orbit, and "dump" it in towards the Sun. The same flyby used to add energy to the orbit could achieve V_∞ of 17 km/s or more without any delta-V, and upwards of 21 km/s with 2.5 km/s of delta-V at Jupiter. The choice between the two methods will require considerably more study in the future.

LOW-THRUST TRAJECTORIES

A large number of propulsion techniques have been proposed that do not depend upon utilization of chemical energy aboard the spacecraft.

TABLE 9

Powered Solar Flyby

ΔV (km/s)	Heliocentric hyperbolic excess velocity, V_∞, (km/s), after burn 0.1 AU from Sun and initial V_∞ as indicated (km/s)		
	0	5	10
.1	5.16	7,19	11.25
.3	8,94	10.25	13.42
.5	11.55	12.59	15.29
1.0	16,35	17,10	19.19
1.5	20.05	20.67	22.42
2.0	23.17	23.71	25.26
2.5	25.93	26.41	27.82

Among the more recent reviews pertinent to this mission are those by Forward (1976), Papailiou et al (1975), and James et al (1976). A very useful bibliography is that of Mallove et al (1977).

Most of the techniques provide relative low thrust and involve long periods of propulsion. The following paragraphs consider methods that seem the more promising for an extraplanetary mission launched around 2000.

Solar Sailing

Solar sails operate by using solar radiation pressure to add or subtract angular momentum from the spacecraft (Garwin, 1958). The basic design considered in this study is a helio-gyro of twelve 6200-meter mylar strips, spin-stabilized.

According to Jerome Wright (private communication), the sail is capable of achieving spacecraft solar system escape velocities of 15-20 km/s. This requires spiralling into a close orbit approximately 0.3 AU from the sun and then accelerating rapidly outward. The spiral-in maneuver requires approximately one year and the acceleration outward, which involves approximately 1-1/2 - 2 revolutions about the sun, takes about 1-1/2 - 2 years, at which time the sail/spacecraft is crossing the orbit of Mars, 1.5 AU from the sun, on its way out.

The sail is capable of reaching any inclination and therefore any point of the celestial sphere. This is accomplished by performing a "cranking" maneuver when the sail is at 0.3 AU from the sun, before the spiral outward begins. The cranking maneuver keeps the sail in a circular orbit at 0.3 AU as the inclination is steadily raised. The sail can reach 90° inclination in approximately one year's time.

Chauncey Uphoff (private communication) has discussed the possibility of a super sail capable of going as close as 0.1 AU from the sun, and capable of an acceleration outward equal to or greater than the sun's gravitational attraction. Such a sail might permit escape V_∞'s on the order of 100 km/s, possible up to 300 km/s. However, no such design exists at present and the possibility of developing such a sail has not been studied.

Laser Sailing

Rather et al (1976) have recently re-examined the proposal (Forward, 1962, Marx, 1966, Moeckle, 1972) of using high energy lasers, rather than sunlight, to illuminate a sail. The lasers could be in orbit around the earth or moon and powered by solar collectors.

Rather et al found that the technique was not promising for star missions but could be useful for outer planet missions. Based on their assumptions*, a heliocentric escape velocity of 60 km/s could be reached with a laser output power of about 30 kW, 100 km/s with about 1500 kW, and 200 km/s with 20 MW. Acceleration is about 0.35 g and thrusting would continue until the S/C was some millions of kilometers from earth.

Solar Electric Propulsion

Solar electric propulsion uses ion engines, where mercury or other atoms are ionized and then accelerated across a potential gap to a very high exhaust velocity. The electricity for generating the potential comes from a large solar cell array on the spacecraft. Current designs call for a 100 kilowatt unit which is also proposed for a future comet rendezvous mission. A possible improvement to the current design is the use of mirror "concentrators" to focus additional sunlight on the solar cells at large heliocentric distances.

According to Carl Sauer (private communication) the solar powered ion drive is capable of escape V_∞'s on the order of 10-15 km/s in the ecliptic plane. Going out of the ecliptic is more of a problem because the solar cell arrays cannot be operated efficiently inside about 0.6 AU from the sun. Thus the solar electric drive cannot be operated close into the sun for a cranking maneuver as can the solar sail. Modest inclinations can still be reached through slower cranking or the initial inclination imparted by the launch vehicle.

Laser Electric Propulsion

An alternative to solar electric propulsion is laser electric: lasers, perhaps in earth orbit, radiate power to the spacecraft, which is collected and utilized in ion engines. The primary advantage is that higher energy flux densities at the spacecraft are possible. This would permit reducing the receiver area and so, hopefully, the spacecraft weight. To take advantage of this possibility, receivers that can operate at considerably higher temperatures than present solar cells will be needed. A recent study by Forward (1975) suggests that a significant performance gain, as compared to solar electric, may be feasible.

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* Rather et al assumed an allowable flux incident on the sail of 10^6 W/m^2, laser wavelength 0.5 μm, and laser beam size twice the diffraction limit. For this calculation, 10 km^2 of sail area and 20,000 kg total mass were assumed.

Nuclear Electric Propulsion

Nuclear electric propulsion (NEP) may use ion engines like solar electric, or, alternatively, magnetohydrodynamic drive. It obtains electricity from a generator heated by a nuclear fission reactor. Thus, NEP is not power-limited by increasing solar distance.

Previous studies indicate that an operational S/C is possible by the year 2000 with power levels up to a megawatt (electric) or more (James et al, 1976).

Preliminary estimates were made based on previous calculations for a Neptune mission. Those indicated that heliocentric escape velocity of 50-60 km/s can be obtained.

Fusion

With a fusion energy source, thermal energy could be converted to provide ion or MHD drive and charged particles produced by the nuclear reaction can also be accelerated to produce thrust.

A look at one fusion concept gave a V_∞ of about 70 km/s. The spacecraft weight was 3×10^6 kg. Controlled fusion has still to be attained.

Bussard (1960) has suggested that interstellar hydrogen could be collected by a spacecraft and used to fuel a fusion reaction.

Antimatter

Morgan (1975, 1976), James et al, (1976), and Massier (1977a and b) have recently examined the use of antimatter-matter annihilation to obtain rocket thrust. A calculation based on Morgan's concepts suggests that a V_∞ over 700 km/s could be obtained with a mass comparable to NEP.

Low Thrust Plus Gravity Assist

A possible mix of techniques discussed would be to use a low-thrust propulsion system to target a spacecraft for a Jupiter gravity assist to achieve a very high V_∞ escape. If for example one accelerated a spacecraft to a parabolic orbit as it crossed the orbit of Jupiter, the V_{in} at Jupiter would be about 17.2 km/s. One could use gravity assist then to give a solar system escape V_∞ of 24 km/s in the ecliptic plane, or inclinations up to about 63° above the plane. Powered swingby at Jupiter could further enhance both V_∞ and inclination.

A second possibility is to use a solar sail to crank the spacecraft into a retrograde (180° inclination) orbit and then spiral out to encounter Jupiter at a V_{in} of over 26 km/s. This would result in escape V_{∞} 's on the order of 30 km/s and inclinations up to 90°, thus covering the entire celestial sphere. Again, powered swingby would improve performance but less so, because of the high V_{in} already present. This method is somewhat limited by the decreasing bend angle possible at Jupiter as V_{in} increases. With still higher approach velocities the possible performance increment from a Jupiter swingby continues to decrease.

Solar Plus Nuclear Electric

One might combine solar electric with nuclear electric, using solar first and then, when the solar distance becomes greater and the solar distance becomes greater and the solar power falls off, switching to NEP. Possibly the same thrusters could be used for both. Since operating lifetime of the nuclear reactor can limit the impulse attainable with NEP, this combination might provide higher V_{∞} than either solar or nuclear electric single-stage systems.

CHOICE OF PROPULSION

Of the various propulsion techniques outlined above, the only ones that are likely to provide solar system escape velocities above 50 km/s utilize either sails or nuclear energy.

The sail technique could be used with two basic options: solar sailing, going in to perhaps 0.1 AU from the sun, and laser sailing. In either case, the requirements on the sail are formidable. Figure 3 shows solar sail performance attainable with various spacecraft lightness factors (ratios of solar radiation force on the S/C at normal incidence to solar gravitational force on the S/C). The sail surface mass/area ratios required to attain various V_{∞} values are listed in Table 10. For a year 2000 launch, it may be possible to attain a sail surface mass/area of 0.3 g/m^2, if the perihelion distance is constrained to 0.25 AU or more (W. Carroll, private communication). This ratio corresponds to an aluminum film about 100 nm thick, which would probably have to be fabricated in orbit. With such a sail, a V_{∞} of about 120 km/s might be obtained.

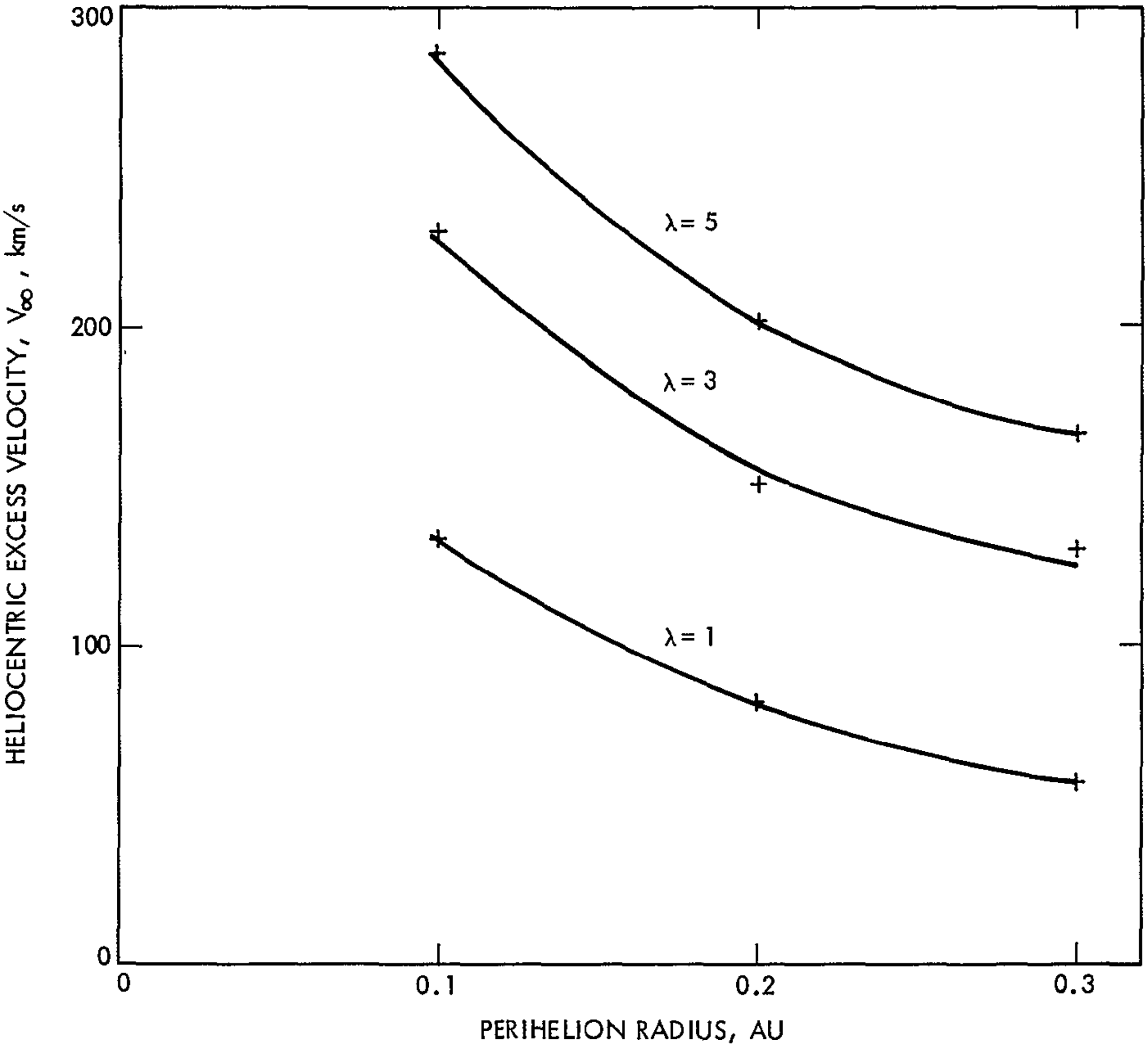

Fig. 3 Solar System Escape with Ultralight Solar Sails. Lightness factor λ = (solar radiation force on S/C at normal incidence)/(solar gravitational force on S/C). From C. Uphoff (private communication).

TABLE 10

PERFORMANCE OF ULTRALIGHT SOLAR SAILS

Initial Perihelion Distance	Heliocentric Excess Velocity, V_∞	Lightness Factor λ	Sail Load/ Efficiency σ_T/μ	Sail Surface Mass/Area σ_F
AU	km/s		g/m^2	g/m^2
0.25	60	0.8	2.0	0.9
0.25	100	1.8	0.85	0.4
0.25	200	5.5	0.3	0.12
0.1	100	0.6	2.7	1.2
0.1	200	2.2	0.7	0.3
0.1	300	5.0	0.3	0.14

Notes:

λ = (solar radiation force on S/C at normal (incidence)/(solar gravitational force on S/C)

σ_T = (total S/C mass)/(sail area)

μ = sail efficiency

σ_F = includes sail film, coatings, and seams; excludes structural and mechanical elements of sail and non-propulsive portions of S/C. Assumed here: $\sigma_F = 0.5\ \sigma_T$; $\mu = 0.9$.

Initial orbit assumed: semi-major axis $\approx 1 \times 10^8$ km. Sail angle optimized for maximum rate of energy gain.

If the perihelion distance is reduced to 0.1 AU the solar radiation force increases but so does the temperature the sail must withstand. With a reflectivity of 0.9 and an emissivity of 1.0 the sail temperature would reach 470°C (740 K), so high temperature material would have to be used. Further, according to Carroll (ibid), it may never be possible to obtain an emissivity of 1.0 with a film mass less than 1 g/m^2, because of the emitted wavelength/thickness ratio. For such films an emissivity of 0.5 is probably attainable; this would increase the temperature to over 600° C (870 K). Carbon films can be considered, but they would need a smooth highly reflective surface. It is doubtful a sail surface mass/area less than 1 g/m^2 could be obtained for use at 600° C. This sail should permit reaching V_∞ of 110 km/s: no better than for the 0.25 AU design.

For laser sailing, higher reflectivity, perhaps 0.99, can be attained because the monochromatic incident radiation permits effective use of interference layers (Carroll, ibid). Incident energy flux equivalent to 700 "suns" (at 1 AU) is proposed, however. The high reflectivity coating reduces the absorbed energy to about the level of that for a solar sail at 0.1 AU, with problems mentioned above. V_∞'s up to 200 km/s might be achieved if the necessary very high power lasers were available in orbit.

Considering nuclear energy systems, a single NEP stage using fission could provide perhaps 60 to 100 km/s V_∞. NEP systems have already been the subject of considerable study and some advanced development. Confidence that the stated performance can be obtained is therefore higher than for any of the competing modes. Using 2 NEP stages or a solar electric followed by NEP, higher V_∞ could be obtained: one preliminary calculation for 2 NEP stages (requiring 3 shuttle launches or the year 2000 equivalent) gave V_∞ = 150 km/s.

The calculation for a fusion propulsion system indicates 30% spacecraft velocity improvement over fission, but at the expense of orders of magnitude heavier vehicle. The cost would probably be prohibitive. Moreover, controlled fusion has not yet been attained, and development of an operational fusion propulsion system for a year 2000 launch is questionable. As to collection of hydrogen enroute to refuel a fusion reactor, this is further in the future and serious question exists as to whether it will ever be feasible (Martin, 1972, 1973).

An antimatter propulsion system is even more speculative than a fusion system and certainly would not be expected by 2000. On the other hand, the very rough calculations indicate an order of magnitude velocity improvement over fission NEP without increasing vehicle mass. Also, the propulsion burn time is reduced by an order of magnitude.

On the basis of these considerations, a fission NEP system was selected as baseline for the remainder of the study. The very lightweight solar sail approach and the high temperature laser sail approach may also be practical for a year 2000 mission and deserve further study. The antimatter concept is the most "far out", but promises orders of magnitude better performance than NEP. Thus, in future studies addressed to star missions, antimatter propulsion should certainly be considered, and a study of antimatter propulsion per se is also warranted.

MISSION CONCEPT

The concept which evolved as outlined above is for a mission outward to 500-1000 AU, directed toward the incoming interstellar gas. Critical science measurements would be made when passing through the heliopause region and at as great a range as possible thereafter. The location of the heliopause is unknown but is estimated as 50-100 AU. Measurements at Pluto are also desired. Launch will be nominally in the year 2000.

The maximum spacecraft lifetime considered reasonable for a year 2000 launch is 50 years. (This is discussed further, below). To attain 500-1000 AU in 50 years requires a heliocentric excess velocity of 50-100 km/s. The propulsion technique selected as baseline is NEP using a fission reactor. Either 1 or 2 NEP stages may be used. If 2 NEP stages are chosen, the first takes the form of an NEP booster stage and the second is the spacecraft itself. The spacecraft, with or without an NEP booster stage, is placed in low earth orbit by some descendant of the Shuttle. NEP is then turned on and used for spiral earth escape. Use of boosters with lower exhaust velocity to go to high earth orbit or earth escape is not economical. The spiral out from low earth orbit to earth escape uses only a small fraction of the total NEP burn time and NEP propellant.

After earth escape, thrusting continues in heliocentric orbit. A long burn time is needed to attain the required velocity: 5 to 10 years are desirable for single stage NEP (see below), and more than 10 years if two NEP stages are used. The corresponding burnout distance, depending on the design, may be as great as 200 AU or even more. Thus, propulsion may be on past Pluto (31 AU from the sun in 2005) and past the heliopause. To measure the mass of Pluto, a coasting trajectory is needed; thrust would have to be shut off temporarily during the Pluto encounter. The reactor would continue operating at a low level during the encounter to furnish spacecraft power. Attitude control would preferably be by momentum wheels to avoid any disturbance to the mass measurements. Scientific measurements, including imagery, would be made during the fast flyby of Pluto.

After the Pluto encounter, thrusting would resume and continue until nominal thrust termination ("burnout") of the spacecraft. Enough propellant is retained at spacecraft burnout to provide attitude control (unloading the momentum wheels) for the 50 year duration of the extended mission. At burnout the reactor power level is reduced and the reactor provides power for the spacecraft, including the ion thrusters used for attitude control.

A very useful add-on would be a Pluto Orbiter. This daughter spacecraft would be separated early in the mission, at approximately the time solar escape is achieved. Its flight time to Pluto would be about 12 years and its hyperbolic approach velocity at Pluto about 8 km/s.

The orbiter would be a full-up daughter spacecraft, with enough chemical propulsion for midcourse, approach, and orbital injection. It would have a full complement of science instruments (including imaging) and RTG power sources, and would communicate directly to Earth.

Because the mass of a dry NEP propulsion system is much greater than that required for the other spacecraft systems, the added mass of a daughter S/C has relatively little effect on the total inert mass and therefore relatively little effect on propulsive performance. The mother NEP spacecraft would fly by Pluto 3 or 4 years after launch, so the flyby data will be obtained at least 5 years before the orbiter reaches Pluto. Accordingly, the flyby data can be used in selecting the most suitable orbit for the daughter spacecraft.

If a second spacecraft is to be flown out parallel to the solar axis, it could be like the one going toward the incoming interstellar gas, but obviously would not carry an orbiter. Since the desired heliocentric escape direction is almost perpendicular to the ecliptic, somewhat more propulsive energy will be required than for the S/C going upwind, if the same escape velocity is to be obtained. A Jupiter swingby may be helpful. An NEP booster stage would be especially advantageous for this mission.

MASS DEFINITION AND PROPULSION

The NEP system considered is similar to those discussed by Pawlik and Phillips (1977) and by Stearns (1977). As a first rule-of-thumb approximation the dry NEP system should be approximately 30-35 percent of the spacecraft mass. A balance is then required between the net spacecraft and propellant, with mission energy and exhaust velocity being variable. For the very high energy requirements of the extraplanetary mission, spacecraft propellant expenditure of the order of 40-60 percent may be appropriate. A booster stage, if required, may use a lower propellant fraction, perhaps 30 percent.

Power and propulsion system mass at 100-140 km/s exhaust velocity will be approximately 17 kg/kWe. This is based on a 500 kWe system with 20% conversion efficiency and ion thrusters. Per unit mass may decrease slightly at higher power levels and higher exhaust velocity. Mercury propellant is desired because of its high liquid density, $\sim 13.6\ g/cm^3$ or $13,600\ kg/m^3$. Mercury is also a very effective gamma shield. If an NEP booster is to be used, it is assumed to utilize two 500 kWe units.

The initial mass in low earth orbit (M_o) is taken as 32,000 kg for the spacecraft (including propulsion) and as 90,000 kg for the spacecraft plus NEP booster. 32,000 kg is slightly heavier than the 1977 figure for the capability of a single shuttle launch. The difference is considered unimportant, because 1977 figures for launch capability will be only of historical interest by 2000. 90,000 kg for the booster plus S/C would require the year 2000 equivalent of three 1977 Shuttle launches.

Figure 4 shows the estimated performance capabilities of the propulsion system for a single NEP stage.

A net spacecraft mass of approximately 1200 kg is assumed and may be broken out in many ways. Communication with Earth is a part of this and may trade off with on-board automation, computation and data processing. Support structure for launch of daughter spacecraft may be needed. Adaptive science capability is also possible. The science instruments may be of the order of 200-300 kg (including a large telescope) and utilize 200 kg of radiation shielding (discussed below) and in excess of 100 W of power. Communications could require as much as 1 kW.

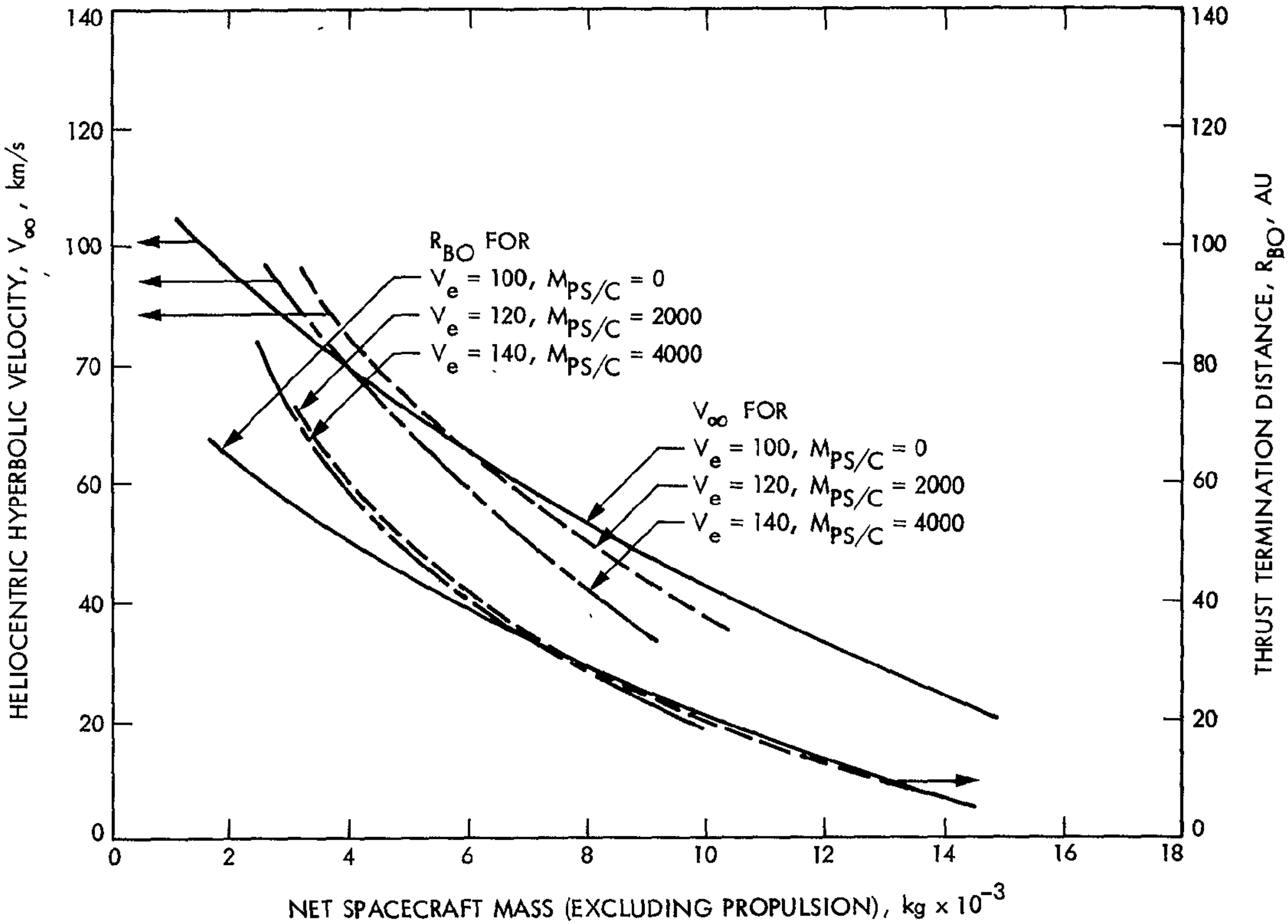

Fig. 4 Performance of NEP for Solar Escape plus Pluto.
α = Ratio (propulsion system dry mass less tankage)/(power input to thrust subsystem) = 17 kg/kWe.
M_o = initial mass (in low Earth orbit) = 32,000 kg.
$M_{PS/C}$ = mass of a Pluto S/C separated when heliocentric escape velocity is attained (kg).
V_e = exhaust velocity (km/s).

One to two kWe of auxiliary power is a first order assumption.

The Pluto Orbiter mass is taken as 500 kg plus 1000 kg of chemical propellant. This allows a total ΔV of approximately 3500 m/s and should permit a good capture orbit at Pluto.

The reactor burnup is taken to be the equivalent of 200,000 hours at full power. This will require providing reactor control capability beyond that in existing NEP concepts. This could consist of reactivity poison rods or other elements to be removed as fission products build up, together with automated power system management to allow major improvement in adaptive control for power and propulsion functions. The full power operating time is, however, constrained to 70,000 h (approximately 8 yr). The remaining burnup is on reduced power operation for S/C power and attitude control. At 1/3 power, this could continue to the 50 yr mission duration.

Preliminary mass and performance estimates for the selected system are given in Table 11. These are for a mission toward the incoming interstellar wind. The Pluto orbiter, separated early in the mission, makes very little difference in the overall performance. The NEP power level, propellant loading, and booster specific impulse were not optimized in these estimates; optimized performance would be somewhat better.

According to Table 11, the performance increment due to the NEP booster is not great. Unless an optimized calculation shows a greater increment, use of the booster is probably not worthwhile.

For a mission parallel to the solar axis, a Jupiter flyby would permit deflection to the desired 83° angle to the ecliptic with a small loss in V_∞. (The approach V_{in} at Jupiter is estimated to be 23 km/s).

TABLE 11

Mass and Performance Estimates for Baseline System

(I_{sp} and propellant loading not yet optimized)

Allocation		Mass kg	
Spacecraft		1200	
Pluto orbiter (optional)		1500	
NEP (500 kWe)		8500	
Propellant:	Earth spiral	2100	
	Heliocentric	18100	
Tankage		600	
Total for 1-stage (M_o, earth orbit)			32000
Booster		58000	
Total for 2-stage (M_o, earth orbit)			90000

Performance		1 Stage	2 Stages
Booster burnout:	Distance	-	8 AU
	Hyperbolic velocity	-	25 km/s
	Time	-	4 yr
Spacecraft burnout:	Distance (total)	65	155 AU
	Hyperbolic velocity	105	150 km/s
	Time (total)	8	12 yr
Distance in:	20 yr	370	410 AU
	50 yr	1030	1350 AU

INFORMATION MANAGEMENT

DATA GENERATION

In cruise mode, the particles and fields instruments, if reading continuously, will generate 1 to 2 kb/s of data. Engineering sensors will provide less. Spectrometers may provide higher raw data rates but only occasional spectrometric observations would be needed. Star TV, if run at 10 frames/day (exposures would probably be several hours) at 10^8 b/frame would provide about 10 kb/s on the average. A typical TV frame might include 10 star images whose intensity need be known only roughly for identification. Fifteen position bits on each axis and 5 intensity bits would make 350 b/frame or 0.04 b/s of useful data. Moreover, most of the other scientific quantities mentioned would be expected to change very slowly, so that their information rate will be considerably lower than their raw data rate. Occasional transients may be encountered, and in the region of the heliopause and shock rapid changes are expected.

During Pluto flyby, data accumulates rapidly. Perhaps 10^{11} bits, mostly TV, will be generated. These can be played back over a period of weeks or months. If a Pluto orbiter is flown, it could generate 10^{10} b/day or more: an average of over 100 kb/s.

INFORMATION MANAGEMENT SYSTEM

Among the functions of the information handling system will be storage and processing of the above data. The system compresses the data, removing the black sky that will constitute almost all of the raw bits of the star pictures. It will remove the large fraction of bits that need not be transmitted when a sensor gives a steady or almost-steady reading. It will vary its processing and the output data stream to accommodate transients during heliopause encounter and other unpredictable periods of high information content.

The spacecraft computers system will provide essential support to the automatic control of the nuclear reactor. It will also support control, monitoring, and maintenance of the ion thrusters, and of the attitude control system, as well as antenna pointing and command processing.

According to James et al (1976), the following performance is projected for a S/C information management system for a year 2000 launch:

Processing rate:	10^9 instruction/s
Data transfer rate:	$\sim 10^9$ b/s
Data storage:	$\sim 10^{14}$ b
Power consumption:	10 - 100 W
Mass:	~30 kg

This projection is based on current and foreseen state of the art and ignores the possibility of major breakthroughs. Obviously, if reliability requirements can be met, the onboard computer can provide more capability than is required for the mission.

The processed data stream provided by the information management system for transmission to earth is estimated to average 20-40 b/s during cruise. Since continuous transmission is not expected (see below), the output rate during transmission will be higher.

At heliosphere encounter, the average rate of processed data is estimated at 1-2 kb/s.

From a Pluto encounter, processed data might be several times 10^{10} bits. If these are returned over a 6-month period, the average rate over these months is about 2 kb/s. If the data are returned over a 4-day period, the average rate is about 100 kb/s.

OPERATIONS

For a mission lasting 20-50 years, with relatively little happening most of the time, it is unreasonable to expect continuous DSN coverage. For the long periods of cruise, perhaps 8 h of coverage per month, or 1% of the time, would be reasonable.

When encounter with the heliopause is detected, it might be possible to increase the coverage for a while; 8 h/day would be more than ample. Since the time of heliosphere encounter is unpredictable, this possibility would depend on the ability of the DSN to readjust its schedule quickly in near-real time.

For Pluto flyby, presumably continuous coverage could be provided. For Pluto orbiters, either 8 or 24 h/day of coverage could be provided for some months.

DATA TRANSMISSION RATE

On the basis outlined above, the cruise data, at 1% of the time, would be transmitted at a rate of 2-4 kb/s.

If heliopause data is merely stored and transmitted the same 1% of the time, the transmission rate rises to 100-200 kb/s. An alternative would be to provide more DSN coverage once the heliosphere is found. If 33% coverage can be obtained, the rate falls to 3-7 kb/s.

For Pluto flyby, transmitting continuously over a 6-month period, the rate is 2 kb/s. At this relatively short range, a higher rate, say, 30-100 kb/s, would probably be more appropriate. This would return the encounter data in 4 days.

The Pluto orbiter requires a transmission rate of 30-50 kb/s at 24 h/day or 90-150 kb/s at 8 h/day.

TELEMETRY

The new and unique feature of establishing a reliable telecommunications link for an extraplanetary mission involves dealing with the enormous distance between the spacecraft (S/C) and the receiving stations on or near Earth. Current planetary missions involve distances between the S/C and receiving stations of tens of astronomical units (AU) at most. Since the extraplanetary mission could extend this distance to 500 or 1000 AU, appropriate extrapolation of the current mission telecommunication parameters must be made. Ideally, this extrapolation should anticipate technological changes that will occur in the next 20-25 years and accordingly incorporate them into the telecommunications system design. In trying to achieve this ideal we have developed a "baseline" design that represents reasonably low risk. Other options which could be utilized around the year 2000 but which may require technological advancement (e.g. development of solid state X-band or Ku-band transmitters) or may depend upon NASA's committing substantial funds for telemetry link reconfiguration (e.g., construction of a spaceborne deep space receiver) are examined to determine how they might affect link capabilities.

In the following paragraphs, the basic model for the telecommunications link is developed. Through the range equation, transmitted and received powers are related to wavelength, antenna dimensions, and separation between antennas. A currently used form of coding is assumed while some tracking loop considerations are examined. A baseline design is outlined. The contributions and effects of various components to link performance is given in the form of a "dB" table breakdown. Other options of greater technological or funding risk are treated. Finally, we compare capability of the various telemetry options with requirements for various phases of the mission and identify the telemetry - operations combinations that provide the needed performance.

THE TELECOMMUNICATION MODEL

Range Equation

We need to know how much transmitted power is picked up by the receiving antenna. The received power P_r is given approximately by

$$P_r = \eta P A_r/(\lambda R)^2 \qquad (1)$$

where

- η = product of all pertinent efficiencies, i.e., transmitter power conversion efficiency, antenna efficiencies, etc.
- P = power to transmitter
- A_t, A_r = areas of transmitter, receiver antennas respectively
- λ = wavelength of transmitted radiation
- R = range to spacecraft

This received signal is corrupted by noise whose effective power spectral density will be denoted by N_0.

Data Coding Considerations

We are assuming a Viterbi (1967) coding scheme with constraint length K = 7 and rate v = 1/3. This system has demonstrated quite good performance producing a bit error rate (BER) of 10^{-4} when the information bit SNR is ρ_D = 3.2 dB (Layland, 1970). Of course, if more suitable schemes are developed in the next 20-25 years, they should certainly be used.

Tracking Loop Considerations

Because of the low received power levels that can be expected in this mission, some question arises as to whether the communication system should be coherent or non-coherent. The short term stability of the received carrier frequency and the desired data rate R_D roughly determine which system is better. From the data coding considerations we see that

$$P_D/N_0 \gtrsim \rho_D R_D \approx 2\ R_D \tag{2}$$

where P_D is the power allocated to the data. Standard phase-locked loop analysis (Lindsey, 1972) gives for the variance σ^2 of the phase error in the loop

$$\sigma^2 \approx N_0\ B_L/P_L \tag{3}$$

where P_L is the power allocated to phase determination and B_L is the closed loop bandwidth (one-sided). In practice, $\sigma^2 \lesssim 10^{-2}$ for acceptable operation, so

$$P_L/N_0 \gtrsim 100\ B_L \tag{4}$$

The total received power P_r (eq. (1)) is the sum of P_L and P_D. To minimize P_r/N_0 subject to the constraint eqs. (2) and (4), we see that a fraction

$$\frac{2R_D}{100\ B_L + 2\ R_D} \tag{5}$$

of the received power must go into the data. Since coherent systems are 3 dB better than non-coherent systems for binary signal detection (Wozencraft and Jacobs, 1965), coherent demodulation is more efficient whenever

$$R_D \gtrsim 50\ B_L \tag{6}$$

Current deep space network (DSN) receivers have $B_L \gtrsim 10$ Hz, so for data rates roughly greater than 500 bits/s coherent detection is desirable. However, the received carrier frequencies suffer variations from Doppler rate, atmospheric (ionospheric) changes, oscillator drifts, etc. If received carrier instabilities for the extraplanetary mission are sufficiently small so that a tracking loop bandwidth of 1 Hz is adequate, then data rates greater than 50 bits/s call for coherent demodulation.

These remarks are summarized by the relation between P_r/N_0 and data rate R_D:

$$P_r/N_0 = \begin{cases} 2R_D + 100\,B_L & \text{for } R_D \geq 50\,B_L \text{ (coherent system)} \\ 4R_D & \text{for } R_D \leq 50\,B_L \text{ (non-coherent system)} \end{cases} \tag{7}$$

This relation is displayed in Figure 5 where P_r/N_0 is plotted vs R_D for B_L having values 1 Hz and 10 Hz. In practice for $R_D > 50\,B_L$ the approach of P_r/N_0 to its asymptotic value of $2\,R_D$ could be made slightly faster by techniques employing suppressed carrier tracking loops which utilize all the received power for both tracking and data demodulation. However, for this study these curves are sufficiently accurate to ascertain P_r/N_0 levels necessary to achieve desired data rates.

BASELINE DESIGN

Parameters of the System

For a "baseline" design we have tried to put together a system that has a good chance of being operational by the year 2000. Consequently in certain areas we have not pushed current technology but have relied on fairly well established systems. In other areas, we have extrapolated from present trends, but hopefully not beyond developments that can be accomplished over 20-25 years. This baseline design will be derived in sufficient detail so that the improvement afforded by the "other options" discussed in the next section can be more easily ascertained.

First, we assume that received carrier frequency stabilities allow tracking with a loop bandwidth $B_L \lesssim 1$ Hz. This circumstance is quite likely if an oscillator quite stable in the short term is carried on the S/C, if the propulsion systems are not operating during transmission at 1000 AU (Doppler rate essentially zero), and if the receiver is orbiting Earth (no ionospheric disturbance). Second, we assume data rates R_D of at least 100 bits/s at 1000 AU or 400 b/s at 500 AU are desired. From the discussion preceding eq. (6) and Figure 5 we see this implies a coherent demodulation system with P_r/N_0 to exceed 25 dB.

As a baseline we are assuming an X-band system (λ = 3.55 cm) with 40 watts transmitter power. We assume the receiving antenna is on Earth (if this assumption makes B_L = 1 Hz unattainable, then the value of P_r/N_0 for the non-coherent system only increases by 1 dB) so the system noise temperature reflects this accordingly.

Decibel Table and Discussion

In Table 12 we give the dB contributions from the various parameters of the range eq. (1), loop tracking, and data coding. By design the parameters of this table give the narrowest performance margins. If any of the "other options" of the next section can be realized, performance margin and data rate should correspondingly increase.

The two antenna parameters that are assumed require some explanation. A current mission (SEASAT-A) has an imaging radar antenna that "unfurls" to a rectangular shape 10.75 m x 2 m, so a 15 m diameter spaceborne antenna should pose no difficulty by the year 2000. A 100 m diameter receiving antenna is assumed. Even though the largest DSN antenna is currently 64 m, an antenna and an array both having effective area $\gtrsim$ (100 m)^2 will be available in West Germany and in this country in the next five years. Consequently, a receiver of this collecting area could be provided for the year 2000.

OPTIONS

More Power

The 40 watts transmitter power of the baseline should be currently realizable being only a factor of 2 above the Voyager value. This might be increased to 0.5 - 1 kW, increasing received signal power by almost 10-15 dB, allowing (after some increase in performance margin) a tenfold gain in data rate: 1 kb/s at 1000 AU, 4 kb/s at 500 AU. The problem of coupling this added energy into the transmission efficiently may cause some difficulty and should definitely be investigated.

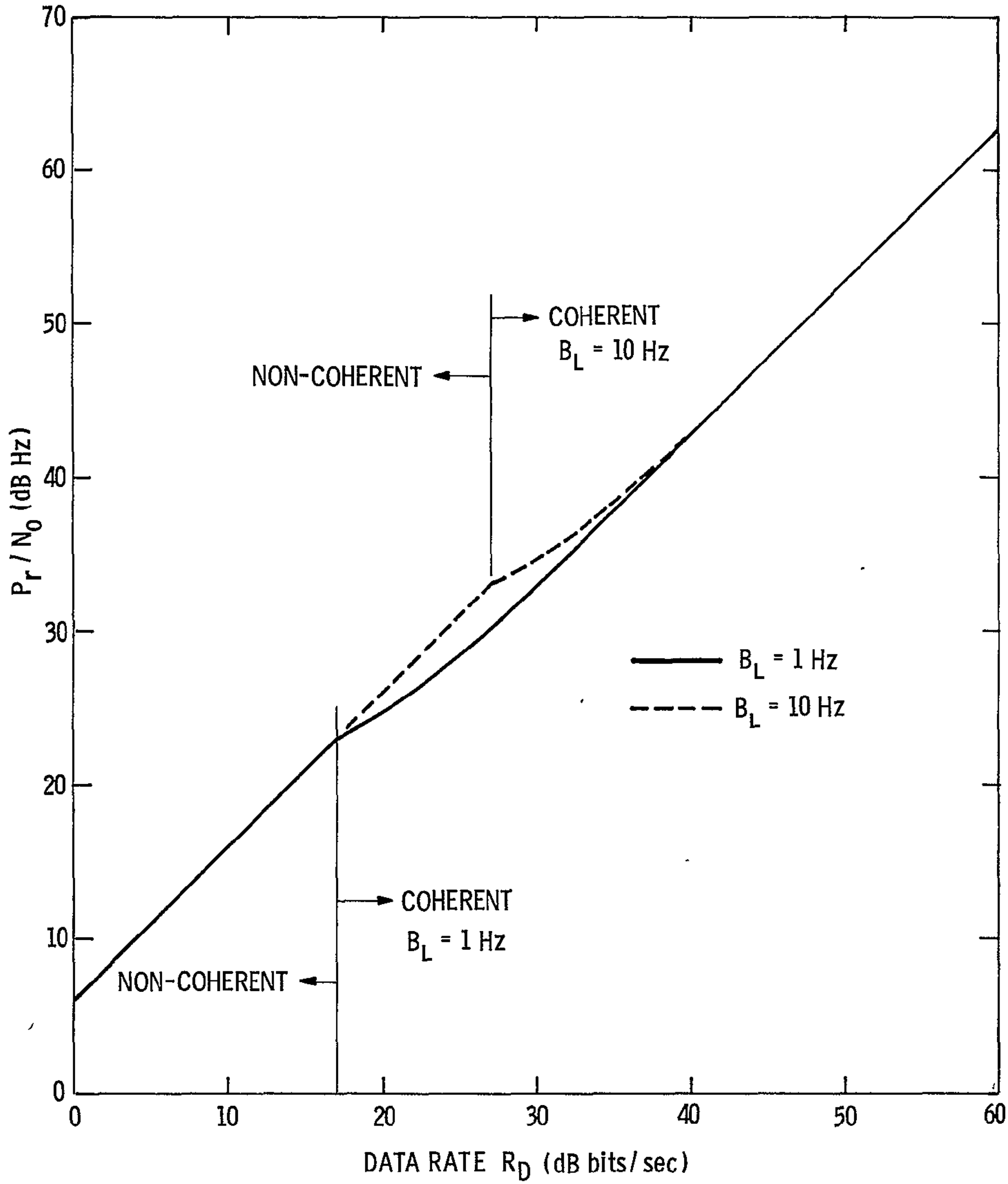

Fig. 5. Data Rate vs. Ratio of Signal Power to Noise Spectral Power Density

Table 12. BASELINE TELEMETRY AT 1000 AU

No.	Parameter	Nominal Value
1.	Total Transmitter power (dBm) (40 watts)	46
2.	Efficiency (dB) (electronics and antenna losses)	-9
3.	Transmitting antenna gain (dB) (diameter = 15 m)	62
4.	Space loss (dB) $(\lambda/4\pi R)^2$	-334
	λ = 3.55 cm, R = 1000 AU	
5.	Receiving antenna gain (dB) (diameter = 100m)	79
6.	Total received power (dBm) (P_r)	-156
7.	Receiver noise spectral density (dBm/Hz) (N_0)	
	kT with T = 25 K	-185
	Tracking (if B_L = 1 Hz is achievable)	
8.	Carrier power/total power 9dB)	-5
	$(100\ B_L/(100B_L + 2\ R_D))$	
9.	Carrier power (dBm) (6 + 8)	-161
10.	Threshold SNR in 2 B_L (dB)	20
11.	Loop noise bandwidth (dB) (B_L)	0
12.	Threshold carrier power (dBm) (7 + 10 + 11)	-165
13.	Performance margin (dB) (9 - 12)	4
	Data Channel	
14.	Estimated loss (waveform distortion, bit sync,	
	etc.) (dB)	-2
15.	Data power/total power (dB)*	-2
	$(2R_D/(100B_L + 2R_D))$	
16.	Data power (dBm) (6 + 14 + 15)*	-160
17.	Threshold data power (dBm) (7 + 17a + 17b)	-162
	a. Threshold P_rT/N_0 (BER = 10^{-4})	3
	b. Bit rate (dB BPS)	20
18.	Performance margin (dB) (16 - 17)*	2

*If a non-coherent system must be used each of these values are reduced by approximately 1 dB.

Larger Antennas and Lower Noise Spectral Density

If programs calling for orbiting DSN station are funded, then larger antennas operating at lower noise spectral densitites should become a reality. Because structural problems caused by gravity at the Earth's surface are absent, antennas even as large as 300 m in diameter have been considered. Furthermore, assuming problems associated with cryogenic amplifiers in space can be overcome, current work indicates X-band and Ku-band effective noise temperatures as low as 10 K and 14 K respectively (R. C. Clauss, private communication). These advances would increase P_r/N_0 by approximately 12-13 dB making a link at data rates of 2 kb/s at 1000 AU and 8 kb/s at 500 AU possible.

Higher Frequencies

Frequencies in the Ku-band could represent a gain in directed power of 5-10 dB over the X-band baseline, but probably would exhibit noise temperatures 1-2 dB worse (Clauss, ibid) for orbiting receivers. Also, the efficiency of a Ku-band system would probably be somewhat less than that of X-band. Without further study, it is not apparent that dramatic gains could be realized with a Ku-band system.

Frequencies in the optical or infrared potentially offer tremendous gains in directed power. However, the efficiency in coupling the raw power into transmission is not very high, the noise spectral density is much higher than that of X-band, and the sizes of practical antennas are much smaller than those for microwave frequencies. To present these factors more quantitatively, Table 13 gives parameter contributions to P_r and N_0. We have drawn heavily on Potter et al (1969) and on M. S. Shumate and R. T. Menzies (private communication) to compile this table. We assume an orbiting receiver to eliminate atmospheric transmission losses. Also, we assume demodulation of the optical signal can be accomplished as efficiently as the microwave signal (which is not likely without some development). Even with these assumptions, P_r/N_0 for the optical system is about 8 dB worse than that for X-band with a ground receiver.

Pointing problems also become much more severe for the highly directed optical, infrared systems. Laser radiation at wavelength 10 μm from a 1 m antenna must be pointed to 5×10^{-6} radians accuracy. The corresponding pointing accuracy of the baseline system is 10^{-3} radians.

Table 13. OPTICAL TELEMETRY AT 1000 AU

No.	Parameter	Nominal Value
1.	Total Transmitter power (dBm) (40 watts)	46
2.	Efficiency (dB) (optical pumping, antenna losses, and quantum detection)	-16
3.	Transmitting antenna gain (dB) (diameter = 1 m)	110
4.	Space loss (dB) $(\lambda/4\pi r)^2$	
	λ = 10 μm, r = 1000 AU	-405
5.	Receiving antenna gain (dB) (diameter = 3m)	119
6.	Total Received power (dBm) (P_r)	-146
7.	Receiver noise spectral density (dBm/Hz) (N_0) (2×10^{-20} watt/Hz)	-167

Higher Data Rates

This mission may have to accommodate video images from Pluto. The Earth-Pluto separation at the time of the mission will be about 31 AU. The baseline system at 31 AU could handle approximately 10^5 b/s. For rates in excess of this, one of the "other option" enhancements would be necessary.

SELECTION OF TELEMETRY OPTION

Table 14 collects the performance capabilities of the various telemetry options. Table 15 shows the proposed data rates in various S/C systems for the different phases of the mission. In both tables the last column lists the product, (data rate) x $(\text{range})^2$, as an index of the telemetry capability or requirements.

Looking first at the last column of Table 15 , it is apparent that the limiting requirement is transmittal of heliopause data if DSN coverage can be provided only 1% of the time. If DSN scheduling is sufficiently flexible that 33% coverage can be cranked up within a month or so after the heliosphere is detected, then the limiting requirement is transmittal of cruise data (at 1% DSN coverage). For these two limiting cases, the product (data rate) x $(\text{range})^2$ is, respectively, 2-40 x 10^8 and 5-10 x 10^8 (b/s) · AU^2.

Looking now at the last column of Table 14 , to cover the cruise requirement some enhancement over the baseline option will be needed. Either increasing transmitter power to 0.5-1 kW or going to orbiting DSN stations will be adequate. No real difficulty is seen in providing the increased transmitter power if the orbiting DSN is not available.

If, however, DSN coverage for transmittal of recorded data from the unpredictable heliosphere encounter is constrained to 1% of the time (8 h/month), then an orbital DSN station (300-m antenna) will be needed for this phase of the mission, as well as either increased transmitter power or use of K-band.

TABLE 14

TELEMETRY OPTIONS

OPTIONS	Improvement Over Baseline, dB	Data Rate (b/s) At 1000 AU	At 500 AU	At 150 AU	At 31 AU	(Data Rate) x (Range)^2 (b/s) · AU^2
Baseline (40 W, 100-m receiving antenna, X-band)	----	1×10^2	4×10^2	4×10^3	1×10^5	1×10^8
More power (0.5 - 1 kW)	10-15	1×10^3	4×10^3	4×10^4	1×10^6	1×10^9
Orbiting DSN (300-m antenna)						
X-band (10 K noise temperature)	13	2×10^3	8×10^3	9×10^4	2×10^6	2×10^9
K-band (14 K noise temperature)	17	5×10^3	2×10^4	2×10^5	5×10^6	5×10^9
Both more power and orbiting DSN						
X-band	23-28	3×10^4	1.2×10^5	1×10^6	3×10^7	3×10^{10}

TABLE 15

PROPOSED DATA RATES

Mission Phase	Tele-Communication Range AU	Estimated Data Rate, b/s — Raw Data	Processed Data, Average	Transmitted Data	Fraction of Time Transmitting	(Data rate x (Range)^2 b/s · AU^2
Cruise	500	$1.2\text{–}1.5 \times 10^4$	$2\text{–}4 \times 10^1$	$2\text{–}4 \times 10^3$	0.01	$5\text{–}10 \times 10^8$
Heliopause	50–150	$1.2\text{–}1.5 \times 10^4$	$1\text{–}2 \times 10^3$	$1\text{–}2 \times 10^5$	0.01	$2\text{–}40 \times 10^8$
				$3\text{–}7 \times 10^3$	0.33	$0.8\text{–}15 \times 10^7$
Pluto Flyby	~31	$1\text{–}2 \times 10^5$ (10^{11} total bits)	$3\text{–}5 \times 10^4$ (3×10^{10} bits)	1×10^5	0.33*	1×10^8
				3×10^4	1.00*	3×10^7
Pluto Orbiter	~31	$1\text{–}2 \times 10^5$	$3\text{–}5 \times 10^4$	$9\text{–}15 \times 10^4$	0.33	$9\text{–}15 \times 10^7$
				$3\text{–}5 \times 10^4$	1.00	$3\text{–}5 \times 10^7$

*To return flyby data in 4 days.

RELATION OF THE MISSION TO SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE

The relation of this mission to the search for extraterrestrial intelligence appears to lie only in its role in development and test of technology for subsequent interstellar missions.

TECHNOLOGY REQUIREMENTS AND PROBLEM AREAS

LIFETIME

A problem area common to all S/C systems for this mission is that of lifetime. The design lifetime of many items of spacecraft equipment is now approaching 7 years. To increase this lifetime to 50 years will be a very difficult engineering task.

These consequences follow:

a) It is proposed that the design lifetime of the S/C for this mission be limited to 20 years, with an extended mission contemplated to a total of 50 years.

b) Quality control and reliability methods, such as failure mode effects and criticality analysis, must be detailed and applied to the elements that may eventually be used in the spacecraft, so as to predict what the failure profile will be for system operating times that are much longer than the test time and extend out to 50 years. One approach is to prepare for design and fabrication from highly controlled materials whose failure modes are completely understood.

c) To the extent that environmental or functional stresses are conceived to cause material migration or failure during a 50-year period, modeling and accelerated testing of such modes will be needed to verify the 50-year scale. Even the accelerated tests may require periods of many years.

d) A major engineering effort will be needed to develop devices, circuits, components, and fabrication techniques which, with appropriate design, testing, and quality assurance methods, will assure the lifetime needed.

PROPULSION AND POWER

The greatest need for subsystem development is clearly in propulsion. Further advance development of NEP is required. Designs are needed to permit higher uranium loadings and higher burnup. This in turn will require better control systems to handle the increased reactivity, including perhaps throw-away control rods. Redundancy must be increased to assure long life and moving parts will need especial attention. Development should also be aimed at reducing system size and mass, improving efficiency, and providing better and simpler thermal control and heat dissipation. Simpler and lighter power conditioning is needed, as are ion thrusters with longer lifetime or self-repair capability.

Among the alternatives to fission NEP, ultralight solar sails and laser sailing look most promising. A study should be undertaken of the feasibility of developing ultralight solar sails (sails sufficiently light so that the solar radiation pressure on the sail and spacecraft system would be greater than the solar gravitational pull) and of the implications such development would have for spacecraft design and mission planning. Similarly, a study should be made of the possibility of developing a high power orbiting laser system together with high temperature spacecraft sails, and of the outer planet and extraplanetary missions that could be carried out with such laser sails.

Looking toward applications further in the future, an antimatter propulsion system appears an exceptionally promising candidate for interstellar missions and would be extremely useful for missions within the solar system. This should not be dismissed as merely "blue sky": matter-antimatter reactions are routinely carried out in particle physics laboratories. The engineering difficulties of obtaining an antimatter propulsion system will be great; containing the antimatter and producing it in quantity will obviously be problems. A study of possible approaches would be worthwhile. (Chapline (1976) has suggested that antimatter could be produced in quantity by the interaction of beams of heavy ions with deuterium/tritium in a fusion reactor). Besides this, a more general study of propulsion possibilities for interstellar flight (see Appendix C) should also be considered.

PROPULSION/SCIENCE INTERFACE

Three kinds of interactions between the propulsion/attitude control system and science measurements deserve attention. They are:

1) Interaction of thrust and attitude control with mass measurements.
2) Interaction of electrical and magnetic fields, primarily from the thrust subsystem, with particles and fields measurements.
3) Interactions of nuclear radiation, primarily from the power subsystem, with photon measurements.

Interaction of thrust with mass measurements

It is desired to measure the mass of Pluto and of the solar system as a whole through radio tracking observations of the spacecraft accelerations. In practice, this requires that thrust be off during the acceleration observations.

The requirement can be met by temporarily shutting off propulsive thrusting during the Pluto encounter and, if desired, at intervals later on. Since imbalance in attitude control thrusting can also affect the trajectory, attitude control during these periods should preferably be by momentum wheels. The wheels can afterwards be unloaded by attitude-control ion thrusters.

Interaction of thrust subsystem with particles and fields measurements

A variety of electrical and magnetic interference with particles and fields measurements can be generated by the thrust subsystem. The power subsystem can also generate some electrical and magnetic interference. Furthermore, materials evolved from the thrusters can possibly deposit upon critical surfaces.

Thruster interferences have been examined by Sellen (1973), by Parker et al. (1973), and by others. It appears that thruster interferences should be reducible to acceptable levels by proper design, but some advanced development will be needed. Power system interferences are probably simpler to handle. Essentially all the thruster effects disappear when the engines are turned off.

Interaction of power subsystem with photon measurements

Neutrons and gamma rays produced by the reactor can interfere with photon measurements. A reactor that has operated for some time will be highly radioactive even after it is shut down. Also, exposure to neutrons from the reactor will induce radioactivity in other parts of the spacecraft. In the suggested science payload the instruments most sensitive to reactor radiation are the gamma-ray instruments, and, to a lesser degree, the ultraviolet spectrometer.

A very preliminary analysis of reactor interferences has been done. Direct neutron and gamma radiation from the reactor was considered and also neutron-gamma interactions. The latter were found to be of little significance if the direct radiation is properly handled. Long-lived radioactivity is no problem except possibly for structure or equipment that uses nickel. Expected flux levels per gram of nickel are approximately 0.007 γ/cm^2-s.

The nuclear reactor design includes neutron and gamma shadow shielding to fully protect electronic equipment from radiation damage. Requirements are defined in terms of total integrated dose. Neutron dose is to be limited to 10^{12} nvt and gamma dose to 10^6 rad. A primary mission time of 20 years is assumed, yielding a LiH neutron shield thickness of 0.9 m and a mercury gamma shield thickness of 2.75 cm (or 2 cm of tungsten). Mass of this shielding is included in the 8500 kg estimate for the propulsion system.

For the science instruments, it is the flux that is important, not total dose. The reactor shadow shield limits the flux level to 1.6×10^3 neutrons or gammas/cm^2. This is apparently satisfactory for all science sensors except the gamma-ray detectors. They require that flux levels be reduced to 10 neutrons/cm^2-s and 0.1 gamma/cm^2-s. Such reduction is most economically accomplished by local shielding. The gamma ray transient detector should have a shielded area of possibly 1,200 cm^2 (48 cm x 25 cm). Its shielding will include a tungsten thickness of 8.7 cm and a lithium-hydride thickness of 33 cm. The weight of this shielding is approximately 235 kg and is included in the spacecraft mass estimate. It may also be noted that the gamma ray transient detector is probably the lowest-priority science instrument. An alternative to shielding it would be to omit this instrument from the payload. (The gamma ray spectrometer is proposed as an orbiter instrument and need not operate until the orbiter is separated from the NEP mother spacecraft). A detailed Monte Carlo analysis and shield development program will be needed to assure a satisfactory solution of spacecraft interfaces.

TELECOMMUNICATIONS

Microwave vs. Optical Telemetry Systems

Eight years ago JPL made a study of weather-dependent data links in which performance at six wavelengths ranging from S-band to the visible was analyzed (Potter et al., 1969). A similar study for an orbiting DSN (weatherindependent) should determine which wavelengths are the most advantageous. The work of this report indicates X-band or K-band are prime candidates, but a more thorough effort is required that investigates such areas as feasibility of constructing large spaceborne optical antennas, efficiency of power conversion, feasibility of implementing requisite pointing control, and overall costs.

Space Cryogenics

We have assumed cryogenic amplifiers for orbiting DSN stations in order to reach 4-5 K amplifier noise contributions. Work is being done that indicates such performance levels are attainable (R. C. Clauss, private communication; D. A. Bathker, private communication) and certainly should be continued. At the least, future studies for this mission should maintain awareness of this work and probably should sponsor some of it.

Lifetime of Telecommunications Components

The telecommunications component most obviously vulnerable to extended use is the microwave transmitter. Current traveling-wave-tube (TWT) assemblies have demonstrated 11-12 year operating lifetimes (H. K. Detweiler, private communication; also, James et al., 1976) and perhaps their performance over 20-50 year intervals could be simulated. However, the simple expedient measure of carrying 4-5 replaceable TWT's on the missions might pose a problem since shelf-lifetimes (primarily limited by outgasing) are not known as well as the operating lifetimes. A more attractive solution is use of solid-state transmitters. Projections indicate that by 1985 to 1990 power transistors for X-band and Ku-band will deliver 5-10 watts/device and a few watts/device respectively with lifetimes of 50-100 years (J. T. Boreham, private communication). Furthermore, with array feed techniques, 30-100 elements could be combined in a near-field Cassegrainian reflector for signal transmission (Boreham, ibid). This means a Ku-band system could probably operate at a power level of 50-200 watts and an X-band system could likely utilize 0.2 - 1 kW.

Other solid state device components with suitable modular replacement strategies should endure a 50 year mission.

Baseline Enhancement vs. Non-Coherent Communication System

The coherent detection system proposed requires stable phase reference tracking with a closed loop bandwidth of approximately 1 Hz. Of immediate concern is whether tracking with this loop bandwidth will be stable. Moreover, if the tracking is not stable, what work is necessary to implement a non-coherent detection system?

The most obvious factors affecting phase stability are the accelerations of the S/C, the local oscillator on the S/C, and the medium between transmitter and receiver. If the propulsion system is not operating during transmission, the first factor should be negligible. However, the feasibility of putting on board a very stable (short term) local oscillator with a 20-50 year lifetime needs to be studied. Also, the effect of the Earth's atmosphere and the planetary or extraplanetary media on received carrier stability must be determined.

If stability cannot be maintained, then trade-off studies must be performed between providing enhancements to increase P_r/N_0 and employing non-coherent communication systems.

INFORMATION SYSTEMS

Continued development of the on-board information system capability will be necessary to support control of the reactor, thrusters, and other portions of the propulsion system, to handle the high rates of data acquisition of a fast Pluto flyby, to perform on-board data filtering and compression, etc. Continued rapid development of information system capability to very high levels is assumed, as mentioned above, and this is not considered to be a problem.

THERMAL CONTROL

The new thermal control technology requirement for a mission beyond the solar system launched about 2000 A.D. involve significant advancements in thermal isolation techniques, in heat transfer capability and in lifetime extension. Extraplanetary space is a natural cryogenic region (~3 K). Advantage may be taken of it for passive cooling of detectors in scientific instruments and also for the operation of cryogenic computers. If cryogenic computer systems and instruments can be developed, the gains in reliability, lifetime, and performance can be considered. However, a higher degree of isolation will be required to keep certain components (electronics, fluids) warm in extra-planetary space and to protect the cryogenic experiments after launch near Earth. This latter is especially true if any early near-solar swingby is used to assist escape in the mission. A navigational interest in a 0.1 AU solar swingby would mean a solar input of 100 suns which is beyond any anticipated nearterm capability.

More efficient heat transfer capability from warm sources (e.g., RTG's) to electronics, such as advanced heat pipes or active fluid loops, will be necessary along with long life (20-50 years). The early mission phase also will require high heat rejection capability, especially for the cryogenic experiments and/or a near solar swingby.

NEP imposes new technology requirements such as long-term active heat rejection (heat pipes, noncontaminated radiators), and thermal isolation. NEP also might be used as a heat source for the S/C electronics.

Beyond this, the possibility of an all-cryogenic spacecraft has been suggested by Whitney and Mason (see Appendix C). This may be more appropriate to missions after 2000 but warrants study. Again, there would be a transition necessary from Earth environment (one g plus launch, near solar) to extraplanetary environment (zero g, cryogenic). The extremely low power ($\sim$ 1 W) requirement for superconducting electronics and the possibility of further miniaturation of the S/C (or packing in more electronics with low heat dissipation requirements) is very attractive. Also looking ahead, the antimatter propulsion system mentioned above would require cryogenic storage of both solid hydrogen and solid antihydrogen using superconducting (cryo) magnets and electrostatic suspension.

Table 16 summarizes the unusual thermal control features of an extra-planetary mission.

TABLE 16

THERMAL CONTROL CHARACTERISTICS OF EXTRAPLANETARY MISSIONS

Baseline Mission

1. Natural environment will be cryogenic

   a) Good for cryogenic experiments - can use passive thermal control.
   b) Need for transition from near Earth environment to extraplanetary space.
      i. Can equipment take slow cooling?
      ii. Well insolated near sun.*†
      iii. Cryogenic control needed near Earth?*†

2. NEP

   a) Active thermal control - heat pipes - lifetime problems.*
   b) Heat source has advantages & disadvantages for S/C design.

Not Part of Baseline Mission

3. Radioisotope thermal electric generator (RTG) power source provides hot environment to cold S/C

   a) Requires high isolation.*
   b) Could be used as source of heat for warm S/C.
      i. Fluid loop - active devices will wear - lifetime problem.*
      ii. Heat pipes.
   c) Must provide means of cooling RTG's.

4. Close Solar Swingby $\sim$ 0.1 AU*

   a) 100 "suns" is very high thermal input - must isolate better.*
   b) Contrasts with later extraplanetary environment: almost no sun.
   c) Solar Sail requirements 0.3 AU (11 suns), Super Sail 0.1 AU.*

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* Significant technology advancement required.
† Not part of baseline mission.

COMPONENTS AND MATERIALS

By far the most important problem in this area is prediction of long-term materials properties from short-term tests. This task encompasses most of the other problems noted. Sufficient time does not exist to generate the required material properties in real time. However, if in the time remaining we can establish the scaling parameters, the required data could be generated in a few years. Hence development of suitable techniques should be initiated.

Another critical problem is obtaining bearings and other moving parts with 50 years lifetime. Effort on this should be started.

Less critical but also desirable are electronic devices that are inherently radiation-resistant and have high life expectancy. DOE has an effort under-way on this looking both at semiconductor devices, utilizing amorphous semi-conductors and other approaches that do not depend on minority carriers, and at non-semiconductor devices, such as integrated thermionic circuits.

Other special requirements are listed in Table 17.

SCIENCE INSTRUMENTS

Both the problem of radiation compatibility of science instruments with NEP propulsion and the problem of attaining 50-year lifetime have been noted above. Many of the proposed instruments have sensors whose lifetime for even current missions is of concern and whose performance for this mission is at best uncertain. Instruments in this category, such as the spectrometers and radiometers, should have additional detector work performed to insure reasonable performance.

Calibration of scientific instruments will be very difficult for a 20-50 year mission. Even relatively short term missions like Viking and Voyager pose serious problems in the area of instrument stability and calibration verification. Assuming that "reliable" 50-year instruments could be built, some means of verifying the various instrument transfer functions are needed. Calibration is probably the most serious problem for making quantitative measurements on a 50-year mission.

The major problems in the development of individual science instruments are listed below. These are problems beyond those likely to be encountered and resolved in the normal course of development between now and, say, 1995 or 2000.

TABLE 17

TECHNOLOGY REQUIREMENTS FOR COMPONENTS & MATERIALS

1. Diffusion Phenomena
   - 1.1 Fuses
   - 1.2 Heaters
   - 1.3 Thrusters
   - 1.4 Plume Shields
   - 1.5 RTG's
   - 1.6 Shunt Radiator
2. Sublimation and Erosion Phenomena
   - 2.1 Fuses
   - 2.2 Heater
   - 2.3 Thrusters
   - 2.4 Plume Shields
   - 2.5 RTG's
   - 2.6 Polymers
   - 2.7 Temperature Control Coatings
   - 2.8 Shunt Radiator
3. Radiation Effects
   - 3.1 Electronic components
   - 3.2 Polymers
   - 3.3 Temperature Control Coatings
   - 3.4 NEP and RTG Degradation
4. Materials Compatibility
   - 4.1 Thrusters
   - 4.2 Heat Pipes
   - 4.3 Polymeric Diaphragms & Bladders
   - 4.4 Propulsion Feed System
5. Wear and Lubrication
   - 5.5 Bearings
6. Hermetic Sealing and Leak Testing
   - 6.1 Permeation Rates
   - 6.2 Pressure Vessels
7. Long-Term Material Property Prediction from Short-Term Tests
   - 7.1 Diffusion
   - 7.2 Sublimation
   - 7.3 Wear and Lubrication
   - 7.4 Radiation Effects
   - 7.5 Compatibility
   - 7.6 Thermal Effects
8. Size Scale-Up
   - 8.1 Antennae
   - 8.2 Shunt Radiator
   - 8.3 Pressure Vessels
9. Thermal Effects on Material Properties
   - 9.1 Strength
   - 9.2 Creep and Stress Rupture

Neutral Gas Mass Spectrometer

Designing a mass spectrometer to measure the concentration of light gas species in the interstellar medium poses difficult questions of sensitivity. Current estimates of H concentration in the interstellar medium near the solar system are 10^{-1}-10^{-2} atom/cm^3 and of He contraction about 10^{-2} atom/cm^3 (Bertaux and Blamont, 1971; Thomas and Krassna, 1974; Weller and Meier 1974; Freeman et al., 1977; R. Carlson, private communication; Fahr et al., 1977; Ajello, 1977; Thomas, 1978). On the basis of current estimates of cosmic relative abundances the corresponding concentration of C, N, O is 10^{-5} to 10^{-4} atom/cm^3 and of Li, Be, B about 10^{-10} atom/cm^3.

These concentrations are a long way beyond mass spectrometer present capabilities, and it is not clear that adequate capabilities can be attained by 2000. Even measuring H and He at 10^{-2} to H^{-1} atom/cm^3 will require a considerable development effort. Included in the effort should be:

a) Collection: Means of collecting incoming gas over a substantial frontal area and possibly of storing it to increase the input rate and so the S/N ratio during each period of analysis.

b) Source: Development of ionization sources of high efficiency and satisfying the other requirements.

c) Lifetime: Attaining a 50-year lifetime will be a major problem, especially for the source.

d) S/N: Attaining a satisfactory S/N ratio will be a difficult problem in design of the whole instrument.

Thus, if a mass spectrometer suitable for the mission is to be provided, considerable advanced development work will be needed.

Camera Field of View vs. Resolution

Stellar parallax measurements present a problem in camera design because of the limited number of pixels/frame in conventional and planned spacecraft cameras. For example, one would like to utilize the diffraction-limited resolution of the objective. For a 1-m objective, this is 0".12. To find the center of the circle of confusion accurately, one would like about 6 measurements across it, or, for a 1-m objective, a pizel size of about 0".02 or 0.1 μrad. (Note that this also implies fine-pointing stability similar to that for earth-orbiting telescopes). But according to James et al. (1976) the number of elements per frame expected in solid state cameras by the year 2000 is 10^6 for a single chip and 10^7 for a mosaic. With 10^7 elements, or 3000 x 3000, the field of view for the case mentioned would be 3000 x 0".02 = 1 minute of arc. At least five or six stars need to be in the field for a parallax measurement. Thus, a density of 5 stars per square minute or 18,000 stars per square degree is needed. To obtain this probably requires detecting stars to about magnitude 26 near the galactic poles and to magnitude 23 near galactic latitude 45°. This would be very difficult with a 1-m telescope.

A number of approaches could be considered, among them:

a) Limit parallax observations to those portions of the sky having high local stellar densities.

b) Use film.

c) Find and develop some other technique for providing for more pixels per frame than CCD's and vidicons.

d) Sense the total irradiation over the field and develop a masking technique to detect relative star positions. An example would be the method proposed for the Space Telescope Astrometric Multiplexing Area Scanner (Wissinger and McCarthy, 1976).

e) Use individual highly accurate single-star sensors, like the Fine Guiding Sensors to be used in Space Telescope astrometry (Wissinger, 1976).

Other possibilities doubtless exist. A study will be needed to determine which approaches are most promising and development effort may be needed to bring them to the stage needed for project initiation.

The problems of imaging Pluto, it may be noted, are rather different than those of star imagery. For a fast flyby, the very low light intensity at Pluto plus the high angular rate make a smear a problem. Different optical trains may be needed for stellar parallax, for which resolution must be emphasized, and for Pluto flyby, for which image brightness will be critical. Besides this, image motion compensation may be necessary at Pluto; it may be possible to provide this electronically with CCD's. It is expected that these needs can be met by the normal process of development between now and 1995.

ACKNOWLEDGEMENT

Participants in this study are listed in Appendix A, contributors to the science objectives and requirements in Appendix B. Brooks Morris supplied valuable comments on quality assurance and reliability.

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APPENDIX A

STUDY PARTICIPANTS

Participants in this study and their technical areas were as follows:

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APPENDIX B

SCIENCE CONTRIBUTORS

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APPENDIX C

THOUGHTS FOR A STAR MISSION STUDY

The primary problem in a mission to another star is still propulsion: obtaining enough velocity to bring the mission duration down enough to be of much interest. The heliocentric escape velocity of about 100 km/s believed feasible for a year 2000 launch, as described in this study, is too low by two orders of magnitude.

PROPULSION

A most interesting approach, discussed recently in Papailou in James et al. (1976) and by Morgan (1975, 1976) is an antimatter propulsion system. The antimatter is solid (frozen antihydrogen), suspended electrostatically or electromagnetically. Antimatter is today produced in small quantities in particle physics laboratories. Chapline (1976) has suggested that much larger quantities could be produced in fusion reactors utilizing heavy-ion beams. For spacecraft propulsion, antimatter-matter reactions have the great advantage over fission and fusion that no critical mass, temperature, or reaction containment time is required; the propellants react spontaneously. (They are "hypergolic"). To store the antimatter (antihydrogen) it would be frozen and suspended electrostatically or electromagnetically. Attainable velocities are estimated at least an order of magnitude greater than for fission NEP.

Spencer and Jaffe (1962) showed that multistage fission or fusion systems can theoretically attain a good fraction of the speed of light. To do this, the products of the nuclear reaction should be used as the propellants and the burnup fraction must be high. The latter requirement may imply that fuel reprocessing must be done aboard the vehicle.

The mass of fusion propulsion systems, according to James et al. (1976) is expected to be much greater than that of fission systems. As this study shows, the spacecraft velocity attainable with fusion, for moderate payloads, is likely to be only a little greater than for fission.

CRYOGENIC SPACECRAFT

P. V. Mason (private communication, 1975) has discussed the advantages for extraplanetary or interstellar flight of a cryogenic spacecraft. The following is extracted from his memorandum:

"If one is to justify the cost of providing a cryogenic environment, one must perform a number of functions. The logical extension of this is to do all functions cryogenically. Recently William Whitney suggested that an ideal mission for such a spacecraft would be an ultraplanetary or interstellar voyager. Since the background of space is at about 3 Kelvin, the spacecraft would approach this temperature at great distances from the Sun using only passive radiation (this assumes that heat sources aboard are kept at a very low level). Therefore, I suggest that we make the most optimistic assumptions about low temperature phenomena in the year 2000, and try to come up with a spacecraft which will be far out in design, as well as in mission. Make the following assumptions:

1. The mission objective will be to make measurements in ultraplanetary space for a period of 10 years.
2. The spacecraft can be kept at a temperature not greater than 20 Kelvin merely by passive radiation.
3. Superconductors with critical temperatures above 20 Kelvin will be available. All known superconducting phenomena will be exhibited by these superconductors (e.g., persistent current, Josephson effect, quantization of flux, etc.).
4. All functions aboard the spacecraft are to be performed at 20 Kelvin or below.

I have been able to think of the following functions:

I. SENSING

A. Magnetic Field

Magnetic fields in interstellar space are estimated to be about 10^{-6} Gauss. The Josephson-Junction magnetometer will be ideal for measuring the absolute value and fluctuations in this field.

B. High Energy Particles

Superconducting thin films have been used as alpha-particle detectors. We assume that by 2000 A.D. superconducting devices will be able to measure a wide variety of energetic particles. Superconducting magnets will be used to analyze particle energies.

C. Microwave and Infrared Radiation

It is probable that by 2000 A.D. Josephson Junction detectors will be superior to any other device in the microwave and infrared regions.

II. SPACECRAFT ANGULAR POSITION DETECTION

We will navigate by the visible radiation from the fixed stars, especially our Sun. We assume that a useful optical sensor will be feasible using superconductive phenomena. Alternatively, a Josephson Junction array of narrow beam width, tuned to an Earth-based microwave beacon could provide pointing information.

III. DATA PROCESSING AND OTHER ELECTRONICS

Josephson Junction computers are already being built. It takes very little imagination to assume that all electronic and data processing, sensor excitation and amplification and housekeeping functions aboard our spacecraft will be done this way.

IV. DATA TRANSMISSION

Here we have to take a big leap. Josephson Junction devices can now radiate about one-billionth of a watt each. Since we need at least one watt to transmit data back to Earth, we must assume that we can form an array of 10^{+9} elements which will radiate coherently. We will also assume that these will be arranged to give a very narrow beam width. Perhaps it could even be the same array used for pointing information, operating in a time-shared mode.

V. SPACECRAFT POINTING

We can carry no consumables to point the spacecraft--or can we? If we can't, the only source of torque available is the interstellar magnetic field. We will point the spacecraft by superconducting coils interacting with the field. This means that all other field sources will have to be shielded with superconducting shields.

It may be that the disturbance torques in interstellar space are so small that a very modest ration of consumables would provide sufficient torque for a reasonable lifetime, say <u>100 years.</u>

Can anyone suggest a way of emitting equal numbers of positive and negative charged particles at high speed, given that we are to consume little power, and are to operate under 20 Kelvin? These could be used for both attitude control and propulsion.

VI. POWER

We must have a <u>watt</u> to radiate back to Earth. All other functions can be assumed to consume the same amount. Where are we to get our power?

First try--we assume that we can store our energy in the magnetic field of a superconducting coil. Fields of one mega-Gauss will certainly be feasible by this time. Assuming a volume of one cubic meter, we can store 4×10^9 joules.

This will be enough for a lifetime of 60 years.

If this is unsatisfactory, the only alternate I can think of is a Radio Isotope Thermal Generator. Unfortunately, this violates our ground rule of no operation above 20 Kelvin and gives us thermal power of 20 watts to radiate. If this is not to warm the rest of the spacecraft unduly, it will have to be placed at a distance of (TBD) meters away. (No doubt we will allow it to unreel itself on a tape rule extension after achieving our interstellar trajectory.) We will also use panels of TBD square meters to radiate the power at a temperature of TBD."

LOCATING PLANETS ORBITING ANOTHER STAR

Probably the most important scientific objective for a mission to another star here would be the discovery of planets orbiting it. What might we expect of a spacecraft under such circumstances?

1) As soon as the vehicle is close enough to permit optical detection techniques to function, a search must begin for planets. Remember, at this point we don't even know the orientation of the ecliptic planet for the system in question. The vehicle must search the region around the primary for objects that
   a) exhibit large motion terms with respect to the background stars and
   b) have spectral properties that are characteristic of reflecting bodies rather than self luminous ones. When one considers that several thousand bright points (mostly background stars) will be visable in the field of view and that at most only about a dozen of these can be reasonably expected to be planets, the magnitude of the problem becomes apparent.

Some means of keeping track of all these candidate planets or some technique for comprehensive spectral analysis is in order. Probably a combination of these methods will prove to be the most effective.

Consider the following scenario. When the vehicle is about 50 AU from the star, a region of space about 10 or 15 AU in radius is observed. Here the radius referred to is centered at the target star. This corresponds to a total field of interest that is about 10 to 15 degrees in solid angle.

Each point of light (star, maybe planet) must be investigated by spectrographic analysis and the positions of each candidate object recorded for future use. As the vehicle plunges deeper into the system, parallax produced by its own motion and motion of the planets in their orbits will change their apparent position relative to the background stars. By an iterative process, this technique should locate several of the planets in the system.

Once their positions are known then the onboard computer must compute the orbital parameters for the objects that have been located. This will result in, among other things, the identification of the ecliptic plane. This plane can now be searched for additional planets.

Now that we know where all of the planets in the system may be found, a gross assumption, we can settle down to a search for bodies that might harbor life.

If we know the total thermal output of the star, and for Barnard we do, we can compute the range of distances where black body equilibrium temperature ranges between 0°C and 100°C. This is where the search for life begins.

If one or more of our planets falls between these boundaries of fire and ice, we might expect the vehicle to compute a trajectory that would permit either a flyby or even an orbital encounter with the planet. Beyond observation of the planet from this orbit, anything that can be discussed from this point on moves rapidly out of the range of science and into science fiction and as such is outside the scope of this report.

APPENDIX D

SOLAR SYSTEM BALLISTIC ESCAPE TRAJECTORIES

The listings which follow give distance (RAD) in astronomical units and velocity (VEL) in km/s for ballistic escape trajectories with perihelia (Q) of 0.1, 0.3, 0.5, 1.0, 2.0, and 5.2 AU, and hyperbolic excess velocities (V_∞) of 0., 1., 5., 10., 20., 30., 40., 50., and 60. km/s. For each V_∞ output is given at 0.2 year intervals for time (T) less than 10 years after perihelion, and one year intervals for time between 10 and 60 years after perihelion.

For higher V_∞ and long times, the distance (RAD) can be scaled as proportional to V_∞ and the velocity VEL V_∞.

V-INFINITY = .0 KM/S

T - YRS	Q = .1 AU RAD	VEL	Q = .3 AU RAD	VEL	Q = .5 AU RAD	VEL	Q = 1.0 AU RAD	VEL	Q = 2.0 AU RAD	VEL	Q = 5.2 AU RAD	VEL
.00	.1000	133.2018	.3000	76.9041	.5000	59.5696	1.0000	42.1221	2.0000	29.7847	5.2000	18.4717
.20	1.8279	31.1552	1.6741	32.5553	1.5732	33.5829	1.5605	33.7190	2.1857	28.4913	5.2291	18.4203
.40	2.9552	24.5029	2.7832	25.2484	2.6424	25.9125	2.4411	26.9597	2.6439	25.9051	5.3151	18.2706
.60	3.9016	21.3250	3.7226	21.8315	3.5666	22.3038	3.2875	23.2314	3.2251	23.4551	5.4544	18.0358
.80	4.7466	19.3339	4.5638	19.7172	4.3996	20.0818	4.0778	20.8590	3.8466	21.4768	5.6418	17.7337
1.00	5.5233	17.9229	5.3381	18.2312	5.1686	18.5277	4.8197	19.1866	4.4739	19.9142	5.8710	17.3841
1.20	6.2496	16.8493	6.0627	17.1071	5.8895	17.3568	5.5216	17.9256	5.0935	18.6637	6.1356	17.0052
1.40	6.9365	15.9932	6.7483	16.2148	6.5723	16.4304	6.1904	16.9297	5.7003	17.6424	6.4293	16.6121
1.60	7.5914	15.2879	7.4021	15.4821	7.2240	15.6718	6.8312	16.1161	6.2927	16.7015	6.7468	16.2166
1.80	8.2195	14.6922	8.0294	14.8651	7.8495	15.0344	7.4480	15.4344	6.8707	16.0697	7.0831	15.8270
2.00	8.8247	14.1794	8.6339	14.3352	8.4526	14.4881	8.0430	14.8517	7.4346	15.4482	7.4341	15.4497
2.20	9.4100	13.7313	9.2186	13.8731	9.0362	14.0125	8.6214	14.3456	7.9854	14.9059	7.7967	15.0853
2.40	9.9779	13.3349	9.7860	13.4650	9.6025	13.5930	9.1826	13.9003	8.5238	14.4275	8.1670	14.7385
2.60	10.5302	12.9805	10.3378	13.1007	10.1535	13.2191	9.7291	13.5043	9.0507	14.0012	8.5457	14.4090
2.80	11.0684	12.6609	10.8757	12.7726	10.6906	12.8827	10.2624	13.1487	9.5668	13.6183	8.9291	14.0070
3.00	11.5940	12.3706	11.4010	12.4749	11.2152	12.5778	10.7835	12.8271	10.0729	13.2718	9.3139	13.8020
3.20	12.1081	12.1052	11.9148	12.2030	11.7283	12.2996	11.2936	12.5340	10.5606	12.9562	9.7018	13.5033
3.40	12.6115	11.8611	12.4179	11.9532	12.2309	12.0442	11.7935	12.2655	11.0575	12.6672	10.0909	13.2600
3.60	13.1052	11.6355	12.9114	11.7225	12.7239	11.8086	12.2840	12.0182	11.5371	12.4011	10.4805	13.0112
3.80	13.5898	11.4262	13.3958	11.5087	13.2078	11.5903	12.7657	11.7893	12.0090	12.1550	10.8700	12.7759
4.00	14.0660	11.2311	13.8717	11.3095	13.6834	11.3871	13.2392	11.5765	12.4736	11.9265	11.2590	12.5533
4.20	14.5343	11.0487	14.3398	11.1234	14.1511	11.1973	13.7051	11.3781	12.9313	11.7135	11.6470	12.3425
4.40	14.9952	10.8776	14.8006	10.9488	14.6115	11.0195	14.1637	11.1923	13.3825	11.5144	12.0337	12.1425
4.60	15.4492	10.7165	15.2544	10.7847	15.0650	10.8523	14.6156	11.0179	13.8275	11.3276	12.4190	11.9527
4.80	15.8967	10.5646	15.7017	10.6300	15.5120	10.6948	15.0612	10.8537	14.2666	11.1519	12.8026	11.7722
5.00	16.3380	10.4210	16.1429	10.4838	15.9529	10.5460	15.5007	10.6988	14.7001	10.9862	13.1844	11.6005
5.20	16.7734	10.2848	16.5782	10.3452	16.3879	10.4051	15.9344	10.5521	15.1283	10.8296	13.5643	11.4369
5.40	17.2033	10.1555	17.0080	10.2137	16.8175	10.2714	16.3627	10.4131	15.5514	10.6813	13.9422	11.2809
5.60	17.6279	10.0325	17.4325	10.0885	17.2417	10.1442	16.7850	10.2810	15.9607	10.5405	14.3181	11.1318
5.80	18.0475	9.9152	17.8520	9.9693	17.6610	10.0231	17.2041	10.1553	16.3834	10.4065	14.6918	10.9893
6.00	18.4623	9.8031	18.2667	9.8555	18.0755	9.9075	17.6176	10.0354	16.7925	10.2790	15.0634	10.8529
6.20	18.8725	9.6960	18.6768	9.7467	18.4854	9.7970	18.0266	9.9209	17.1975	10.1572	15.4328	10.7222
6.40	19.2784	9.5934	19.0825	9.6425	18.8910	9.6913	18.4312	9.8114	17.5983	10.0409	15.8001	10.5969
6.60	19.6800	9.4950	19.4841	9.5426	19.2923	9.5899	18.8317	9.7065	17.9952	9.9296	16.1652	10.4765
6.80	20.0776	9.4005	19.8816	9.4468	19.6807	9.4927	19.2283	9.6059	18.3883	9.8229	16.5282	10.3609
7.00	20.4713	9.3097	20.2752	9.3546	20.0831	9.3992	19.6210	9.5093	18.7777	9.7205	16.8890	10.2496
7.20	20.8612	9.2223	20.6651	9.2659	20.4729	9.3093	20.0100	9.4164	19.1636	9.6221	17.2477	10.1424
7.40	21.2476	9.1380	21.0514	9.1805	20.8590	9.2228	20.3955	9.3270	19.5461	9.5275	17.6043	10.0392
7.60	21.6305	9.0568	21.4342	9.0982	21.2417	9.1393	20.7775	9.2408	19.9253	9.4364	17.9588	9.9396
7.80	22.0101	8.9784	21.8138	9.0187	21.6211	9.0588	21.1562	9.1578	20.3014	9.3486	18.3112	9.8435
8.00	22.3864	8.9026	22.1900	8.9419	21.9973	8.9810	21.5318	9.0775	20.6743	9.2639	18.6616	9.7507
8.20	22.7596	8.8293	22.5632	8.8676	22.3703	8.9058	21.9042	9.0000	21.0443	9.1821	19.0100	9.6609
8.40	23.1298	8.7583	22.9333	8.7958	22.7403	8.8330	22.2737	8.9251	21.4114	9.1030	19.3564	9.5740
8.60	23.4971	8.6896	23.3005	8.7262	23.1074	8.7626	22.6403	8.8525	21.7757	9.0266	19.7009	9.4900
8.80	23.8615	8.6230	23.6649	8.6588	23.4717	8.6943	23.0040	8.7823	22.1373	8.9525	20.0434	9.4085
9.00	24.2232	8.5584	24.0265	8.5934	23.8332	8.6281	23.3650	8.7141	22.4962	8.8808	20.3841	9.3296
9.20	24.5822	8.4957	24.3855	8.5299	24.1921	8.5639	23.7234	8.6481	22.8526	8.8113	20.7229	9.2530
9.40	24.9386	8.4347	24.7419	8.4682	24.5484	8.5015	24.0793	8.5839	23.2064	8.7439	21.0598	9.1787
9.60	25.2925	8.3755	25.0957	8.4083	24.9021	8.4409	24.4326	8.5216	23.5579	8.6784	21.3950	9.1065
9.80	25.6440	8.3179	25.4471	8.3500	25.2534	8.3820	24.7835	8.4611	23.9070	8.6148	21.7284	9.0364
10.00	25.9931	8.2619	25.7962	8.2934	25.6024	8.3247	25.1320	8.4022	24.2538	8.5530	22.0600	8.9682

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V-INFINITY = .0 KM/S

T - YRS	Q = .1 AU RAD	VEL	Q = .3 AU RAD	VEL	Q = .5 AU RAD	VEL	Q = 1.0 AU RAD	VEL	Q = 2.0 AU RAD	VEL	Q = 5.2 AU RAD	VEL
10.00	25.9931	8.2619	25.7962	8.2934	25.6024	8.3247	25.1320	8.4022	24.2538	8.5530	22.0600	8.9682
11.00	27.7048	8.0026	27.5077	8.0312	27.3135	8.0597	26.8412	8.1303	25.9551	8.2679	23.6931	8.6536
12.00	29.3653	7.7730	29.1681	7.7993	28.9736	7.8254	28.4997	7.8902	27.6068	8.0168	25.2866	8.3765
13.00	30.9803	7.5677	30.7829	7.5920	30.5881	7.6161	30.1129	7.6760	29.2142	7.7931	26.8438	8.1299
14.00	32.5544	7.3825	32.3568	7.4050	32.1618	7.4274	31.6853	7.4831	30.7815	7.5921	28.3674	7.9086
15.00	34.0914	7.2142	33.8937	7.2352	33.6985	7.2561	33.2209	7.3081	32.3126	7.4101	29.8600	7.7084
16.00	35.5946	7.0602	35.3968	7.0799	35.2014	7.0995	34.7228	7.1483	33.8105	7.2441	31.3236	7.5261
17.00	37.0667	6.9186	36.8689	6.9371	36.6733	6.9556	36.1939	7.0015	35.2779	7.0918	32.7603	7.3593
18.00	38.5103	6.7877	38.3124	6.8052	38.1166	6.8226	37.6364	6.8660	36.7172	6.9514	34.1720	7.2057
19.00	39.9274	6.6661	39.7294	6.6827	39.5334	6.6992	39.0525	6.7404	38.1304	6.8214	35.5600	7.0636
20.00	41.3198	6.5528	41.1217	6.5686	40.9256	6.5843	40.4441	6.6234	39.5102	6.7005	36.9260	6.9317
21.00	42.6892	6.4469	42.4911	6.4619	42.2948	6.4769	41.8127	6.5141	40.8853	6.5876	38.2712	6.8098
22.00	44.0370	6.3475	43.8388	6.3618	43.6425	6.3761	43.1598	6.4116	42.2301	6.4818	39.5968	6.6939
23.00	45.3645	6.2539	45.1663	6.2676	44.9698	6.2813	44.4866	6.3153	43.5540	6.3825	40.9037	6.5861
24.00	46.6730	6.1656	46.4747	6.1787	46.2781	6.1918	45.7944	6.2245	44.8607	6.2889	42.1931	6.4847
25.00	47.9633	6.0821	47.7650	6.0947	47.5684	6.1073	47.0842	6.1386	46.1486	6.2005	43.4658	6.3890
26.00	49.2366	6.0029	49.0382	6.0151	48.8415	6.0272	48.3570	6.0573	47.4197	6.1169	44.7225	6.2986
27.00	50.4937	5.9277	50.2953	5.9394	50.0984	5.9511	49.6135	5.9801	48.6746	6.0375	45.9641	6.2130
28.00	51.7353	5.8562	51.5368	5.8674	51.3400	5.8787	50.8547	5.9067	49.9143	5.9621	47.1913	6.1317
29.00	52.9622	5.7880	52.7637	5.7988	52.5668	5.8097	52.0811	5.8367	51.1393	5.8902	48.4046	6.0543
30.00	54.1751	5.7228	53.9766	5.7333	53.7796	5.7438	53.2936	5.7699	52.3505	5.8217	49.6047	5.9806
31.00	55.3746	5.6605	55.1761	5.6706	54.9790	5.6808	54.4927	5.7061	53.5483	5.7562	50.7921	5.9103
32.00	56.5613	5.6008	56.3627	5.6106	56.1656	5.6205	55.6790	5.6450	54.7334	5.6935	51.9673	5.8431
33.00	57.7357	5.5435	57.5371	5.5531	57.3399	5.5626	56.8530	5.5864	55.9063	5.6335	53.1308	5.7788
34.00	58.8983	5.4885	58.6996	5.4978	58.5023	5.5071	58.0152	5.5302	57.0674	5.5759	54.2831	5.7171
35.00	60.0495	5.4357	59.8508	5.4447	59.6535	5.4537	59.1661	5.4761	58.2173	5.5205	55.4246	5.6579
36.00	61.1898	5.3848	60.9911	5.3936	60.7937	5.4023	60.3061	5.4241	59.3563	5.4673	56.5556	5.6011
37.00	62.3196	5.3358	62.1209	5.3443	61.9235	5.3528	61.4356	5.3740	60.4849	5.4161	57.6765	5.5464
38.00	63.4393	5.2885	63.2405	5.2968	63.0431	5.3051	62.5550	5.3257	61.6034	5.3667	58.7877	5.4937
39.00	64.5491	5.2428	64.3504	5.2509	64.1529	5.2590	63.6646	5.2791	62.7121	5.3190	59.8895	5.4429
40.00	65.6496	5.1987	65.4508	5.2066	65.2532	5.2144	64.7648	5.2341	63.8115	5.2730	60.9822	5.3939
41.00	66.7409	5.1560	66.5421	5.1637	66.3445	5.1714	65.8558	5.1905	64.9018	5.2285	62.0661	5.3466
42.00	67.8233	5.1147	67.6245	5.1222	67.4269	5.1297	66.9381	5.1484	65.9832	5.1855	63.1415	5.3009
43.00	68.8973	5.0747	68.6984	5.0820	68.5008	5.0893	68.0118	5.1076	67.0562	5.1439	64.2086	5.2567
44.00	69.9629	5.0359	69.7640	5.0430	69.5663	5.0502	69.0771	5.0681	68.1209	5.1035	65.2677	5.2139
45.00	71.0204	4.9982	70.8216	5.0052	70.6238	5.0122	70.1345	5.0297	69.1776	5.0644	66.3189	5.1724
46.00	72.0702	4.9617	71.8713	4.9686	71.6736	4.9754	71.1841	4.9925	70.2265	5.0264	67.3627	5.1321
47.00	73.1124	4.9262	72.9135	4.9329	72.7157	4.9396	72.2261	4.9563	71.2679	4.9895	68.3990	5.0931
48.00	74.1472	4.8917	73.9483	4.8983	73.7505	4.9049	73.2607	4.9212	72.3019	4.9537	69.4282	5.0552
49.00	75.1749	4.8582	74.9760	4.8646	74.7781	4.8710	74.2882	4.8871	73.3288	4.9189	70.4504	5.0184
50.00	76.1956	4.8255	75.9966	4.8318	75.7987	4.8381	75.3087	4.8538	74.3488	4.8851	71.4659	4.9826
51.00	77.2095	4.7937	77.0105	4.7999	76.8126	4.8061	76.3224	4.8215	75.3620	4.8521	72.4747	4.9478
52.00	78.2168	4.7628	78.0178	4.7688	77.8199	4.7749	77.3295	4.7900	76.3686	4.8200	73.4772	4.9140
53.00	79.2177	4.7326	79.0187	4.7385	78.8207	4.7445	78.3303	4.7593	77.3688	4.7888	74.4733	4.8810
54.00	80.2123	4.7031	80.0133	4.7090	79.8153	4.7148	79.3247	4.7294	78.3628	4.7583	75.4633	4.8489
55.00	81.2007	4.6744	81.0017	4.6802	80.8037	4.6859	80.3130	4.7002	79.3506	4.7286	76.4473	4.8176
56.00	82.1832	4.6464	81.9842	4.6520	81.7862	4.6577	81.2954	4.6717	80.3325	4.6996	77.4255	4.7870
57.00	83.1599	4.6190	82.9609	4.6246	82.7628	4.6301	82.2719	4.6439	81.3086	4.6713	78.3980	4.7572
58.00	84.1309	4.5923	83.9318	4.5977	83.7337	4.6032	83.2427	4.6167	82.2790	4.6437	79.3649	4.7282
59.00	85.0963	4.5662	84.8972	4.5715	84.6991	4.5769	84.2080	4.5902	83.2438	4.6167	80.3264	4.6998
60.00	86.0562	4.5406	85.8572	4.5459	85.6590	4.5512	85.1678	4.5643	84.2033	4.5903	81.2826	4.6721

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V-INFINITY =   1.0 KM/S

T - YRS	Q = .1 AU RAD	VEL	Q = .3 AU RAD	VEL	Q = .5 AU RAD	VEL	Q = 1.0 AU RAD	VEL	Q = 2.0 AU RAD	VEL	Q = 5.2 AU RAD	VEL
.00	.1000	133.2050	.3000	76.9103	.5000	59.5778	1.0000	42.1338	2.0000	29.8015	5.2000	18.4987
.20	1.8283	31.1677	1.6745	32.5663	1.5737	33.5926	1.5610	33.7280	2.1861	28.5062	5.2293	18.4471
.40	2.9562	24.5189	2.7843	25.2633	2.6435	25.9262	2.4424	26.9712	2.6452	25.9181	5.3158	18.2068
.60	3.9034	21.3435	3.7245	21.8490	3.5685	22.3202	3.2896	23.2456	3.2274	23.4680	5.4550	18.0610
.80	4.7492	19.3543	4.5665	19.7367	4.4023	20.1004	4.0808	20.8754	3.8499	21.4007	5.6443	17.7590
1.00	5.5269	17.9450	5.3417	18.2525	5.1722	18.5482	4.8236	19.2049	4.4783	19.9205	5.8747	17.4073
1.20	6.2542	16.8728	6.0672	17.1290	5.8941	17.3788	5.5265	17.9456	5.0990	18.6805	6.1407	17.0275
1.40	6.9421	16.0181	6.7539	16.2389	6.5780	16.4538	6.1963	16.9511	5.7070	17.6605	6.4359	16.6337
1.60	7.5981	15.3138	7.4088	15.5074	7.2308	15.6964	6.8382	16.1398	6.3005	16.8108	6.7549	16.2377
1.80	8.2273	14.7192	8.0372	14.8915	7.8574	15.0601	7.4562	15.4583	6.8796	16.0903	7.0927	15.8477
2.00	8.8337	14.2074	8.6429	14.3626	8.4617	14.5148	8.0532	14.8767	7.4448	15.4700	7.4454	15.4694
2.20	9.4202	13.7603	9.2289	13.9015	9.0465	14.0402	8.6320	14.3716	7.9969	14.9288	7.8006	15.1059
2.40	9.9893	13.3647	9.7975	13.4942	9.6141	13.6216	9.1944	13.9273	8.5366	14.4513	8.1825	14.7592
2.60	10.5429	13.0111	10.3506	13.1307	10.1663	13.2485	9.7423	13.5322	9.0648	14.0261	8.5619	14.4301
2.80	11.0825	12.6923	10.8898	12.8034	10.7047	12.9130	10.2768	13.1775	9.5822	13.6441	8.9461	14.1184
3.00	11.6095	12.4028	11.4165	12.5065	11.2307	12.6088	10.7993	12.8566	10.0897	13.2984	9.3335	13.8237
3.20	12.1249	12.1380	11.9316	12.2353	11.7452	12.3313	11.3108	12.5644	10.5878	12.9837	9.7231	13.5454
3.40	12.6297	11.8946	12.4362	11.9862	12.2492	12.0767	11.8121	12.2966	11.0771	12.6954	10.1139	13.2826
3.60	13.1249	11.6697	12.9310	11.7562	12.7436	11.8418	12.3040	12.0499	11.5582	12.4300	10.5052	13.0343
3.80	13.6109	11.4610	13.4169	11.5430	13.2290	11.6241	12.7872	11.8217	12.0316	12.1847	10.8965	12.7995
4.00	14.0886	11.2666	13.8944	11.3444	13.7061	11.4215	13.2622	11.6096	12.4977	11.9569	11.2871	12.5775
4.20	14.5584	11.0847	14.3640	11.1589	14.1753	11.2323	13.7296	11.4118	12.9569	11.7446	11.6769	12.3671
4.40	15.0209	10.9142	14.8263	10.9850	14.6373	11.0551	14.1898	11.2266	13.4096	11.5461	12.0654	12.1677
4.60	15.4765	10.7537	15.2817	10.8214	15.0923	10.8885	14.6433	11.0528	13.8562	11.3599	12.4524	11.9784
4.80	15.9255	10.6023	15.7306	10.6672	15.5409	10.7316	15.0904	10.8802	14.2969	11.1848	12.8378	11.7995
5.00	16.3684	10.4592	16.1734	10.5215	15.9834	10.5833	15.5315	10.7348	14.7321	11.0198	13.2214	11.6274
5.20	16.8055	10.3236	16.6103	10.3835	16.4201	10.4429	15.9669	10.5887	15.1619	10.8637	13.6031	11.4643
5.40	17.2370	10.1947	17.0417	10.2524	16.8513	10.3097	16.3969	10.4502	15.5867	10.7159	13.9828	11.3098
5.60	17.6633	10.0722	17.4679	10.1278	17.2772	10.1830	16.8217	10.3186	16.0067	10.5757	14.3604	11.1603
5.80	18.0846	9.9553	17.8891	10.0090	17.6982	10.0623	17.2416	10.1934	16.4220	10.4423	14.7360	11.0183
6.00	18.5011	9.8438	18.3055	9.8957	18.1144	9.9472	17.6568	10.0740	16.8329	10.3152	15.1094	10.8824
6.20	18.9131	9.7371	18.7174	9.7873	18.5261	9.8372	18.0675	9.9600	17.2396	10.1940	15.4807	10.7523
6.40	19.3206	9.6349	19.1249	9.6836	18.9334	9.7319	18.4730	9.8509	17.6421	10.0782	15.8498	10.6274
6.60	19.7240	9.5370	19.5282	9.5842	19.3365	9.6310	18.8762	9.7465	18.0408	9.9673	16.2168	10.5075
6.80	20.1234	9.4429	19.9275	9.4887	19.7356	9.5342	19.2745	9.6463	18.4357	9.8611	16.5817	10.3924
7.00	20.5189	9.3525	20.3229	9.3970	20.1309	9.4412	19.6690	9.5502	18.8269	9.7591	16.9444	10.2816
7.20	20.9107	9.2655	20.7146	9.3087	20.5225	9.3517	20.0599	9.4577	19.2147	9.6612	17.3050	10.1749
7.40	21.2989	9.1816	21.1028	9.2237	20.9105	9.2655	20.4472	9.3687	19.5990	9.5670	17.6635	10.0721
7.60	21.6837	9.1008	21.4875	9.1418	21.2950	9.1825	20.8311	9.2830	19.9801	9.4763	18.0199	9.9730
7.80	22.0651	9.0227	21.8688	9.0627	21.6763	9.1023	21.2117	9.2003	20.3580	9.3890	18.3743	9.8773
8.00	22.4434	8.9473	22.2470	8.9862	22.0543	9.0249	21.5891	9.1205	20.7329	9.3047	18.7267	9.7849
8.20	22.8185	8.8744	22.6221	8.9124	22.4293	8.9501	21.9635	9.0433	21.1048	9.2233	19.0771	9.6956
8.40	23.1906	8.8038	22.9941	8.8409	22.8012	8.8777	22.3349	8.9688	21.4738	9.1446	19.4255	9.6092
8.60	23.5598	8.7355	23.3633	8.7717	23.1702	8.8077	22.7034	8.8966	21.8400	9.0686	19.7720	9.5255
8.80	23.9262	8.6692	23.7296	8.7046	23.5364	8.7398	23.0691	8.8267	22.2035	8.9949	20.1165	9.4445
9.00	24.2898	8.6050	24.0932	8.6395	23.8999	8.6739	23.4321	8.7589	22.5644	8.9236	20.4592	9.3660
9.20	24.6508	8.5426	24.4541	8.5764	24.2608	8.6100	23.7924	8.6932	22.9228	8.8545	20.8000	9.2898
9.40	25.0092	8.4820	24.8125	8.5151	24.6191	8.5480	24.1503	8.6294	23.2786	8.7874	21.1390	9.2159
9.60	25.3651	8.4231	25.1684	8.4555	24.9748	8.4877	24.5056	8.5675	23.6321	8.7223	21.4763	9.1441
9.80	25.7186	8.3658	25.5218	8.3976	25.3282	8.4292	24.8585	8.5073	23.9832	8.6590	21.8117	9.0744
10.00	26.0697	8.3101	25.8728	8.3412	25.6791	8.3722	25.2091	8.4488	24.3320	8.5976	22.1455	9.0066

V-INFINITY = 1.0 KM/S

T - YRS	Q = .1 AU RAD	VEL	Q = .3 AU RAD	VEL	Q = .5 AU RAD	VEL	Q = 1.0 AU RAD	VEL	Q = 2.0 AU RAD	VEL	Q = 5.2 AU RAD	VEL
10.00	26.0697	8.3101	25.8728	8.3412	25.6791	8.3722	25.2091	8.4488	24.3320	8.5976	22.1455	9.0066
11.00	27.7918	8.0524	27.5947	8.0806	27.4007	8.1088	26.9287	8.1785	26.0438	8.3142	23.7891	8.6038
12.00	29.4630	7.8243	29.2658	7.8502	29.0714	7.8760	28.5978	7.9399	27.7062	8.0646	25.3936	8.4184
13.00	31.0890	7.6204	30.8917	7.6443	30.6970	7.6681	30.2220	7.7271	29.3246	7.8425	26.9619	8.1735
14.00	32.6744	7.4365	32.4769	7.4586	32.2819	7.4807	31.8058	7.5355	30.9032	7.6429	28.4970	7.9537
15.00	34.2229	7.2694	34.0253	7.2901	33.8301	7.3107	33.3529	7.3618	32.4458	7.4621	30.0012	7.7550
16.00	35.7379	7.1166	35.5402	7.1360	35.3448	7.1553	34.8666	7.2033	33.9556	7.2974	31.4767	7.5741
17.00	37.2222	6.9761	37.0244	6.9944	36.8288	7.0125	36.3497	7.0577	35.4351	7.1464	32.9256	7.4086
18.00	38.6780	6.8463	38.4802	6.8636	38.2844	6.8807	37.8046	6.9233	36.8866	7.0072	34.3497	7.2562
19.00	40.1076	6.7259	39.9097	6.7422	39.7138	6.7584	39.2332	6.7988	38.3123	6.8783	35.7504	7.1154
20.00	41.5128	6.6136	41.3148	6.6291	41.1187	6.6445	40.6375	6.6829	39.7139	6.7584	37.1292	6.9847
21.00	42.8951	6.5087	42.6970	6.5234	42.5009	6.5381	42.0191	6.5746	41.0930	6.6465	38.4874	6.8629
22.00	44.2561	6.4102	44.0580	6.4242	43.8617	6.4383	43.3793	6.4731	42.4509	6.5418	39.8262	6.7491
23.00	45.5970	6.3176	45.3988	6.3310	45.2024	6.3444	44.7195	6.3777	43.7891	6.4435	41.1466	6.6423
24.00	46.9190	6.2302	46.7208	6.2431	46.5243	6.2559	46.0409	6.2878	45.1084	6.3508	42.4496	6.5419
25.00	48.2231	6.1476	48.0248	6.1599	47.8283	6.1722	47.3444	6.2029	46.4102	6.2634	43.7360	6.4473
26.00	49.5103	6.0693	49.3120	6.0811	49.1153	6.0930	48.6311	6.1224	47.6951	6.1806	45.0067	6.3578
27.00	50.7815	5.9949	50.5831	6.0063	50.3864	6.0177	49.9018	6.0461	48.9642	6.1021	46.2625	6.2731
28.00	52.0374	5.9242	51.8390	5.9352	51.6422	5.9462	51.1572	5.9735	50.2181	6.0275	47.5040	6.1927
29.00	53.2788	5.8567	53.0804	5.8674	52.8835	5.8780	52.3981	5.9043	51.4576	5.9565	48.7318	6.1163
30.00	54.5063	5.7924	54.3078	5.8026	54.1109	5.8129	53.6252	5.8383	52.6834	5.8888	49.9465	6.0434
31.00	55.7206	5.7308	55.5221	5.7407	55.3251	5.7506	54.8391	5.7753	53.8960	5.8241	51.1487	5.9740
32.00	56.9222	5.6718	56.7237	5.6815	56.5266	5.6910	56.0403	5.7149	55.0960	5.7622	52.3389	5.9076
33.00	58.1117	5.6153	57.9131	5.6246	57.7160	5.6339	57.2294	5.6571	56.2840	5.7029	53.5176	5.8440
34.00	59.2895	5.5611	59.0909	5.5701	58.8937	5.5791	58.4069	5.6016	57.4604	5.6461	54.6852	5.7832
35.00	60.4561	5.5089	60.2575	5.5177	60.0602	5.5264	59.5732	5.5482	58.6257	5.5914	55.8420	5.7248
36.00	61.6120	5.4587	61.4133	5.4672	61.2160	5.4757	60.7287	5.4969	59.7802	5.5389	56.9886	5.6686
37.00	62.7575	5.4103	62.5588	5.4186	62.3614	5.4269	61.8739	5.4475	60.9245	5.4884	58.1253	5.6147
38.00	63.8930	5.3637	63.6943	5.3718	63.4969	5.3798	63.0091	5.3999	62.0588	5.4397	59.2523	5.5627
39.00	65.0188	5.3187	64.8201	5.3265	64.6226	5.3344	64.1347	5.3539	63.1835	5.3927	60.3701	5.5127
40.00	66.1353	5.2752	65.9366	5.2829	65.7391	5.2905	65.2510	5.3095	64.2990	5.3473	61.4789	5.4644
41.00	67.2429	5.2331	67.0441	5.2406	66.8466	5.2481	66.3583	5.2666	65.4055	5.3035	62.5791	5.4178
42.00	68.3417	5.1925	68.1429	5.1997	67.9454	5.2070	67.4569	5.2251	66.5033	5.2611	63.6708	5.3727
43.00	69.4321	5.1530	69.2333	5.1602	69.0357	5.1673	68.5470	5.1850	67.5928	5.2201	64.7545	5.3291
44.00	70.5144	5.1148	70.3155	5.1218	70.1179	5.1287	69.6291	5.1460	68.6741	5.1803	65.8302	5.2870
45.00	71.5887	5.0778	71.3898	5.0846	71.1922	5.0914	70.7032	5.1083	69.7476	5.1418	66.8982	5.2461
46.00	72.6553	5.0418	72.4565	5.0485	72.2588	5.0551	71.7696	5.0716	70.8134	5.1044	67.9588	5.2065
47.00	73.7145	5.0069	73.5156	5.0134	73.3179	5.0199	72.8286	5.0361	71.8717	5.0682	69.0122	5.1681
48.00	74.7664	4.9730	74.5675	4.9794	74.3698	4.9857	73.8903	5.0015	72.9229	5.0330	70.0585	5.1308
49.00	75.8113	4.9400	75.6124	4.9462	75.4146	4.9524	74.9250	4.9679	73.9670	4.9987	71.0980	5.0946
50.00	76.8493	4.9079	76.6504	4.9140	76.4526	4.9201	75.9629	4.9353	75.0043	4.9654	72.1308	5.0594
51.00	77.8807	4.8767	77.6818	4.8826	77.4839	4.8886	76.9941	4.9035	76.0350	4.9330	73.1571	5.0252
52.00	78.9056	4.8462	78.7066	4.8521	78.5088	4.8579	78.0188	4.8725	77.0591	4.9015	74.1771	4.9919
53.00	79.9241	4.8166	79.7252	4.8223	79.5273	4.8280	79.0372	4.8424	78.0770	4.8708	75.1909	4.9595
54.00	80.9365	4.7876	80.7376	4.7933	80.5396	4.7989	80.0494	4.8130	79.0888	4.8408	76.1988	4.9279
55.00	81.9429	4.7594	81.7439	4.7650	81.5460	4.7705	81.0556	4.7843	80.0945	4.8117	77.2007	4.8972
56.00	82.9434	4.7319	82.7444	4.7374	82.5464	4.7428	82.0560	4.7563	81.0944	4.7832	78.1969	4.8672
57.00	83.9382	4.7051	83.7392	4.7104	83.5412	4.7157	83.0506	4.7290	82.0886	4.7554	79.1875	4.8379
58.00	84.9274	4.6788	84.7284	4.6841	84.5304	4.6893	84.0397	4.7024	83.0773	4.7283	80.1727	4.8094
59.00	85.9111	4.6532	85.7121	4.6583	85.5141	4.6635	85.0233	4.6763	84.0604	4.7018	81.1525	4.7816
60.00	86.8895	4.6281	86.6905	4.6332	86.4924	4.6383	86.0015	4.6509	85.0383	4.6759	82.1271	4.7543

V-INFINITY = 5.0 KM/S

T - YRS	Q = .1 AU RAD	VEL	Q = .3 AU RAD	VEL	Q = .5 AU RAD	VEL	Q = 1.0 AU RAD	VEL	Q = 2.0 AU RAD	VEL	Q = 5.2 AU RAD	VEL
.00	.1000	133.2950	.3000	77.0661	.5000	59.7789	1.0000	42.4176	2.0000	30.2015	5.2000	19.1364
.20	1.8384	31.4660	1.6853	32.8300	1.5853	33.8256	1.5737	33.9472	2.1957	28.8627	5.2333	19.0706
.40	2.9814	24.9019	2.8103	25.6193	2.6707	26.2552	2.4730	27.2479	2.6759	26.2308	5.3317	18.9149
.60	3.9465	21.7847	3.7684	22.2671	3.6138	22.7148	3.3395	23.5859	3.2822	23.7817	5.4907	18.6594
.80	4.8124	19.8414	4.6305	20.2032	4.4678	20.5457	4.1515	21.2692	3.9206	21.8292	5.7037	18.3322
1.00	5.6119	18.4706	5.4275	18:7591	5.2595	19.0353	4.9166	19.6437	4.5833	20.3006	5.9632	17.9593
1.20	6.3624	17.4317	6.1763	17.6711	6.0047	17.9019	5.6431	18.4231	5.2200	19.0854	6.2614	17.5604
1.40	7.0750	16.6066	6.8875	16.8108	6.7132	17.0086	6.3378	17.4628	5.8645	18.0982	6.5912	17.1519
1.60	7.7567	15.9292	7.5682	16.1070	7.3917	16.2798	7.0056	16.6812	6.4854	17.2794	6.9462	16.7459
1.80	8.4127	15.3591	8.2234	15.5163	8.0452	15.6696	7.6505	16.0286	7.0927	16.5878	7.3213	16.3506
2.00	9.0468	14.8701	8.8569	15.0108	8.6773	15.1483	8.2755	15.4725	7.6869	15.9944	7.7118	15.9709
2.20	9.6621	14.4440	9.4716	14.5714	9.2908	14.6959	8.8830	14.9912	8.2684	15.4784	8.1143	15.6095
2.40	10.2607	14.0683	10.0697	14.1844	9.8879	14.2981	9.4751	14.5689	8.8385	15.0247	8.5250	15.2677
2.60	10.8447	13.7334	10.6532	13.8400	10.4705	13.9446	10.0534	14.1945	9.3977	14.6218	8.9442	14.9456
2.80	11.4154	13.4323	11.2236	13.5308	11.0401	13.6276	10.6191	13.8593	9.9460	14.2609	9.3674	14.6427
3.00	11.9742	13.1595	11.7820	13.2510	11.5979	13.3410	11.1735	13.5569	10.4867	13.9352	9.7941	14.3581
3.20	12.5221	12.9108	12.3297	12.9962	12.1449	13.0802	11.7176	13.2822	11.0178	13.6305	10.2231	14.0909
3.40	13.0602	12.6828	12.8675	12.7627	12.6821	12.8414	12.2521	13.0312	11.5408	13.3603	10.6535	13.8399
3.60	13.5891	12.4726	13.3961	12.5477	13.2103	12.6217	12.7779	12.8005	12.0560	13.1213	11.0846	13.6038
3.80	14.1096	12.2780	13.9164	12.3489	13.7301	12.4187	13.2955	12.5876	12.5642	12.9025	11.5159	13.3918
4.00	14.6222	12.0971	14.4288	12.1641	14.2422	12.2302	13.8055	12.3902	13.0656	12.6805	11.9467	13.1725
4.20	15.1276	11.9284	14.9340	11.9919	14.7470	12.0546	14.3085	12.2066	13.5606	12.4835	12.3768	12.9751
4.40	15.6261	11.7705	15.4324	11.8309	15.2450	11.8905	14.8048	12.0351	14.0497	12.2998	12.8059	12.7987
4.60	16.1183	11.6223	15.9244	11.6798	15.7367	11.7365	15.2949	11.8745	14.5331	12.1278	13.2338	12.6123
4.80	16.6044	11.4828	16.4104	11.5377	16.2224	11.5918	15.7792	11.7236	15.0112	11.9664	13.6602	12.4453
5.00	17.0849	11.3512	16.8908	11.4036	16.7025	11.4554	16.2579	11.5815	15.4841	11.8146	14.0852	12.2968
5.20	17.5601	11.2267	17.3658	11.2770	17.1772	11.3266	16.7314	11.4474	15.9523	11.6715	14.5084	12.1364
5.40	18.0302	11.1088	17.8357	11.1570	17.6469	11.2045	17.1999	11.3205	16.4158	11.5361	14.9300	11.9933
5.60	18.4954	10.9968	18.3009	11.0431	18.1119	11.0888	17.6638	11.2003	16.8749	11.4080	15.3498	11.8570
5.80	18.9562	10.8903	18.7615	10.9348	18.5723	10.9787	18.1231	11.0860	17.3298	11.2963	15.7677	11.7271
6.00	19.4125	10.7888	19.2178	10.8316	19.0283	10.8740	18.5782	10.9773	17.7808	11.1707	16.1838	11.6031
6.20	19.8647	10.6919	19.6699	10.7332	19.4803	10.7740	19.0292	10.8738	18.2278	11.0606	16.5980	11.4946
6.40	20.3130	10.5993	20.1181	10.6392	19.9282	10.6786	19.4763	10.7749	18.6712	10.9556	17.0103	11.3712
6.60	20.7574	10.5107	20.5624	10.5492	20.3724	10.5873	19.9197	10.6804	19.1111	10.8554	17.4208	11.2626
6.80	21.1983	10.4258	21.0032	10.4631	20.8130	10.4999	20.3594	10.5899	19.5476	10.7595	17.8294	11.1585
7.00	21.6356	10.3444	21.4404	10.3804	21.2501	10.4160	20.7958	10.5032	19.9808	10.6676	18.2361	11.0586
7.20	22.0696	10.2661	21.8744	10.3010	21.6839	10.3356	21.2289	10.4201	20.4109	10.5796	18.6410	10.9627
7.40	22.5004	10.1909	22.3051	10.2247	22.1145	10.2582	21.6588	10.3401	20.8370	10.4950	19.0441	10.8704
7.60	22.9281	10.1185	22.7327	10.1513	22.5420	10.1838	22.0856	10.2633	21.2620	10.4139	19.4453	10.7816
7.80	23.3528	10.0487	23.1574	10.0805	22.9665	10.1121	22.5095	10.1893	21.6833	10.3357	19.8448	10.6961
8.00	23.7747	9.9814	23.5792	10.0123	23.3882	10.0430	22.9306	10.1181	22.1010	10.2604	20.2425	10.6137
8.20	24.1938	9.9164	23.9982	9.9465	23.8071	9.9763	23.3489	10.0493	22.5178	10.1879	20.6385	10.5341
8.40	24.6102	9.8537	24.4145	9.8829	24.2233	9.9119	23.7646	9.9830	22.9312	10.1180	21.0328	10.4574
8.60	25.0240	9.7930	24.8283	9.8215	24.6370	9.8497	24.1777	9.9189	23.3422	10.0504	21.4255	10.3832
8.80	25.4353	9.7343	25.2396	9.7620	25.0481	9.7895	24.5884	9.8569	23.7507	9.9852	21.8164	10.3115
9.00	25.8442	9.6774	25.6484	9.7044	25.4569	9.7312	24.9967	9.7969	24.1569	9.9220	22.2058	10.2421
9.20	26.2507	9.6223	26.0549	9.6487	25.8633	9.6748	25.4026	9.7389	24.5609	9.8610	22.5936	10.1749
9.40	26.6550	9.5689	26.4591	9.5946	26.2674	9.6201	25.8063	9.6826	24.9627	9.8018	22.9798	10.1099
9.60	27.0571	9.5171	26.8612	9.5422	26.6693	9.5670	26.2078	9.6281	25.3624	9.7445	23.3644	10.0468
9.80	27.4570	9.4668	27.2610	9.4913	27.0691	9.5155	26.6071	9.5751	25.7601	9.6890	23.7476	9.9856
10.00	27.8549	9.4179	27.6588	9.4418	27.4669	9.4655	27.0045	9.5238	26.1557	9.6351	24.1293	9.9263

V-INFINITY = 5.0 KM/S

T - YRS	Q = .1 AU RAD	Q = .1 AU VEL	Q = .3 AU RAD	Q = .3 AU VEL	Q = .5 AU RAD	Q = .5 AU VEL	Q = 1.0 AU RAD	Q = 1.0 AU VEL	Q = 2.0 AU RAD	Q = 2.0 AU VEL	Q = 5.2 AU RAD	Q = 5.2 AU VEL
10.00	27.8549	9.4179	27.6588	9.4418	27.4669	9.4655	27.0045	9.5238	26.1557	9.6351	24.1293	9.9263
11.00	29.8149	9.1929	29.6187	9.2143	29.4263	9.2355	28.9621	9.2877	28.1057	9.3877	26.0162	9.6539
12.00	31.7306	8.9953	31.5343	9.0147	31.3416	9.0338	30.8758	9.0810	30.0129	9.1715	27.8699	9.4161
13.00	33.6074	8.8201	33.4109	8.8377	33.2179	8.8551	32.7508	8.8980	31.8823	8.9805	29.6931	9.2062
14.00	35.4493	8.6632	35.2527	8.6793	35.0595	8.6952	34.5911	8.7345	33.7178	8.8103	31.4883	9.0192
15.00	37.2600	8.5216	37.0633	8.5365	36.8698	8.5512	36.4004	8.5874	35.5227	8.6572	33.2578	8.8515
16.00	39.0423	8.3931	38.8455	8.4068	38.6519	8.4204	38.1815	8.4539	37.3000	8.5186	35.0035	8.6999
17.00	40.7989	8.2757	40.6020	8.2885	40.4081	8.3011	39.9370	8.3323	39.0519	8.3925	36.7273	8.5621
18.00	42.5318	8.1680	42.3348	8.1799	42.1408	8.1916	41.6689	8.2207	40.7807	8.2769	38.4307	8.4361
19.00	44.2430	8.0686	44.0459	8.0797	43.8518	8.0908	43.3791	8.1180	42.4881	8.1706	40.1151	8.3204
20.00	45.9341	7.9766	45.7370	7.9870	45.5427	7.9974	45.0694	8.0229	44.1758	8.0724	41.7818	8.2137
21.00	47.6066	7.8911	47.4094	7.9009	47.2149	7.9106	46.7411	7.9347	45.8451	7.9813	43.4310	8.1149
22.00	49.2616	7.8113	49.0644	7.8206	48.8699	7.8298	48.3955	7.8525	47.4973	7.8965	45.0665	8.0231
23.00	50.9005	7.7368	50.7032	7.7455	50.5086	7.7542	50.0337	7.7757	49.1335	7.8173	46.6865	7.9375
24.00	52.5242	7.6668	52.3269	7.6751	52.1321	7.6833	51.6568	7.7037	50.7547	7.7432	48.2926	7.8575
25.00	54.1337	7.6010	53.9363	7.6089	53.7414	7.6167	53.2657	7.6361	52.3618	7.6736	49.8857	7.7824
26.00	55.7297	7.5390	55.5322	7.5465	55.3373	7.5540	54.8611	7.5724	53.9557	7.6081	51.4665	7.7119
27.00	57.3130	7.4805	57.1155	7.4876	56.9205	7.4947	56.4440	7.5123	55.5370	7.5463	53.0357	7.6455
28.00	58.8844	7.4250	58.6868	7.4319	58.4918	7.4386	58.0149	7.4554	57.1064	7.4879	54.5937	7.5828
29.00	60.4444	7.3725	60.2468	7.3790	60.0517	7.3855	59.5744	7.4015	58.6647	7.4326	56.1412	7.5235
30.00	61.9936	7.3226	61.7960	7.3288	61.6008	7.3350	61.1233	7.3503	60.2122	7.3802	57.6787	7.4673
31.00	63.5326	7.2751	63.3350	7.2811	63.1397	7.2870	62.6619	7.3017	61.7496	7.3303	59.2066	7.4140
32.00	65.0618	7.2298	64.8642	7.2356	64.6689	7.2413	64.1907	7.2554	63.2773	7.2828	60.7254	7.3633
33.00	66.5818	7.1866	66.3841	7.1922	66.1887	7.1976	65.7103	7.2112	64.7959	7.2376	62.2354	7.3150
34.00	68.0928	7.1454	67.8951	7.1507	67.6997	7.1560	67.2210	7.1690	66.3056	7.1944	63.7370	7.2689
35.00	69.5954	7.1059	69.3977	7.1110	69.2022	7.1161	68.7233	7.1286	67.8068	7.1531	65.2307	7.2249
36.00	71.0898	7.0681	70.8921	7.0730	70.6965	7.0779	70.2174	7.0900	69.3001	7.1135	66.7166	7.1829
37.00	72.5765	7.0318	72.3787	7.0366	72.1831	7.0413	71.7038	7.0530	70.7855	7.0757	68.1952	7.1426
38.00	74.0556	6.9970	73.8578	7.0016	73.6622	7.0062	73.1827	7.0174	72.2636	7.0394	69.6666	7.1041
39.00	75.5276	6.9636	75.3298	6.9680	75.1341	6.9724	74.6544	6.9833	73.7345	7.0045	71.1313	7.0671
40.00	76.9927	6.9314	76.7949	6.9357	76.5992	6.9399	76.1192	6.9505	75.1986	6.9710	72.5903	7.0315
41.00	78.4512	6.9004	78.2533	6.9046	78.0576	6.9087	77.5774	6.9189	76.6560	6.9387	74.0410	6.9974
42.00	79.9032	6.8706	79.7053	6.8746	79.5095	6.8786	79.0292	6.8884	78.1072	6.9077	75.4866	6.9645
43.00	81.3491	6.8418	81.1512	6.8457	80.9554	6.8496	80.4749	6.8591	79.5521	6.8777	76.9263	6.9328
44.00	82.7890	6.8140	82.5911	6.8178	82.3952	6.8215	81.9146	6.8308	80.9912	6.8489	78.3603	6.9023
45.00	84.2232	6.7872	84.0252	6.7909	83.8294	6.7945	83.3486	6.8035	82.4245	6.8210	79.7887	6.8729
46.00	85.6518	6.7613	85.4538	6.7648	85.2579	6.7683	84.7770	6.7771	83.8524	6.7941	81.2118	6.8445
47.00	87.0750	6.7362	86.8771	6.7396	86.6811	6.7431	86.2001	6.7515	85.2749	6.7680	82.6298	6.8171
48.00	88.4931	6.7119	88.2951	6.7153	88.0992	6.7186	87.6179	6.7268	86.6922	6.7429	84.0428	6.7905
49.00	89.9061	6.6884	89.7081	6.6916	89.5121	6.6949	89.0308	6.7029	88.1045	6.7185	85.4509	6.7649
50.00	91.3143	6.6656	91.1163	6.6688	90.9203	6.6719	90.4388	6.6797	89.5119	6.6949	86.8543	6.7400
51.00	92.7177	6.6435	92.5197	6.6466	92.3236	6.6496	91.8420	6.6572	90.9147	6.6720	88.2532	6.7160
52.00	94.1166	6.6221	93.9185	6.6251	93.7225	6.6280	93.2407	6.6354	92.3129	6.6498	89.6476	6.6926
53.00	95.5110	6.6012	95.3129	6.6042	95.1168	6.6071	94.6350	6.6143	93.7067	6.6283	91.0377	6.6700
54.00	96.9010	6.5810	96.7030	6.5839	96.5069	6.5867	96.0249	6.5937	95.0962	6.6074	92.4237	6.6481
55.00	98.2869	6.5614	98.0889	6.5642	97.8927	6.5669	97.4107	6.5738	96.4815	6.5871	93.8055	6.6268
56.00	99.6687	6.5423	99.4707	6.5450	99.2745	6.5477	98.7923	6.5543	97.8627	6.5673	95.1835	6.6061
57.00	101.0466	6.5237	100.8485	6.5264	100.6523	6.5290	100.1700	6.5355	99.2400	6.5482	96.5576	6.5860
58.00	102.4205	6.5056	102.2224	6.5082	102.0262	6.5108	101.5439	6.5171	100.6134	6.5295	97.9279	6.5664
59.00	103.7908	6.4880	103.5927	6.4905	103.3964	6.4931	102.9140	6.4992	101.9831	6.5113	99.2946	6.5474
60.00	105.1573	6.4709	104.9592	6.4733	104.7630	6.4758	104.2804	6.4818	103.3492	6.4937	100.6577	6.5289

77-70

V-INFINITY = 10.0 KM/S

T - YRS	Q = .1 AU RAD	VEL	Q = .3 AU RAD	VEL	Q = .5 AU RAD	VEL	Q = 1.0 AU RAD	VEL	Q = 2.0 AU RAD	VEL	Q = 5.2 AU RAD	VEL
.00	.1000	133.5761	.3000	77.5512	.5000	60.4029	1.0000	43.2927	2.0000	31.4186	5.2000	21.0048
.20	1.8696	32.3882	1.7185	33.6517	1.6214	34.5587	1.6128	34.6422	2.2255	29.9541	5.2461	20.9334
.40	3.0591	26.0767	2.8902	26.7186	2.7545	27.2789	2.5669	28.1285	2.7697	27.2137	5.3814	20.7992
.60	4.0789	23.1297	3.9032	23.5492	3.7528	23.9329	3.4920	24.6595	3.4484	24.7894	5.5982	20.4189
.80	5.0056	21.3179	4.8262	21.6248	4.6678	21.9113	4.3671	22.5007	4.1700	22.9233	5.8856	20.0364
1.00	5.8708	20.0554	5.6889	20.2048	5.5255	20.5208	5.1993	21.0059	4.8994	21.4074	6.2316	19.6142
1.20	6.6912	19.1092	6.5076	19.3040	6.3406	19.4891	5.9967	19.8965	5.6233	20.3843	6.6240	19.1786
1.40	7.4771	18.3655	7.2922	18.5286	7.1226	18.6843	6.7656	19.0328	6.3371	19.4031	7.0553	18.7478
1.60	8.2354	17.7607	8.0495	17.9002	7.8778	18.0339	7.5106	18.3367	7.0303	18.7630	7.5146	18.3332
1.80	8.9709	17.2563	8.7842	17.3777	8.6108	17.4043	8.2354	17.7607	7.7297	18.1531	7.9961	17.9413
2.00	9.6871	16.8273	9.4997	16.9343	9.3250	17.0373	8.9429	17.2742	8.4090	17.6350	8.4946	17.5747
2.20	10.3868	16.4566	10.1989	16.5519	10.0230	16.6439	9.6353	16.8565	9.0778	17.1896	9.0058	17.2340
2.40	11.0721	16.1321	10.8837	16.2179	10.7068	16.3007	10.3143	16.4930	9.7369	16.7904	9.5268	16.9186
2.60	11.7447	15.8452	11.5559	15.9228	11.3782	15.9980	10.9816	16.1730	10.3869	16.4565	10.0549	16.6270
2.80	12.4060	15.5890	12.2169	15.6598	12.0384	15.7284	11.6382	15.8887	11.0284	16.1518	10.5894	16.3575
3.00	13.0573	15.3585	12.8678	15.4235	12.6887	15.4864	12.2853	15.6340	11.6623	15.8789	11.1257	16.1082
3.20	13.6994	15.1497	13.5096	15.2096	13.3299	15.2677	12.9237	15.4041	12.2890	15.6326	11.6656	15.8774
3.40	14.3332	14.9595	14.1432	15.0150	13.9630	15.0688	13.5542	15.1954	12.9090	15.4092	12.2074	15.6634
3.60	14.9595	14.7853	14.7692	14.8369	14.5885	14.8869	14.1775	15.0049	13.5228	15.2054	12.7503	15.4646
3.80	15.5787	14.6250	15.3882	14.6731	15.2071	14.7198	14.7940	14.8301	14.1308	15.0187	13.2937	15.2796
4.00	16.1916	14.4768	16.0009	14.5219	15.8193	14.5656	15.4044	14.6690	14.7333	14.8467	13.8372	15.1071
4.20	16.7984	14.3395	16.6076	14.3817	16.4257	14.4228	16.0090	14.5199	15.3308	14.6878	14.3804	14.9459
4.40	17.3998	14.2116	17.2088	14.2514	17.0265	14.2900	16.6083	14.3816	15.9235	14.5404	14.9232	14.7950
4.60	17.9960	14.0923	17.8048	14.1298	17.6223	14.1663	17.2025	14.2527	16.5119	14.4033	15.4653	14.6535
4.80	18.5873	13.9805	18.3960	14.0160	18.2132	14.0505	17.7921	14.1323	17.0959	14.2753	16.0065	14.5205
5.00	19.1742	13.8756	18.9827	13.9092	18.7996	13.9419	18.3773	14.0195	17.6758	14.1555	16.5469	14.3954
5.20	19.7568	13.7770	19.5652	13.8088	19.3819	13.8399	18.9583	13.9136	18.2520	14.0431	17.0860	14.2774
5.40	20.3354	13.6839	20.1437	13.7142	19.9601	13.7437	19.5355	13.8138	18.8246	13.9374	17.6240	14.1659
5.60	20.9102	13.5960	20.7184	13.6249	20.5346	13.6530	20.1089	13.7198	19.3930	13.8378	18.1609	14.0605
5.80	21.4814	13.5128	21.2895	13.5403	21.1055	13.5671	20.6789	13.6309	19.9590	13.7438	18.6964	13.9606
6.00	22.0492	13.4338	21.8572	13.4601	21.6730	13.4857	21.2455	13.5467	20.5228	13.6548	19.2307	13.8658
6.20	22.6138	13.3589	22.4218	13.3840	22.2374	13.4085	21.8090	13.4668	21.0828	13.5704	19.7637	13.7758
6.40	23.1754	13.2875	22.9832	13.3116	22.7987	13.3350	22.3695	13.3909	21.6390	13.4904	20.2954	13.6902
6.60	23.7340	13.2195	23.5418	13.2426	23.3571	13.2651	22.9271	13.3187	22.1944	13.4142	20.8259	13.6086
6.80	24.2899	13.1547	24.0976	13.1768	23.9127	13.1984	23.4820	13.2498	22.7464	13.3417	21.3550	13.5308
7.00	24.8431	13.0927	24.6507	13.1140	24.4657	13.1347	24.0343	13.1842	23.2959	13.2726	21.8829	13.4566
7.20	25.3937	13.0334	25.2013	13.0539	25.0161	13.0738	24.5841	13.1214	23.8430	13.2066	22.4095	13.3856
7.40	25.9420	12.9766	25.7494	12.9963	25.5642	13.0155	25.1315	13.0614	24.3878	13.1435	22.9348	13.3177
7.60	26.4879	12.9222	26.2953	12.9412	26.1099	12.9597	25.6766	13.0039	24.9305	13.0831	23.4589	13.2526
7.80	27.0316	12.8700	26.8389	12.8883	26.6534	12.9061	26.2195	12.9487	25.4711	13.0253	23.9818	13.1903
8.00	27.5731	12.8198	27.3804	12.8375	27.1947	12.8547	26.7603	12.8958	26.0097	12.9698	24.5035	13.1304
8.20	28.1125	12.7716	27.9198	12.7886	27.7340	12.8052	27.2991	12.8450	26.5464	12.9165	25.0240	13.0730
8.40	28.6500	12.7251	28.4572	12.7416	28.2713	12.7577	27.8359	12.7961	27.0812	12.8653	25.5433	13.0177
8.60	29.1856	12.6804	28.9927	12.6963	28.8067	12.7119	28.3708	12.7490	27.6142	12.8161	26.0615	12.9646
8.80	29.7193	12.6373	29.5264	12.6527	29.3403	12.6677	28.9039	12.7037	28.1454	12.7687	26.5785	12.9134
9.00	30.2513	12.5957	30.0583	12.6106	29.8721	12.6252	29.4353	12.6600	28.6750	12.7230	27.0944	12.8641
9.20	30.7815	12.5555	30.5885	12.5700	30.4022	12.5841	29.9650	12.6179	29.2030	12.6790	27.6093	12.8165
9.40	31.3101	12.5167	31.1170	12.5307	30.9307	12.5444	30.4930	12.5772	29.7294	12.6365	28.1231	12.7706
9.60	31.8371	12.4792	31.6439	12.4928	31.4575	12.5061	31.0195	12.5379	30.2542	12.5954	28.6358	12.7263
9.80	32.3625	12.4428	32.1693	12.4561	31.9828	12.4690	31.5444	12.4999	30.7776	12.5558	29.1476	12.6835
10.00	32.8864	12.4077	32.6932	12.4205	32.5067	12.4331	32.0678	12.4631	31.2996	12.5174	29.6583	12.6421

V-INFINITY = 10.0 KM/S

T - YRS	Q = .1 AU RAD	VEL	Q = .3 AU RAD	VEL	Q = .5 AU RAD	VEL	Q = 1.0 AU RAD	VEL	Q = 2.0 AU RAD	VEL	Q = 5.2 AU RAD	VEL
10.00	32.8864	12.4077	32.6932	12.4205	32.5067	12.4331	32.0678	12.4631	31.2996	12.5174	29.6583	12.6491
11.00	35.4852	12.2474	35.2918	12.2586	35.1049	12.2695	34.6644	12.2957	33.8805	12.3432	32.1976	12.4541
12.00	38.0527	12.1089	37.8592	12.1188	37.6719	12.1284	37.2300	12.1514	36.4405	12.1933	34.7148	12.2927
13.00	40.5930	11.9878	40.3993	11.9966	40.2119	12.0051	39.7687	12.0256	38.9833	12.0629	37.2118	12.1524
14.00	43.1094	11.8810	42.9157	11.8888	42.7279	11.8964	42.2838	11.9147	41.4941	11.9482	39.6906	12.0292
15.00	45.6047	11.7858	45.4108	11.7928	45.2229	11.7997	44.7778	11.8162	43.9844	11.8464	42.1528	11.9202
16.00	48.0810	11.7005	47.8870	11.7069	47.6989	11.7131	47.2530	11.7281	46.4563	11.7555	44.5999	11.8229
17.00	50.5403	11.6235	50.3463	11.6293	50.1580	11.6350	49.7113	11.6487	48.9116	11.6737	47.0331	11.7356
18.00	52.9842	11.5536	52.7901	11.5590	52.6017	11.5642	52.1543	11.5767	51.3520	11.5996	49.4536	11.6566
19.00	55.4140	11.4899	55.2198	11.4948	55.0313	11.4996	54.5833	11.5111	53.7786	11.5322	51.8623	11.5849
20.00	57.8311	11.4315	57.6368	11.4361	57.4482	11.4405	56.9996	11.4511	56.1927	11.4706	54.2601	11.5195
21.00	60.2363	11.3778	60.0420	11.3820	59.8533	11.3861	59.4042	11.3959	58.5953	11.4140	56.6478	11.4595
22.00	62.6307	11.3282	62.4364	11.3321	62.2475	11.3359	61.7980	11.3451	60.9872	11.3619	59.0261	11.4043
23.00	65.0151	11.2823	64.8207	11.2859	64.6318	11.2895	64.1818	11.2980	63.3694	11.3136	61.3957	11.3534
24.00	67.3901	11.2396	67.1957	11.2430	67.0067	11.2463	66.5563	11.2542	65.7423	11.2689	63.7571	11.3061
25.00	69.7565	11.1998	69.5621	11.2030	69.3729	11.2061	68.9222	11.2135	68.1068	11.2272	66.1109	11.2622
26.00	72.1148	11.1626	71.9203	11.1656	71.7311	11.1685	71.2801	11.1755	70.4632	11.1884	68.4574	11.2213
27.00	74.4655	11.1277	74.2710	11.1305	74.0817	11.1333	73.6303	11.1399	72.8123	11.1520	70.7972	11.1831
28.00	76.8091	11.0950	76.6146	11.0977	76.4252	11.1003	75.9736	11.1065	75.1543	11.1179	73.1305	11.1473
29.00	79.1461	11.0642	78.9515	11.0667	78.7621	11.0692	78.3101	11.0751	77.4898	11.0859	75.4579	11.1136
30.00	81.4767	11.0352	81.2821	11.0376	81.0926	11.0399	80.6404	11.0455	79.8190	11.0557	77.7795	11.0820
31.00	83.8014	11.0078	83.6068	11.0101	83.4173	11.0123	82.9648	11.0175	82.1424	11.0272	80.0958	11.0522
32.00	86.1205	10.9819	85.9258	10.9840	85.7363	10.9861	85.2836	10.9911	84.4603	11.0003	82.4060	11.0241
33.00	88.4343	10.9573	88.2396	10.9593	88.0500	10.9613	87.5971	10.9661	86.7729	10.9748	84.7132	10.9975
34.00	90.7430	10.9340	90.5483	10.9359	90.3587	10.9378	89.9055	10.9423	89.0805	10.9507	87.0148	10.9723
35.00	93.0470	10.9118	92.8523	10.9137	92.6626	10.9155	92.2092	10.9198	91.3835	10.9277	89.3120	10.9483
36.00	95.3464	10.8908	95.1516	10.8925	94.9619	10.8942	94.5084	10.8983	93.6819	10.9059	91.6051	10.9256
37.00	97.6415	10.8707	97.4467	10.8723	97.2569	10.8740	96.8032	10.8779	95.9760	10.8851	93.8941	10.9040
38.00	99.9324	10.8515	99.7376	10.8531	99.5478	10.8546	99.0939	10.8584	98.2661	10.8653	96.1792	10.8834
39.00	102.2194	10.8332	102.0246	10.8347	101.8348	10.8362	101.3807	10.8398	100.5522	10.8464	98.4607	10.8637
40.00	104.5027	10.8156	104.3078	10.8171	104.1179	10.8185	103.6637	10.8220	102.8346	10.8284	100.7387	10.8449
41.00	106.7823	10.7989	106.5874	10.8003	106.3975	10.8017	105.9432	10.8050	105.1135	10.8111	103.0133	10.8270
42.00	109.0584	10.7828	108.8636	10.7842	108.6736	10.7855	108.2191	10.7887	107.3889	10.7945	105.2847	10.8098
43.00	111.3313	10.7674	111.1364	10.7687	110.9464	10.7700	110.4918	10.7730	109.6610	10.7787	107.5529	10.7934
44.00	113.6009	10.7526	113.4060	10.7538	113.2160	10.7551	112.7613	10.7580	111.9300	10.7634	109.8182	10.7776
45.00	115.8676	10.7384	115.6726	10.7396	115.4826	10.7408	115.0277	10.7436	114.1959	10.7488	112.0806	10.7624
46.00	118.1312	10.7247	117.9363	10.7259	117.7463	10.7270	117.2913	10.7297	116.4590	10.7348	114.3403	10.7479
47.00	120.3921	10.7116	120.1971	10.7127	120.0071	10.7138	119.5520	10.7164	118.7192	10.7212	116.5972	10.7339
48.00	122.6502	10.6989	122.4553	10.7000	122.2652	10.7010	121.8099	10.7035	120.9768	10.7082	118.8517	10.7205
49.00	124.9057	10.6867	124.7108	10.6877	124.5206	10.6887	124.0653	10.6912	123.2317	10.6957	121.1036	10.7075
50.00	127.1587	10.6749	126.9637	10.6759	126.7736	10.6769	126.3182	10.6792	125.4842	10.6836	123.3531	10.6950
51.00	129.4093	10.6635	129.2143	10.6645	129.0241	10.6654	128.5686	10.6677	127.7342	10.6719	125.6003	10.6830
52.00	131.6575	10.6525	131.4625	10.6535	131.2723	10.6544	130.8166	10.6566	129.9819	10.6607	127.8453	10.6714
53.00	133.9034	10.6419	133.7084	10.6428	133.5182	10.6437	133.0624	10.6458	132.2273	10.6498	130.0881	10.6602
54.00	136.1471	10.6316	135.9521	10.6325	135.7619	10.6334	135.3060	10.6355	134.4706	10.6393	132.3289	10.6493
55.00	138.3887	10.6217	138.1937	10.6226	138.0034	10.6234	137.5475	10.6254	136.7117	10.6291	134.5676	10.6388
56.00	140.6282	10.6121	140.4332	10.6129	140.2429	10.6137	139.7869	10.6157	138.9508	10.6193	136.8043	10.6287
57.00	142.8658	10.6028	142.6707	10.6036	142.4804	10.6044	142.0244	10.6063	141.1880	10.6097	139.0392	10.6189
58.00	145.1014	10.5938	144.9063	10.5945	144.7160	10.5953	144.2599	10.5971	143.4232	10.6005	141.2722	10.6094
59.00	147.3351	10.5850	147.1400	10.5858	146.9497	10.5865	146.4935	10.5883	145.6565	10.5916	143.5034	10.6002
60.00	149.5670	10.5765	149.3720	10.5772	149.1816	10.5780	148.7253	10.5797	147.8880	10.5829	145.7329	10.5913

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V-INFINITY = 20.0 KM/S

T - YRS	Q = .1 AU RAD	VEL	Q = .3 AU RAD	VEL	Q = .5 AU RAD	VEL	Q = 1.0 AU RAD	VEL	Q = 2.0 AU RAD	VEL	Q = 5.2 AU RAD	VEL
.00	.1000	134.6943	.3000	79.4619	.5000	62.8372	1.0000	46.6289	2.0000	35.8766	5.2000	27.2250
.20	1.9905	35.9357	1.8471	36.8857	1.7598	37.5261	1.7614	37.5140	2.3408	34.0290	5.2967	27.1104
.40	3.3546	30.4778	3.1945	30.9096	3.0722	31.2652	2.9177	31.7506	3.1185	31.1277	5.5757	26.7005
.60	4.5759	28.0667	4.4094	28.3263	4.2739	28.5505	4.0572	28.9363	4.0518	28.9463	6.0092	26.3677
.80	5.7225	26.6467	5.5525	26.8242	5.4100	26.9807	5.1597	27.2740	5.0319	27.4336	6.5638	25.9004
1.00	6.8217	25.6922	6.6495	25.8230	6.5024	25.9396	6.2309	26.1677	6.0231	26.3548	7.2084	25.6103
1.20	7.8875	24.9989	7.7137	25.1000	7.5636	25.1909	7.2774	25.3733	7.0133	25.5536	7.9194	24.9014
1.40	8.9283	24.4688	8.7534	24.5498	8.6009	24.6229	8.3039	24.7723	7.9981	24.9366	8.6754	24.5869
1.60	9.9497	24.0483	9.7739	24.1149	9.6196	24.1752	9.3143	24.3000	8.9763	24.4471	9.4665	24.2368
1.80	10.9554	23.7055	10.7789	23.7614	10.6231	23.8121	10.3112	23.9180	9.9476	24.0401	10.2822	23.9281
2.00	11.9481	23.4200	11.7710	23.4677	11.6141	23.5110	11.2967	23.6021	10.9123	23.7190	11.1160	23.6561
2.20	12.9299	23.1780	12.7523	23.2192	12.5944	23.2568	12.2725	23.3361	11.8708	23.4407	11.9630	23.4161
2.40	13.9023	22.9700	13.7243	23.0061	13.5656	23.0389	13.2399	23.1086	12.8235	23.2026	12.8200	23.2034
2.60	14.8667	22.7891	14.6883	22.8209	14.5289	22.8499	14.1999	22.9117	13.7710	22.9965	13.6843	23.0143
2.80	15.8240	22.6302	15.6453	22.6584	15.4853	22.6843	15.1535	22.7395	14.7136	22.8164	14.5541	22.8453
3.00	16.7751	22.4893	16.5962	22.5146	16.4356	22.5378	16.1013	22.5875	15.6518	22.6574	15.4291	22.6036
3.20	17.7207	22.3634	17.5415	22.3863	17.3804	22.4072	17.0439	22.4522	16.5860	22.5161	16.3052	22.5569
3.40	18.6612	22.2503	18.4818	22.2711	18.3203	22.2901	17.9818	22.3300	17.5164	22.3895	17.1846	22.4332
3.60	19.5973	22.1480	19.4177	22.1669	19.2558	22.1843	18.9155	22.2216	18.4434	22.2755	18.0656	22.3207
3.80	20.5293	22.0551	20.3495	22.0724	20.1873	22.0882	19.8454	22.1225	19.3672	22.1723	18.9470	22.2190
4.00	21.4576	21.9701	21.2776	21.9860	21.1151	22.0006	20.7718	22.0322	20.2881	22.0783	19.8311	22.1239
4.20	22.3825	21.8922	22.2024	21.9069	22.0395	21.9204	21.6949	21.9495	21.2062	21.9924	20.7148	22.0375
4.40	23.3043	21.8205	23.1240	21.8341	22.9609	21.8466	22.6150	21.8736	22.1218	21.9136	21.5989	21.9578
4.60	24.2231	21.7542	24.0427	21.7669	23.8794	21.7784	23.5324	21.8036	23.0350	21.8409	22.4831	21.8841
4.80	25.1393	21.6928	24.9588	21.7045	24.7952	21.7153	24.4473	21.7388	23.9459	21.7737	23.3673	21.8158
5.00	26.0531	21.6357	25.8725	21.6466	25.7087	21.6567	25.3597	21.6786	24.8548	21.7114	24.2515	21.7523
5.20	26.9645	21.5824	26.7838	21.5927	26.6198	21.6021	26.2700	21.6227	25.7617	21.6534	25.1354	21.6930
5.40	27.8737	21.5326	27.6929	21.5423	27.5288	21.5511	27.1781	21.5704	26.6668	21.5994	26.0191	21.6377
5.60	28.7810	21.4860	28.6001	21.4950	28.4357	21.5034	28.0844	21.5215	27.5701	21.5489	26.9025	21.5859
5.80	29.6863	21.4422	29.5054	21.4507	29.3409	21.4586	28.9887	21.4757	28.4718	21.5015	27.7856	21.5373
6.00	30.5899	21.4010	30.4089	21.4090	30.2442	21.4165	29.8914	21.4326	29.3719	21.4571	28.6682	21.4916
6.20	31.4918	21.3621	31.3107	21.3697	31.1459	21.3768	30.7925	21.3921	30.2706	21.4153	29.5505	21.4486
6.40	32.3921	21.3254	32.2109	21.3327	32.0460	21.3393	31.6920	21.3538	31.1678	21.3759	30.4323	21.4080
6.60	33.2909	21.2907	33.1097	21.2976	32.9446	21.3039	32.5900	21.3176	32.0638	21.3386	31.3137	21.3696
6.80	34.1883	21.2579	34.0070	21.2644	33.8418	21.2704	33.4867	21.2834	32.9585	21.3034	32.1947	21.3333
7.00	35.0844	21.2267	34.9030	21.2329	34.7377	21.2385	34.3821	21.2510	33.8520	21.2700	33.0752	21.2989
7.20	35.9791	21.1970	35.7977	21.2029	35.6323	21.2083	35.2762	21.2202	34.7443	21.2383	33.9552	21.2662
7.40	36.8727	21.1688	36.6912	21.1744	36.5257	21.1796	36.1692	21.1909	35.6356	21.2082	34.8348	21.2352
7.60	37.7651	21.1419	37.5836	21.1473	37.4180	21.1522	37.0610	21.1630	36.5259	21.1796	35.7139	21.2057
7.80	38.6564	21.1163	38.4748	21.1214	38.3092	21.1261	37.9518	21.1365	37.4150	21.1523	36.5926	21.1775
8.00	39.5467	21.0918	39.3651	21.0967	39.1993	21.1012	38.8415	21.1111	38.3033	21.1263	37.4708	21.1507
8.20	40.4359	21.0684	40.2543	21.0731	40.0884	21.0774	39.7303	21.0869	39.1906	21.1015	38.3486	21.1250
8.40	41.3242	21.0460	41.1425	21.0505	40.9766	21.0547	40.6181	21.0637	40.0771	21.0777	39.2259	21.1005
8.60	42.2116	21.0246	42.0298	21.0289	41.8638	21.0329	41.5050	21.0416	40.9628	21.0550	40.1028	21.0771
8.80	43.0981	21.0040	42.9163	21.0081	42.7502	21.0120	42.3910	21.0203	41.8476	21.0333	40.9792	21.0546
9.00	43.9837	20.9843	43.8019	20.9882	43.6358	20.9919	43.2763	21.0000	42.7316	21.0124	41.8553	21.0331
9.20	44.8685	20.9653	44.6867	20.9691	44.5205	20.9727	44.1607	20.9804	43.6150	20.9924	42.7309	21.0124
9.40	45.7526	20.9471	45.5707	20.9508	45.4044	20.9542	45.0444	20.9616	44.4975	20.9732	43.6061	20.9926
9.60	46.6359	20.9295	46.4540	20.9331	46.2876	20.9364	45.9273	20.9435	45.3794	20.9547	44.4810	20.9735
9.80	47.5185	20.9126	47.3365	20.9161	47.1701	20.9192	46.8095	20.9262	46.2607	20.9369	45.3554	20.9552
10.00	48.4003	20.8964	48.2184	20.8997	48.0519	20.9027	47.6910	20.9094	47.1412	20.9198	46.2294	20.9375

V-INFINITY = 20.0 KM/S

T - YRS	Q = .1 AU RAD	VEL	Q = .3 AU RAD	VEL	Q = .5 AU RAD	VEL	Q = 1.0 AU RAD	VEL	Q = 2.0 AU RAD	VEL	Q = 5.2 AU RAD	VEL
10.00	48.4003	20.8964	48.2184	20.8997	48.0519	20.9027	47.6910	20.9094	47.1412	20.9198	46.2284	20.9375
11.00	52.8001	20.8231	52.6180	20.8259	52.4513	20.8285	52.0893	20.8342	51.5352	20.8429	50.5941	20.8583
12.00	57.1857	20.7612	57.0035	20.7636	56.8366	20.7658	56.4736	20.7706	55.9159	20.7781	54.9503	20.7915
13.00	61.5593	20.7080	61.3770	20.7101	61.2098	20.7120	60.8460	20.7162	60.2853	20.7227	59.2987	20.7345
14.00	65.9224	20.6619	65.7400	20.6637	65.5728	20.6654	65.2082	20.6690	64.6448	20.6748	63.6402	20.6852
15.00	70.2765	20.6215	70.0940	20.6231	69.9266	20.6246	69.5614	20.6278	68.9957	20.6329	67.9754	20.6422
16.00	74.6226	20.5858	74.4400	20.5872	74.2725	20.5886	73.9068	20.5914	73.3391	20.5959	72.3040	20.6043
17.00	78.9616	20.5541	78.7790	20.5553	78.6113	20.5565	78.2451	20.5591	77.6756	20.5631	76.6292	20.5707
18.00	83.2942	20.5256	83.1116	20.5268	82.9439	20.5278	82.5772	20.5301	82.0061	20.5338	80.9487	20.5406
19.00	87.6212	20.5000	87.4386	20.5010	87.2707	20.5020	86.9037	20.5041	86.3311	20.5074	85.2639	20.5136
20.00	91.9431	20.4768	91.7604	20.4777	91.5925	20.4786	91.2251	20.4805	90.6512	20.4835	89.5751	20.4892
21.00	96.2603	20.4556	96.0775	20.4565	95.9095	20.4573	95.5418	20.4590	94.9667	20.4617	93.8826	20.4670
22.00	100.5732	20.4363	100.3904	20.4371	100.2224	20.4378	99.8544	20.4394	99.2782	20.4419	98.1867	20.4468
23.00	104.8823	20.4185	104.6994	20.4193	104.5313	20.4199	104.1630	20.4214	103.5859	20.4237	102.4877	20.4282
24.00	109.1877	20.4022	109.0048	20.4029	108.8367	20.4035	108.4682	20.4048	107.8901	20.4070	106.7857	20.4112
25.00	113.4899	20.3871	113.3070	20.3877	113.1387	20.3883	112.7700	20.3895	112.1911	20.3915	111.0810	20.3954
26.00	117.7889	20.3731	117.6060	20.3737	117.4378	20.3742	117.0688	20.3754	116.4891	20.3772	115.3738	20.3808
27.00	122.0852	20.3601	121.9022	20.3606	121.7339	20.3611	121.3648	20.3622	120.7843	20.3639	119.6641	20.3673
28.00	126.3788	20.3480	126.1958	20.3485	126.0275	20.3489	125.6581	20.3499	125.0770	20.3515	123.9522	20.3547
29.00	130.6699	20.3366	130.4869	20.3371	130.3185	20.3375	129.9490	20.3385	129.3673	20.3400	128.2383	20.3430
30.00	134.9587	20.3260	134.7757	20.3264	134.6073	20.3269	134.2376	20.3277	133.6553	20.3292	132.5223	20.3320
31.00	139.2454	20.3161	139.0623	20.3165	138.8939	20.3168	138.5241	20.3177	137.9412	20.3190	136.8045	20.3216
32.00	143.5300	20.3067	143.3469	20.3071	143.1785	20.3074	142.8085	20.3082	142.2251	20.3095	141.0849	20.3120
33.00	147.8127	20.2979	147.6296	20.2982	147.4611	20.2986	147.0910	20.2993	146.5071	20.3005	145.3636	20.3028
34.00	152.0936	20.2895	151.9105	20.2899	151.7420	20.2902	151.3717	20.2909	150.7874	20.2920	149.6408	20.2943
35.00	156.3728	20.2817	156.1897	20.2820	156.0211	20.2823	155.6508	20.2830	155.0660	20.2840	153.9165	20.2861
36.00	160.6503	20.2742	160.4673	20.2745	160.2987	20.2748	159.9282	20.2755	159.3430	20.2765	158.1907	20.2785
37.00	164.9264	20.2672	164.7433	20.2675	164.5747	20.2677	164.2041	20.2683	163.6185	20.2693	162.4636	20.2712
38.00	169.2010	20.2605	169.0179	20.2607	168.8492	20.2610	168.4786	20.2616	167.8926	20.2625	166.7352	20.2643
39.00	173.4742	20.2541	173.2911	20.2543	173.1224	20.2546	172.7517	20.2551	172.1653	20.2560	171.0056	20.2577
40.00	177.7461	20.2480	177.5630	20.2483	177.3943	20.2485	177.0235	20.2490	176.4368	20.2498	175.2748	20.2515
41.00	182.0168	20.2422	181.8337	20.2425	181.6649	20.2427	181.2940	20.2432	180.7070	20.2440	179.5429	20.2455
42.00	186.2863	20.2367	186.1031	20.2369	185.9344	20.2372	185.5634	20.2376	184.9761	20.2384	183.8099	20.2399
43.00	190.5546	20.2314	190.3714	20.2317	190.2027	20.2319	189.8316	20.2323	189.2440	20.2330	188.0759	20.2345
44.00	194.8219	20.2264	194.6387	20.2266	194.4699	20.2268	194.0987	20.2272	193.5109	20.2279	192.3409	20.2293
45.00	199.0881	20.2216	198.9049	20.2218	198.7361	20.2220	198.3649	20.2224	197.7767	20.2230	196.6050	20.2244
46.00	203.3533	20.2169	203.1701	20.2171	203.0013	20.2173	202.6300	20.2177	202.0416	20.2183	200.8682	20.2196
47.00	207.6175	20.2125	207.4343	20.2127	207.2655	20.2129	206.8942	20.2133	206.3055	20.2139	205.1305	20.2151
48.00	211.8809	20.2083	211.6977	20.2084	211.5289	20.2086	211.1574	20.2090	210.5686	20.2096	209.3919	20.2107
49.00	216.1434	20.2042	215.9601	20.2043	215.7913	20.2045	215.4198	20.2049	214.8307	20.2054	213.6526	20.2065
50.00	220.4050	20.2002	220.2218	20.2004	220.0529	20.2006	219.6814	20.2009	219.0921	20.2014	217.9125	20.2025
51.00	224.6658	20.1965	224.4826	20.1966	224.3137	20.1968	223.9421	20.1971	223.3526	20.1976	222.1716	20.1987
52.00	228.9258	20.1928	228.7426	20.1930	228.5737	20.1931	228.2020	20.1934	227.6123	20.1939	226.4301	20.1949
53.00	233.1851	20.1893	233.0019	20.1895	232.8330	20.1896	232.4613	20.1899	231.8714	20.1904	230.6878	20.1914
54.00	237.4436	20.1859	237.2604	20.1861	237.0915	20.1862	236.7197	20.1865	236.1297	20.1870	234.9448	20.1879
55.00	241.7015	20.1827	241.5183	20.1828	241.3493	20.1829	240.9775	20.1832	240.3873	20.1837	239.2013	20.1846
56.00	245.9587	20.1795	245.7754	20.1797	245.6065	20.1798	245.2346	20.1801	244.6442	20.1805	243.4570	20.1814
57.00	250.2152	20.1765	250.0319	20.1766	249.8630	20.1767	249.4911	20.1770	248.9005	20.1774	247.7122	20.1783
58.00	254.4711	20.1736	254.2878	20.1737	254.1189	20.1738	253.7469	20.1740	253.1562	20.1745	251.9668	20.1753
59.00	258.7264	20.1707	258.5431	20.1708	258.3742	20.1709	258.0022	20.1712	257.4113	20.1716	256.2209	20.1724
60.00	262.9811	20.1680	262.7978	20.1681	262.6288	20.1682	262.2568	20.1684	261.6657	20.1688	260.4743	20.1696

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V-INFINITY = 30.0 KM/S

T - YRS	Q = .1 AU RAD	VEL	Q = .3 AU RAD	VEL	Q = .5 AU RAD	VEL	Q = 1.0 AU RAD	VEL	Q = 2.0 AU RAD	VEL	Q = 5.2 AU RAD	VEL
.00	.1000	136.5378	.3000	82.5481	.5000	66.6972	1.0000	51.7132	2.0000	42.2744	5.2000	35.2307
.20	2.1796	41.4007	2.0477	42.0293	1.9734	42.4156	1.9965	42.3458	2.5215	40.0456	5.3800	35.0684
.40	3.8036	36.9657	3.6566	37.2186	3.5521	37.4099	3.4349	37.6369	3.6295	37.2672	5.8853	34.6623
.60	5.3147	35.1260	5.1620	35.2663	5.0463	35.3779	4.8790	35.5479	4.9068	35.5189	6.6384	34.1654
.80	6.7699	34.0893	6.6142	34.1797	6.4925	34.2531	6.2985	34.3758	6.2317	34.4107	7.5618	33.6843
1.00	8.1909	33.4158	8.0333	33.4793	7.9079	33.5316	7.6973	33.6230	7.5701	33.6905	8.5974	33.2622
1.20	9.5886	32.9399	9.4297	32.9872	9.3017	33.0264	9.0797	33.0970	8.9108	33.1529	9.7068	32.9057
1.40	10.9694	32.5844	10.8094	32.6212	10.6797	32.6517	10.4493	32.7077	10.2408	32.7582	10.8654	32.6082
1.60	12.3372	32.3081	12.1765	32.3375	12.0453	32.3620	11.8085	32.4076	11.5856	32.4522	12.0577	32.3596
1.80	13.6947	32.0867	13.5334	32.1108	13.4010	32.1309	13.1593	32.1688	12.9179	32.2079	13.2735	32.1507
2.00	15.0439	31.9052	14.8821	31.9252	14.7488	31.9421	14.5030	31.9740	14.2467	32.0084	14.5061	31.9736
2.20	16.3862	31.7534	16.2240	31.7704	16.0899	31.7848	15.8407	31.8120	15.5720	31.8424	15.7508	31.8221
2.40	17.7226	31.6246	17.5601	31.6392	17.4254	31.6515	17.1734	31.6751	16.8942	31.7021	17.0046	31.6913
2.60	19.0541	31.5138	18.8913	31.5265	18.7560	31.5372	18.5016	31.5578	18.2136	31.5819	18.2651	31.5775
2.80	20.3813	31.4174	20.2182	31.4286	20.0825	31.4380	19.8259	31.4562	19.5303	31.4777	19.5306	31.4777
3.00	21.7047	31.3328	21.5414	31.3427	21.4052	31.3511	21.1469	31.3672	20.8445	31.3866	20.8001	31.3905
3.20	23.0247	31.2579	22.8612	31.2668	22.7247	31.2742	22.4647	31.2886	22.1565	31.3062	22.0726	31.3111
3.40	24.3418	31.1912	24.1782	31.1991	24.0413	31.2058	23.7799	31.2188	23.4665	31.2347	23.3470	31.2409
3.60	25.6563	31.1313	25.4925	31.1384	25.3554	31.1444	25.0927	31.1562	24.7745	31.1708	24.6241	31.1778
3.80	26.9684	31.0772	26.8044	31.0836	26.6670	31.0891	26.4032	31.0998	26.0809	31.1132	25.9021	31.1207
4.00	28.2783	31.0281	28.1142	31.0340	27.9766	31.0390	27.7117	31.0488	27.3856	31.0610	27.1812	31.0699
4.20	29.5863	30.9834	29.4221	30.9888	29.2842	30.9933	29.0184	31.0023	28.6889	31.0136	28.4612	31.0216
4.40	30.8924	30.9424	30.7281	30.9474	30.5901	30.9516	30.3234	30.9598	29.9907	30.9703	29.7418	30.9783
4.60	32.1970	30.9048	32.0326	30.9094	31.8943	30.9133	31.6269	30.9209	31.2913	30.9306	31.0220	30.9385
4.80	33.5000	30.8701	33.3355	30.8743	33.1971	30.8779	32.9289	30.8850	32.5907	30.8940	32.3043	30.9018
5.00	34.8016	30.8380	34.6370	30.8419	34.4985	30.8453	34.2296	30.8518	33.8890	30.8602	33.5860	30.8679
5.20	36.1019	30.8082	35.9373	30.8119	35.7986	30.8150	35.5291	30.8211	35.1862	30.8290	34.8679	30.8364
5.40	37.4010	30.7805	37.2363	30.7839	37.0975	30.7868	36.8274	30.7925	36.4824	30.7999	36.1499	30.8071
5.60	38.6990	30.7546	38.5342	30.7578	38.3953	30.7605	38.1246	30.7659	37.7777	30.7728	37.4320	30.7799
5.80	39.9959	30.7305	39.8311	30.7334	39.6920	30.7360	39.4209	30.7410	39.0722	30.7475	38.7141	30.7543
6.00	41.2919	30.7078	41.1270	30.7106	40.9878	30.7130	40.7162	30.7177	40.3658	30.7238	39.9961	30.7305
6.20	42.5869	30.6865	42.4220	30.6892	42.2827	30.6914	42.0107	30.6958	41.6586	30.7016	41.2781	30.7080
6.40	43.8811	30.6665	43.7161	30.6690	43.5767	30.6711	43.3043	30.6753	42.9507	30.6808	42.5601	30.6869
6.60	45.1744	30.6476	45.0094	30.6500	44.8699	30.6520	44.5971	30.6559	44.2421	30.6611	43.8410	30.6671
6.80	46.4670	30.6298	46.3019	30.6320	46.1624	30.6339	45.8892	30.6376	45.5329	30.6426	45.1235	30.6483
7.00	47.7589	30.6129	47.5937	30.6150	47.4541	30.6168	47.1805	30.6203	46.8230	30.6250	46.4052	30.6306
7.20	49.0500	30.5969	48.8848	30.5989	48.7451	30.6006	48.4713	30.6040	48.1125	30.6085	47.6867	30.6138
7.40	50.3405	30.5818	50.1753	30.5837	50.0355	30.5853	49.7613	30.5885	49.4015	30.5927	48.9680	30.5979
7.60	51.6304	30.5674	51.4652	30.5692	51.3253	30.5707	51.0508	30.5738	50.6809	30.5778	50.2491	30.5828
7.80	52.9197	30.5537	52.7544	30.5554	52.6145	30.5569	52.3397	30.5598	51.9778	30.5636	51.5301	30.5685
8.00	54.2084	30.5406	54.0431	30.5423	53.9031	30.5437	53.6281	30.5464	53.2652	30.5501	52.8110	30.5548
8.20	55.4966	30.5282	55.3313	30.5298	55.1913	30.5311	54.9160	30.5337	54.5521	30.5373	54.0917	30.5418
8.40	56.7843	30.5163	56.6190	30.5178	56.4789	30.5191	56.2033	30.5216	55.8386	30.5250	55.3722	30.5294
8.60	58.0715	30.5050	57.9061	30.5064	57.7660	30.5076	57.4902	30.5100	57.1247	30.5133	56.6526	30.5175
8.80	59.3583	30.4941	59.1928	30.4955	59.0526	30.4966	58.7766	30.4990	58.4103	30.5021	57.9328	30.5062
9.00	60.6446	30.4837	60.4791	30.4850	60.3388	30.4861	60.0626	30.4884	59.6955	30.4913	59.2128	30.4953
9.20	61.9304	30.4737	61.7649	30.4750	61.6246	30.4761	61.3482	30.4782	60.9804	30.4811	60.4927	30.4849
9.40	63.2159	30.4642	63.0504	30.4654	62.9100	30.4664	62.6334	30.4685	62.2649	30.4712	61.7724	30.4749
9.60	64.5009	30.4550	64.3354	30.4562	64.1950	30.4572	63.9182	30.4591	63.5490	30.4618	63.0519	30.4654
9.80	65.7856	30.4462	65.6200	30.4473	65.4796	30.4483	65.2026	30.4501	64.8328	30.4527	64.3313	30.4562
10.00	67.0699	30.4377	66.9043	30.4388	66.7639	30.4397	66.4867	30.4415	66.1162	30.4440	65.6106	30.4474

V-INFINITY = 30.0 KM/S

	Q = .1 AU		Q = .3 AU		Q = .5 AU		Q = 1.0 AU		Q = 2.0 AU		Q = 5.2 AU	
T - YRS	RAD	VEL	RAD	VEL	RAD	VEL	RAD	VEL	RAD	VEL	RAD	VEL
10.00	67.0699	30.4377	66.9043	30.4388	66.7639	30.4397	66.4867	30.4415	66.1162	30.4440	65.6106	30.4474
11.00	73.4865	30.3997	73.3208	30.4006	73.1801	30.4014	72.9022	30.4029	72.5289	30.4050	72.0045	30.4079
12.00	79.8957	30.3679	79.7300	30.3686	79.5892	30.3693	79.3106	30.3706	78.9350	30.3723	78.3947	30.3749
13.00	86.2988	30.3407	86.1329	30.3414	85.9920	30.3419	85.7129	30.3430	85.3353	30.3445	84.7817	30.3468
14.00	92.6965	30.3173	92.5306	30.3179	92.3896	30.3184	92.1100	30.3193	91.7307	30.3207	91.1656	30.3226
15.00	99.0897	30.2970	98.9237	30.2975	98.7826	30.2979	98.5026	30.2987	98.1218	30.2999	97.5467	30.3016
16.00	105.4788	30.2791	105.3128	30.2795	105.1716	30.2799	104.8913	30.2806	104.5092	30.2816	103.9253	30.2832
17.00	111.8644	30.2632	111.6984	30.2636	111.5571	30.2639	111.2764	30.2646	110.8932	30.2655	110.3016	30.2669
18.00	118.2468	30.2490	118.0808	30.2494	117.9394	30.2497	117.6585	30.2503	117.2742	30.2511	116.6757	30.2524
19.00	124.6264	30.2363	124.4604	30.2367	124.3190	30.2369	124.0377	30.2375	123.6526	30.2382	123.0479	30.2394
20.00	131.0035	30.2249	130.8374	30.2252	130.6959	30.2254	130.4145	30.2259	130.0285	30.2266	129.4183	30.2276
21.00	137.3783	30.2145	137.2122	30.2147	137.0706	30.2150	136.7890	30.2154	136.4023	30.2160	135.7870	30.2170
22.00	143.7510	30.2050	143.5848	30.2052	143.4433	30.2054	143.1614	30.2059	142.7740	30.2064	142.1541	30.2073
23.00	150.1218	30.1963	149.9556	30.1966	149.8140	30.1967	149.5320	30.1971	149.1439	30.1976	148.5198	30.1984
24.00	156.4908	30.1884	156.3246	30.1886	156.1829	30.1887	155.9008	30.1891	155.5121	30.1896	154.8842	30.1903
25.00	162.8582	30.1810	162.6920	30.1812	162.5503	30.1814	162.2680	30.1817	161.8788	30.1821	161.2473	30.1828
26.00	169.2241	30.1742	169.0579	30.1744	168.9162	30.1746	168.6337	30.1748	168.2441	30.1753	167.6003	30.1759
27.00	175.5887	30.1679	175.4224	30.1681	175.2807	30.1682	174.9981	30.1685	174.6080	30.1689	173.9702	30.1695
28.00	181.9519	30.1621	181.7857	30.1622	181.6439	30.1624	181.3612	30.1626	180.9707	30.1630	180.3301	30.1635
29.00	188.3140	30.1566	188.1477	30.1568	188.0059	30.1569	187.7231	30.1571	187.3322	30.1574	186.6890	30.1580
30.00	194.6750	30.1515	194.5087	30.1516	194.3669	30.1518	194.0839	30.1520	193.6927	30.1523	193.0470	30.1528
31.00	201.0349	30.1467	200.8686	30.1469	200.7267	30.1470	200.4437	30.1472	200.0521	30.1475	199.4041	30.1479
32.00	207.3938	30.1422	207.2275	30.1424	207.0857	30.1425	206.8026	30.1427	206.4106	30.1429	205.7604	30.1434
33.00	213.7518	30.1380	213.5855	30.1381	213.4437	30.1382	213.1605	30.1384	212.7682	30.1387	212.1160	30.1391
34.00	220.1090	30.1340	219.9427	30.1341	219.8008	30.1342	219.5175	30.1344	219.1250	30.1346	218.4709	30.1351
35.00	226.4654	30.1303	226.2990	30.1304	226.1571	30.1305	225.8738	30.1306	225.4810	30.1309	224.8251	30.1312
36.00	232.8209	30.1267	232.6546	30.1268	232.5127	30.1269	232.2293	30.1271	231.8362	30.1273	231.1786	30.1276
37.00	239.1758	30.1234	239.0094	30.1235	238.8675	30.1235	238.5840	30.1237	238.1908	30.1239	237.5315	30.1242
38.00	245.5300	30.1202	245.3636	30.1203	245.2216	30.1203	244.9381	30.1205	244.5446	30.1207	243.8838	30.1210
39.00	251.8835	30.1172	251.7171	30.1172	251.5751	30.1173	251.2915	30.1174	250.8978	30.1176	250.2356	30.1179
40.00	258.2364	30.1143	258.0700	30.1144	257.9280	30.1144	257.6443	30.1146	257.2504	30.1147	256.5868	30.1150
41.00	264.5886	30.1116	264.4223	30.1116	264.2803	30.1117	263.9965	30.1118	263.6024	30.1120	262.9375	30.1123
42.00	270.9404	30.1089	270.7740	30.1090	270.6320	30.1091	270.3482	30.1092	269.9530	30.1093	269.2877	30.1096
43.00	277.2916	30.1065	277.1252	30.1065	276.9831	30.1066	276.6993	30.1067	276.3049	30.1068	275.6375	30.1071
44.00	283.6422	30.1041	283.4758	30.1041	283.3338	30.1042	283.0499	30.1043	282.6553	30.1044	281.9868	30.1047
45.00	289.9924	30.1018	289.8260	30.1019	289.6840	30.1019	289.4001	30.1020	289.0053	30.1021	288.3357	30.1024
46.00	296.3422	30.0996	296.1757	30.0997	296.0337	30.0997	295.7497	30.0998	295.3548	30.1000	294.6841	30.1002
47.00	302.6914	30.0975	302.5250	30.0976	302.3829	30.0976	302.0989	30.0977	301.7038	30.0979	301.0322	30.0981
48.00	309.0403	30.0955	308.8738	30.0956	308.7318	30.0956	308.4477	30.0957	308.0525	30.0958	307.3799	30.0960
49.00	315.3887	30.0936	315.2223	30.0937	315.0802	30.0937	314.7961	30.0938	314.4007	30.0939	313.7272	30.0941
50.00	321.7367	30.0918	321.5703	30.0918	321.4282	30.0919	321.1441	30.0919	320.7486	30.0921	320.0742	30.0922
51.00	328.0844	30.0900	327.9179	30.0900	327.7758	30.0901	327.4917	30.0902	327.0960	30.0903	326.4208	30.0905
52.00	334.4317	30.0883	334.2652	30.0883	334.1231	30.0884	333.8389	30.0884	333.4432	30.0886	332.7671	30.0887
53.00	340.7786	30.0866	340.6121	30.0867	340.4700	30.0867	340.1858	30.0868	339.7899	30.0869	339.1131	30.0871
54.00	347.1252	30.0851	346.9587	30.0851	346.8166	30.0851	346.5324	30.0852	346.1364	30.0853	345.4588	30.0855
55.00	353.4714	30.0835	353.3050	30.0836	353.1629	30.0836	352.8786	30.0837	352.4825	30.0838	351.8042	30.0839
56.00	359.8174	30.0821	359.6509	30.0821	359.5088	30.0821	359.2245	30.0822	358.8283	30.0823	358.1493	30.0825
57.00	366.1630	30.0807	365.9966	30.0807	365.8544	30.0807	365.5701	30.0808	365.1738	30.0809	364.4941	30.0810
58.00	372.5084	30.0793	372.3419	30.0793	372.1998	30.0793	371.9154	30.0794	371.5190	30.0795	370.8386	30.0796
59.00	378.8534	30.0780	378.6870	30.0780	378.5448	30.0780	378.2604	30.0781	377.8639	30.0782	377.1829	30.0783
60.00	385.1982	30.0767	385.0318	30.0767	384.8896	30.0767	384.6052	30.0768	384.2086	30.0769	383.5270	30.0770

V-INFINITY = 40.0 KM/S

T - YRS	Q = .1 AU RAD	VEL	Q = .3 AU RAD	VEL	Q = .5 AU RAD	VEL	Q = 1.0 AU RAD	VEL	Q = 2.0 AU RAD	VEL	Q = 5.2 AU RAD	VEL
.00	.1000	139.0775	.3000	86.6844	.5000	71.7531	1.0000	58.0883	2.0000	49.8711	5.2000	44.0591
.20	2.4236	48.2917	2.3050	48.6799	2.2441	48.8941	2.2669	48.8126	2.7549	47.3712	5.4944	43.9511
.40	4.3647	44.7940	4.2329	44.9350	4.1465	45.0321	4.0617	45.1312	4.2467	44.9109	6.2932	43.3912
.60	6.2188	43.4201	6.0821	43.4939	5.9865	43.5474	5.8615	43.6199	5.9105	43.5911	7.4309	42.8808
.80	8.0316	42.6721	7.8925	42.7177	7.7920	42.7516	7.6460	42.8025	7.6205	42.8115	8.7724	42.4530
1.00	9.8201	42.1981	9.6793	42.2292	9.5758	42.2526	9.4169	42.2896	9.3447	42.3068	10.2346	42.1113
1.20	11.5922	41.8695	11.4504	41.8921	11.3449	41.9093	11.1771	41.9373	11.0730	41.9551	11.7705	41.8418
1.40	13.3527	41.6278	13.2101	41.6451	13.1031	41.6582	12.9289	41.6801	12.8016	41.6965	13.3532	41.6278
1.60	15.1045	41.4423	14.9612	41.4559	14.8531	41.4663	14.6740	41.4839	14.5201	41.4084	14.9669	41.4554
1.80	16.8493	41.2953	16.7056	41.3063	16.5965	41.3147	16.4137	41.3291	16.2549	41.3419	16.6015	41.3143
2.00	18.5886	41.1758	18.4445	41.1849	18.3348	41.1919	18.1488	41.2039	17.9788	41.2151	18.2519	41.1073
2.20	20.3234	41.0768	20.1790	41.0844	20.0686	41.0903	19.8802	41.1005	19.7010	41.1103	19.9113	41.0988
2.40	22.0544	40.9933	21.9097	40.9998	21.7089	41.0048	21.6083	41.0135	21.4213	41.0223	21.5794	41.0149
2.60	23.7822	40.9219	23.6372	40.9275	23.5260	40.9319	23.3336	40.9395	23.1401	40.9472	23.2536	40.9426
2.80	25.5072	40.8602	25.3620	40.8651	25.2504	40.8689	25.0564	40.8755	24.8573	40.8825	24.9323	40.8709
3.00	27.2298	40.8064	27.0845	40.8106	26.9725	40.8140	26.7772	40.8198	26.5731	40.8261	26.6144	40.8248
3.20	28.9502	40.7589	28.8048	40.7627	28.6926	40.7656	28.4960	40.7709	28.2876	40.7765	28.2994	40.7762
3.40	30.6688	40.7167	30.5232	40.7201	30.4108	40.7228	30.2132	40.7274	30.0010	40.7325	29.9865	40.7329
3.60	32.3858	40.6790	32.2400	40.6821	32.1273	40.6845	31.9288	40.6887	31.7132	40.6933	31.6753	40.6942
3.80	34.1012	40.6452	33.9554	40.6479	33.8425	40.6501	33.6431	40.6539	33.4244	40.6581	33.3655	40.6593
4.00	35.8153	40.6145	35.6693	40.6170	35.5563	40.6190	35.3561	40.6224	35.1347	40.6263	35.0567	40.6277
4.20	37.5281	40.5867	37.3821	40.5889	37.2689	40.5907	37.0680	40.5939	36.8441	40.5975	36.7489	40.5990
4.40	39.2398	40.5613	39.0937	40.5633	38.9804	40.5650	38.7789	40.5679	38.5527	40.5712	38.4418	40.5728
4.60	40.9506	40.5380	40.8044	40.5399	40.6909	40.5414	40.4888	40.5441	40.2606	40.5471	40.1353	40.5488
4.80	42.6603	40.5165	42.5141	40.5183	42.4005	40.5197	42.1979	40.5222	41.9677	40.5250	41.8292	40.5267
5.00	44.3692	40.4968	44.2230	40.4984	44.1092	40.4997	43.9061	40.5020	43.6742	40.5046	43.5235	40.5064
5.20	46.0774	40.4785	45.9310	40.4800	45.8171	40.4812	45.6136	40.4833	45.3800	40.4858	45.2181	40.4875
5.40	47.7847	40.4615	47.6383	40.4629	47.5244	40.4640	47.3204	40.4660	47.0953	40.4683	46.9129	40.4700
5.60	49.4914	40.4456	49.3450	40.4470	49.2309	40.4480	49.0266	40.4498	48.7901	40.4520	48.6080	40.4537
5.80	51.1975	40.4309	51.0510	40.4321	50.9368	40.4331	50.7321	40.4348	50.4943	40.4368	50.3032	40.4385
6.00	52.9029	40.4171	52.7564	40.4182	52.6421	40.4191	52.4371	40.4207	52.1981	40.4227	51.9984	40.4243
6.20	54.6078	40.4041	54.4612	40.4052	54.3469	40.4060	54.1415	40.4076	53.9014	40.4094	53.6938	40.4109
6.40	56.3121	40.3919	56.1655	40.3929	56.0511	40.3937	55.8455	40.3952	55.6042	40.3969	55.3892	40.3984
6.60	58.0160	40.3805	57.8693	40.3814	57.7549	40.3822	57.5490	40.3835	57.3067	40.3852	57.0847	40.3866
6.80	59.7194	40.3697	59.5727	40.3706	59.4582	40.3713	59.2520	40.3726	59.0088	40.3741	58.7802	40.3755
7.00	61.4223	40.3595	61.2756	40.3603	61.1611	40.3610	60.9546	40.3622	60.7105	40.3637	60.4757	40.3651
7.20	63.1249	40.3498	62.9781	40.3506	62.8635	40.3513	62.6568	40.3524	62.4118	40.3538	62.1711	40.3552
7.40	64.8270	40.3407	64.6802	40.3414	64.5655	40.3420	64.3586	40.3431	64.1128	40.3444	63.8666	40.3458
7.60	66.5288	40.3320	66.3819	40.3327	66.2672	40.3333	66.0601	40.3343	65.8136	40.3356	65.5620	40.3369
7.80	68.2302	40.3237	68.0833	40.3244	67.9686	40.3250	67.7612	40.3260	67.5140	40.3272	67.2574	40.3284
8.00	69.9312	40.3159	69.7844	40.3166	69.6696	40.3171	69.4620	40.3180	69.2141	40.3192	68.9528	40.3204
8.20	71.6320	40.3084	71.4851	40.3091	71.3702	40.3096	71.1625	40.3105	70.9139	40.3115	70.6481	40.3127
8.40	73.3324	40.3013	73.1855	40.3019	73.0706	40.3024	72.8627	40.3032	72.6135	40.3043	72.3433	40.3054
8.60	75.0326	40.2945	74.8856	40.2951	74.7707	40.2955	74.5627	40.2963	74.3128	40.2973	74.0385	40.2984
8.80	76.7324	40.2880	76.5855	40.2885	76.4705	40.2890	76.2623	40.2898	76.0119	40.2907	75.7336	40.2918
9.00	78.4320	40.2818	78.2850	40.2823	78.1700	40.2827	77.9617	40.2835	77.7107	40.2844	77.4287	40.2854
9.20	80.1314	40.2758	79.9844	40.2763	79.8693	40.2767	79.6608	40.2774	79.4093	40.2783	79.1237	40.2793
9.40	81.8305	40.2701	81.6834	40.2706	81.5684	40.2710	81.3597	40.2717	81.1078	40.2725	80.8187	40.2735
9.60	83.5293	40.2646	83.3823	40.2651	83.2672	40.2655	83.0584	40.2661	82.8059	40.2669	82.5136	40.2679
9.80	85.2279	40.2594	85.0809	40.2598	84.9658	40.2602	84.7569	40.2608	84.5039	40.2616	84.2084	40.2625
10.00	86.9264	40.2543	86.7793	40.2548	86.6642	40.2551	86.4551	40.2557	86.2018	40.2565	85.9032	40.2573

V-INFINITY = 40.0 KM/S

T - YRS	Q = .1 AU RAD	Q = .1 AU VEL	Q = .3 AU RAD	Q = .3 AU VEL	Q = .5 AU RAD	Q = .5 AU VEL	Q = 1.0 AU RAD	Q = 1.0 AU VEL	Q = 2.0 AU RAD	Q = 2.0 AU VEL	Q = 5.2 AU RAD	Q = 5.2 AU VEL
10.00	86.9264	40.2543	86.7793	40.2548	86.6642	40.2551	86.4551	40.2557	86.2018	40.2565	85.9032	40.2573
11.00	95.4155	40.2318	95.2684	40.2321	95.1531	40.2324	94.9435	40.2329	94.6881	40.2335	94.3759	40.2343
12.00	103.9003	40.2129	103.7531	40.2132	103.6377	40.2134	103.4276	40.2139	103.1706	40.2144	102.8471	40.2151
13.00	112.3814	40.1969	112.2341	40.1971	112.1186	40.1973	111.9082	40.1977	111.6498	40.1981	111.3166	40.1987
14.00	120.8593	40.1831	120.7121	40.1833	120.5965	40.1835	120.3857	40.1838	120.1262	40.1842	119.7847	40.1847
15.00	129.3346	40.1711	129.1873	40.1713	129.0717	40.1715	128.8606	40.1717	128.6000	40.1721	128.2513	40.1726
16.00	137.8075	40.1606	137.6602	40.1608	137.5445	40.1609	137.3332	40.1612	137.0716	40.1615	136.7167	40.1619
17.00	146.2784	40.1513	146.1310	40.1515	146.0153	40.1516	145.8037	40.1518	145.5414	40.1521	145.1809	40.1525
18.00	154.7474	40.1431	154.6000	40.1432	154.4842	40.1433	154.2724	40.1435	154.0094	40.1437	153.6439	40.1441
19.00	163.2147	40.1357	163.0673	40.1358	162.9514	40.1359	162.7395	40.1360	162.4758	40.1363	162.1059	40.1366
20.00	171.6806	40.1290	171.5331	40.1291	171.4173	40.1292	171.2052	40.1293	170.9409	40.1295	170.5670	40.1298
21.00	180.1451	40.1229	179.9976	40.1230	179.8817	40.1231	179.6695	40.1232	179.4047	40.1234	179.0272	40.1237
22.00	188.6084	40.1174	188.4609	40.1175	188.3450	40.1176	188.1326	40.1177	187.8673	40.1179	187.4866	40.1181
23.00	197.0706	40.1124	196.9231	40.1125	196.8071	40.1125	196.5947	40.1127	196.3289	40.1128	195.9452	40.1130
24.00	205.5318	40.1078	205.3843	40.1078	205.2683	40.1079	205.0557	40.1080	204.7896	40.1082	204.4030	40.1084
25.00	213.9920	40.1035	213.8445	40.1036	213.7285	40.1036	213.5158	40.1037	213.2493	40.1039	212.8602	40.1041
26.00	222.4514	40.0996	222.3039	40.0996	222.1878	40.0997	221.9750	40.0998	221.7082	40.0999	221.3168	40.1001
27.00	230.9100	40.0959	230.7624	40.0960	230.6464	40.0960	230.4335	40.0961	230.1664	40.0962	229.7728	40.0964
28.00	239.3678	40.0925	239.2203	40.0926	239.1042	40.0926	238.8912	40.0927	238.6238	40.0928	238.2282	40.0930
29.00	247.8250	40.0894	247.6774	40.0894	247.5613	40.0895	247.3483	40.0896	247.0806	40.0897	246.6831	40.0898
30.00	256.2815	40.0864	256.1339	40.0865	256.0178	40.0865	255.8047	40.0866	255.5367	40.0867	255.1376	40.0868
31.00	264.7374	40.0837	264.5898	40.0837	264.4737	40.0838	264.2605	40.0838	263.9923	40.0839	263.5915	40.0841
32.00	273.1928	40.0811	273.0452	40.0811	272.9290	40.0812	272.7158	40.0812	272.4474	40.0813	272.0450	40.0814
33.00	281.6476	40.0787	281.5000	40.0787	281.3838	40.0787	281.1705	40.0788	280.9019	40.0789	280.4981	40.0790
34.00	290.1019	40.0764	289.9543	40.0764	289.8381	40.0764	289.6248	40.0765	289.3560	40.0766	288.9508	40.0767
35.00	298.5558	40.0742	298.4082	40.0743	298.2920	40.0743	298.0786	40.0743	297.8096	40.0744	297.4031	40.0745
36.00	307.0092	40.0722	306.8616	40.0722	306.7454	40.0722	306.5319	40.0723	306.2627	40.0724	305.8551	40.0724
37.00	315.4622	40.0702	315.3146	40.0703	315.1983	40.0703	314.9848	40.0703	314.7155	40.0704	314.3067	40.0705
38.00	323.9148	40.0684	323.7671	40.0684	323.6509	40.0685	323.4374	40.0685	323.1679	40.0686	322.7580	40.0687
39.00	332.3670	40.0667	332.2194	40.0667	332.1031	40.0667	331.8896	40.0668	331.6199	40.0668	331.2090	40.0669
40.00	340.8189	40.0650	340.6712	40.0650	340.5550	40.0651	340.3414	40.0651	340.0715	40.0652	339.6596	40.0652
41.00	349.2704	40.0634	349.1227	40.0635	349.0065	40.0635	348.7928	40.0635	348.5229	40.0636	348.1100	40.0637
42.00	357.7216	40.0620	357.5739	40.0620	357.4577	40.0620	357.2440	40.0620	356.9739	40.0621	356.5602	40.0622
43.00	366.1725	40.0605	366.0248	40.0605	365.9086	40.0606	365.6948	40.0606	365.4246	40.0606	365.0101	40.0607
44.00	374.6231	40.0592	374.4754	40.0592	374.3591	40.0592	374.1454	40.0592	373.8751	40.0593	373.4597	40.0593
45.00	383.0734	40.0579	382.9257	40.0579	382.8094	40.0579	382.5957	40.0579	382.3252	40.0580	381.9091	40.0580
46.00	391.5234	40.0566	391.3758	40.0566	391.2595	40.0566	391.0457	40.0567	390.7751	40.0567	390.3582	40.0568
47.00	399.9732	40.0554	399.8256	40.0554	399.7093	40.0554	399.4954	40.0555	399.2248	40.0555	398.8072	40.0556
48.00	408.4228	40.0543	408.2751	40.0543	408.1588	40.0543	407.9449	40.0543	407.6742	40.0544	407.2559	40.0544
49.00	416.8721	40.0532	416.7244	40.0532	416.6081	40.0532	416.3942	40.0532	416.1234	40.0533	415.7044	40.0533
50.00	425.3212	40.0521	425.1735	40.0521	425.0572	40.0521	424.8432	40.0522	424.5723	40.0522	424.1528	40.0523
51.00	433.7700	40.0511	433.6223	40.0511	433.5060	40.0511	433.2921	40.0512	433.0211	40.0512	432.6009	40.0512
52.00	442.2187	40.0501	442.0710	40.0501	441.9547	40.0502	441.7407	40.0502	441.4696	40.0502	441.0489	40.0503
53.00	450.6671	40.0492	450.5194	40.0492	450.4031	40.0492	450.1891	40.0492	449.9179	40.0493	449.4966	40.0493
54.00	459.1154	40.0483	458.9677	40.0483	458.8514	40.0483	458.6373	40.0483	458.3661	40.0484	457.9443	40.0484
55.00	467.5635	40.0474	467.4158	40.0474	467.2994	40.0474	467.0854	40.0475	466.8140	40.0475	466.3917	40.0475
56.00	476.0114	40.0466	475.8636	40.0466	475.7473	40.0466	475.5332	40.0466	475.2618	40.0466	474.8390	40.0467
57.00	484.4591	40.0458	484.3114	40.0458	484.1950	40.0458	483.9809	40.0458	483.7094	40.0458	483.2861	40.0459
58.00	492.9066	40.0450	492.7589	40.0450	492.6425	40.0450	492.4284	40.0450	492.1569	40.0450	491.7331	40.0451
59.00	501.3540	40.0442	501.2063	40.0442	501.0899	40.0442	500.8758	40.0443	500.6042	40.0443	500.1800	40.0443
60.00	509.8012	40.0435	509.6535	40.0435	509.5371	40.0435	509.3230	40.0435	509.0513	40.0435	508.6267	40.0436

V-INFINITY = 50.0 KM/S

T - YRS	Q = .1 AU RAD	VEL	Q = .3 AU RAD	VEL	Q = .5 AU RAD	VEL	Q = 1.0 AU RAD	VEL	Q = 2.0 AU RAD	VEL	Q = 5.2 AU RAD	VEL
.00	.1000	142.2764	.3000	91.7289	.5000	77.7722	1.0000	65.3778	2.0000	58.1000	5.2000	53.3029
.20	2.7095	56.1678	2.6048	56.4017	2.5558	56.5173	2.5858	56.4461	3.0291	55.5494	5.6382	53.0536
.40	5.0041	53.4281	4.8879	53.5069	4.8176	53.5564	4.7577	53.5996	4.9314	53.4770	6.7820	52.5511
.60	7.2315	52.3961	7.1113	52.4357	7.0333	52.4620	6.9408	52.4941	7.0014	52.4730	8.3407	52.0838
.80	9.4283	51.8477	9.3060	51.8716	9.2241	51.8879	9.1147	51.9101	9.1148	51.9101	10.1202	51.7235
1.00	11.6073	51.5059	11.4836	51.5219	11.3993	51.5330	11.2796	51.5490	11.2422	51.5541	12.0202	51.4549
1.20	13.7746	51.2719	13.6500	51.2833	13.5641	51.2914	13.4373	51.3034	13.3745	51.3094	13.9898	51.2526
1.40	15.9336	51.1014	15.8084	51.1100	15.7213	51.1161	15.5895	51.1254	15.5083	51.1313	16.0022	51.0967
1.60	18.0864	50.9715	17.9607	50.9783	17.8727	50.9831	17.7371	50.9905	17.6419	50.9958	18.0423	50.9739
1.80	20.2344	50.8693	20.1083	50.8747	20.0196	50.8785	19.8810	50.8846	19.7750	50.8893	20.1011	50.8750
2.00	22.3786	50.7866	22.2522	50.7911	22.1629	50.7942	22.0219	50.7993	21.9071	50.8034	22.1730	50.7939
2.20	24.5197	50.7184	24.3930	50.7221	24.3033	50.7248	24.1603	50.7291	24.0382	50.7327	24.2543	50.7262
2.40	26.6581	50.6612	26.5312	50.6643	26.4411	50.6666	26.2964	50.6702	26.1684	50.6735	26.3425	50.6691
2.60	28.7943	50.6124	28.6673	50.6151	28.5768	50.6171	28.4307	50.6202	28.2976	50.6231	28.4360	50.6201
2.80	30.9287	50.5704	30.8015	50.5727	30.7107	50.5744	30.5634	50.5772	30.4258	50.5798	30.5335	50.5777
3.00	33.0614	50.5338	32.9340	50.5359	32.8430	50.5373	32.6947	50.5398	32.5533	50.5421	32.6342	50.5408
3.20	35.1926	50.5016	35.0651	50.5035	34.9739	50.5048	34.8247	50.5069	34.6799	50.5090	34.7373	50.5082
3.40	37.3226	50.4731	37.1950	50.4748	37.1036	50.4759	36.9535	50.4778	36.8058	50.4798	36.8424	50.4793
3.60	39.4514	50.4477	39.3238	50.4492	39.2322	50.4502	39.0814	50.4519	38.9310	50.4537	38.9481	50.4535
3.80	41.5793	50.4249	41.4515	50.4262	41.3598	50.4272	41.2084	50.4287	41.0556	50.4303	41.0570	50.4303
4.00	43.7062	50.4043	43.5784	50.4055	43.4865	50.4064	43.3345	50.4078	43.1796	50.4092	43.1660	50.4094
4.20	45.8323	50.3856	45.7044	50.3867	45.6124	50.3875	45.4599	50.3888	45.3031	50.3901	45.2758	50.3904
4.40	47.9577	50.3686	47.8297	50.3696	47.7376	50.3703	47.5846	50.3715	47.4260	50.3727	47.3864	50.3730
4.60	50.0824	50.3530	49.9543	50.3539	49.8621	50.3546	49.7086	50.3557	49.5485	50.3568	49.4975	50.3572
4.80	52.2064	50.3387	52.0783	50.3395	51.9860	50.3401	51.8321	50.3411	51.6705	50.3422	51.6091	50.3426
5.00	54.3299	50.3255	54.2018	50.3263	54.1094	50.3268	53.9551	50.3278	53.7921	50.3288	53.7212	50.3292
5.20	56.4528	50.3133	56.3247	50.3140	56.2322	50.3145	56.0776	50.3154	55.9133	50.3163	55.8335	50.3168
5.40	58.5753	50.3020	58.4471	50.3027	58.3545	50.3031	58.1996	50.3039	58.0341	50.3048	57.9461	50.3053
5.60	60.6973	50.2915	60.5690	50.2921	60.4764	50.2925	60.3211	50.2933	60.1546	50.2941	60.0590	50.2946
5.80	62.8188	50.2816	62.6905	50.2822	62.5978	50.2826	62.4423	50.2833	62.2749	50.2841	62.1721	50.2846
6.00	64.9400	50.2725	64.8117	50.2730	64.7189	50.2734	64.5631	50.2741	64.3947	50.2748	64.2853	50.2752
6.20	67.0608	50.2639	66.9324	50.2644	66.8396	50.2647	66.6836	50.2654	66.5142	50.2660	66.3986	50.2665
6.40	69.1812	50.2558	69.0528	50.2563	68.9600	50.2566	68.8037	50.2572	68.6335	50.2578	68.5121	50.2583
6.60	71.3013	50.2482	71.1729	50.2487	71.0800	50.2490	70.9235	50.2495	70.7526	50.2501	70.6257	50.2506
6.80	73.4211	50.2411	73.2927	50.2415	73.1997	50.2418	73.0431	50.2423	72.8714	50.2429	72.7393	50.2433
7.00	75.5406	50.2343	75.4122	50.2347	75.3191	50.2350	75.1623	50.2355	74.9899	50.2360	74.8570	50.2365
7.20	77.6599	50.2279	77.5314	50.2283	77.4383	50.2286	77.2813	50.2291	77.1083	50.2296	76.9667	50.2300
7.40	79.7788	50.2219	79.6503	50.2223	79.5572	50.2225	79.4000	50.2230	79.2264	50.2234	79.0805	50.2239
7.60	81.8975	50.2162	81.7690	50.2165	81.6759	50.2168	81.5185	50.2172	81.3443	50.2176	81.1942	50.2180
7.80	84.0160	50.2107	83.8875	50.2111	83.7943	50.2113	83.6368	50.2117	83.4620	50.2121	83.3080	50.2125
8.00	86.1343	50.2056	86.0057	50.2059	85.9125	50.2061	85.7549	50.2065	85.5796	50.2069	85.4218	50.2073
8.20	88.2523	50.2006	88.1238	50.2009	88.0305	50.2011	87.8727	50.2015	87.6960	50.2019	87.5357	50.2023
8.40	90.3702	50.1959	90.2416	50.1962	90.1483	50.1964	89.9904	50.1968	89.8141	50.1972	89.6495	50.1975
8.60	92.4879	50.1915	92.3592	50.1917	92.2659	50.1919	92.1079	50.1923	91.9311	50.1926	91.7633	50.1930
8.80	94.6053	50.1872	94.4767	50.1874	94.3834	50.1876	94.2252	50.1879	94.0480	50.1883	93.8771	50.1886
9.00	96.7226	50.1831	96.5940	50.1833	96.5006	50.1835	96.3423	50.1838	96.1647	50.1842	95.9908	50.1845
9.20	98.8397	50.1792	98.7111	50.1794	98.6177	50.1796	98.4593	50.1799	98.2813	50.1802	98.1046	50.1805
9.40	100.9567	50.1754	100.8280	50.1757	100.7346	50.1758	100.5761	50.1761	100.3977	50.1764	100.2183	50.1767
9.60	103.0735	50.1718	102.9448	50.1721	102.8514	50.1722	102.6928	50.1725	102.5140	50.1728	102.3321	50.1731
9.80	105.1902	50.1684	105.0615	50.1686	104.9680	50.1687	104.8093	50.1690	104.6302	50.1693	104.4458	50.1696
10.00	107.3067	50.1651	107.1780	50.1653	107.0845	50.1654	106.9257	50.1657	106.7463	50.1659	106.5594	50.1662

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V-INFINITY = 50.0 KM/S

T - YRS	Q = .1 AU RAD	VEL	Q = .3 AU RAD	VEL	Q = .5 AU RAD	VEL	Q = 1.0 AU RAD	VEL	Q = 2.0 AU RAD	VEL	Q = 5.2 AU RAD	VEL
10.00	107.3067	50.1651	107.1780	50.1653	107.0845	50.1654	106.9257	50.1657	106.7463	50.1659	106.5594	50.1662
11.00	117.8874	50.1503	117.7586	50.1504	117.6650	50.1506	117.5058	50.1508	117.3249	50.1510	117.1274	50.1513
12.00	128.4652	50.1379	128.3364	50.1381	128.2427	50.1382	128.0831	50.1383	127.9009	50.1385	127.6946	50.1388
13.00	139.0406	50.1274	138.9117	50.1276	138.8180	50.1276	138.6582	50.1278	138.4749	50.1280	138.2611	50.1282
14.00	149.6140	50.1184	149.4851	50.1186	149.3913	50.1186	149.2312	50.1188	149.0470	50.1189	148.8267	50.1191
15.00	160.1856	50.1106	160.0566	50.1107	159.9628	50.1108	159.8025	50.1109	159.6175	50.1110	159.3917	50.1112
16.00	170.7556	50.1038	170.6267	50.1039	170.5328	50.1039	170.3723	50.1040	170.1866	50.1041	169.9559	50.1043
17.00	181.3243	50.0978	181.1954	50.0978	181.1014	50.0979	180.9407	50.0980	180.7545	50.0981	180.5194	50.0982
18.00	191.8918	50.0924	191.7628	50.0924	191.6689	50.0925	191.5080	50.0926	191.3212	50.0927	191.0823	50.0928
19.00	202.4583	50.0876	202.3293	50.0876	202.2353	50.0877	202.0743	50.0877	201.8870	50.0878	201.6446	50.0879
20.00	213.0237	50.0832	212.8947	50.0833	212.8007	50.0833	212.6396	50.0834	212.4518	50.0834	212.2064	50.0835
21.00	223.5883	50.0793	223.4593	50.0793	223.3653	50.0794	223.2040	50.0794	223.0159	50.0795	222.7677	50.0796
22.00	234.1521	50.0757	234.0231	50.0758	233.9290	50.0758	233.7677	50.0758	233.5792	50.0759	233.3284	50.0760
23.00	244.7152	50.0725	244.5862	50.0725	244.4921	50.0725	244.3307	50.0726	244.1418	50.0726	243.8887	50.0727
24.00	255.2777	50.0695	255.1486	50.0695	255.0545	50.0695	254.8930	50.0696	254.7039	50.0696	254.4486	50.0697
25.00	265.8395	50.0667	265.7104	50.0667	265.6163	50.0668	265.4547	50.0668	265.2653	50.0668	265.0081	50.0669
26.00	276.4008	50.0642	276.2717	50.0642	276.1775	50.0642	276.0159	50.0642	275.8262	50.0643	275.5672	50.0643
27.00	286.9615	50.0618	286.8324	50.0618	286.7382	50.0618	286.5766	50.0619	286.3866	50.0619	286.1259	50.0620
28.00	297.5218	50.0596	297.3927	50.0596	297.2985	50.0596	297.1367	50.0597	296.9466	50.0597	296.6843	50.0598
29.00	308.0816	50.0576	307.9525	50.0576	307.8583	50.0576	307.6965	50.0576	307.5061	50.0577	307.2424	50.0577
30.00	318.6410	50.0557	318.5119	50.0557	318.4177	50.0557	318.2558	50.0557	318.0653	50.0558	317.8002	50.0558
31.00	329.2000	50.0539	329.0709	50.0539	328.9767	50.0539	328.8148	50.0539	328.6240	50.0540	328.3577	50.0540
32.00	339.7587	50.0522	339.6296	50.0522	339.5353	50.0522	339.3734	50.0523	339.1825	50.0523	338.9150	50.0523
33.00	350.3170	50.0506	350.1879	50.0506	350.0936	50.0507	349.9316	50.0507	349.7406	50.0507	349.4719	50.0507
34.00	360.8750	50.0491	360.7458	50.0492	360.6516	50.0492	360.4896	50.0492	360.2984	50.0492	360.0287	50.0493
35.00	371.4327	50.0477	371.3035	50.0478	371.2093	50.0478	371.0472	50.0478	370.8558	50.0478	370.5852	50.0479
36.00	381.9901	50.0464	381.8609	50.0464	381.7667	50.0465	381.6045	50.0465	381.4131	50.0465	381.1414	50.0465
37.00	392.5472	50.0452	392.4181	50.0452	392.3238	50.0452	392.1616	50.0452	391.9700	50.0452	391.6975	50.0453
38.00	403.1041	50.0440	402.9749	50.0440	402.8806	50.0440	402.7185	50.0440	402.5267	50.0441	402.2534	50.0441
39.00	413.6607	50.0429	413.5316	50.0429	413.4373	50.0429	413.2750	50.0429	413.0832	50.0429	412.8091	50.0430
40.00	424.2171	50.0418	424.0880	50.0418	423.9937	50.0418	423.8314	50.0418	423.6395	50.0419	423.3646	50.0419
41.00	434.7733	50.0408	434.6441	50.0408	434.5498	50.0408	434.3876	50.0408	434.1955	50.0408	433.9199	50.0409
42.00	445.3293	50.0398	445.2001	50.0398	445.1058	50.0398	444.9435	50.0399	444.7514	50.0399	444.4750	50.0399
43.00	455.8851	50.0389	455.7559	50.0389	455.6616	50.0389	455.4992	50.0389	455.3070	50.0390	455.0300	50.0390
44.00	466.4406	50.0380	466.3115	50.0380	466.2171	50.0380	466.0548	50.0381	465.8625	50.0381	465.5849	50.0381
45.00	476.9961	50.0372	476.8669	50.0372	476.7725	50.0372	476.6102	50.0372	476.4177	50.0372	476.1396	50.0372
46.00	487.5513	50.0364	487.4221	50.0364	487.3278	50.0364	487.1654	50.0364	486.9729	50.0364	486.6941	50.0364
47.00	498.1063	50.0356	497.9772	50.0356	497.8828	50.0356	497.7204	50.0356	497.5278	50.0356	497.2485	50.0357
48.00	508.6613	50.0349	508.5321	50.0349	508.4377	50.0349	508.2753	50.0349	508.0826	50.0349	507.8028	50.0349
49.00	519.2160	50.0342	519.0868	50.0342	518.9925	50.0342	518.8300	50.0342	518.6373	50.0342	518.3570	50.0342
50.00	529.7706	50.0335	529.6414	50.0335	529.5471	50.0335	529.3846	50.0335	529.1918	50.0335	528.9110	50.0335
51.00	540.3251	50.0328	540.1959	50.0328	540.1015	50.0328	539.9390	50.0328	539.7462	50.0329	539.4649	50.0329
52.00	550.8794	50.0322	550.7502	50.0322	550.6558	50.0322	550.4933	50.0322	550.3004	50.0322	550.0187	50.0322
53.00	561.4336	50.0316	561.3044	50.0316	561.2100	50.0316	561.0475	50.0316	560.8545	50.0316	560.5724	50.0316
54.00	571.9877	50.0310	571.8585	50.0310	571.7641	50.0310	571.6016	50.0310	571.4085	50.0310	571.1260	50.0311
55.00	582.5416	50.0304	582.4124	50.0305	582.3181	50.0305	582.1555	50.0305	581.9624	50.0305	581.6794	50.0305
56.00	593.0955	50.0299	592.9663	50.0299	592.8719	50.0299	592.7093	50.0299	592.5162	50.0299	592.2328	50.0299
57.00	603.6492	50.0294	603.5200	50.0294	603.4256	50.0294	603.2630	50.0294	603.0698	50.0294	602.7861	50.0294
58.00	614.2028	50.0289	614.0736	50.0289	613.9792	50.0289	613.8166	50.0289	613.6234	50.0289	613.3393	50.0289
59.00	624.7563	50.0284	624.6271	50.0284	624.5327	50.0284	624.3701	50.0284	624.1768	50.0284	623.8924	50.0284
60.00	635.3098	50.0279	635.1805	50.0279	635.0861	50.0279	634.9235	50.0279	634.7302	50.0279	634.4454	50.0280

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V-INFINITY = 60.0 KM/S

T - YRS	Q = .1 AU RAD	VEL	Q = .3 AU RAD	VEL	Q = .5 AU RAD	VEL	Q = 1.0 AU RAD	VEL	Q = 2.0 AU RAD	VEL	Q = 5.2 AU RAD	VEL
.00	.1000	146.0909	.3000	97.5407	.5000	84.5489	1.0000	73.3093	2.0000	66.9860	5.2000	62.7790
.20	3.0269	64.7005	2.9354	64.8417	2.8964	64.9043	2.9310	64.8486	3.3341	64.2818	5.8091	62.4034
.40	5.6975	62.5413	5.5961	62.5863	5.5391	62.6124	5.4976	62.6317	5.6598	62.5578	7.3353	61.9829
.60	8.3159	61.7524	8.2110	61.7744	8.1477	61.7880	8.0790	61.8030	8.1451	61.7886	9.3337	61.5637
.80	10.9109	61.3401	10.8043	61.3532	10.7377	61.3615	10.6550	61.3720	10.6705	61.3700	11.5578	61.2659
1.00	13.4926	61.0860	13.3849	61.0947	13.3163	61.1002	13.2252	61.1078	13.2096	61.1090	13.8975	61.0546
1.20	16.0656	60.9134	15.9572	60.9195	15.8872	60.9235	15.7904	60.9292	15.7538	60.9313	16.3016	60.9002
1.40	18.6325	60.7884	18.5236	60.7930	18.4527	60.7960	18.3517	60.8003	18.3090	60.8026	18.7444	60.7837
1.60	21.1949	60.6936	21.0855	60.6972	21.0139	60.6995	20.9099	60.7030	20.8467	60.7051	21.2120	60.6930
1.80	23.7538	60.6193	23.6441	60.6221	23.5719	60.6240	23.4654	60.6268	23.3933	60.6287	23.6963	60.6207
2.00	26.3099	60.5594	26.1999	60.5617	26.1273	60.5633	26.0189	60.5656	25.9396	60.5673	26.1921	60.5619
2.20	28.8637	60.5101	28.7536	60.5120	28.6805	60.5133	28.5705	60.5153	28.4853	60.5169	28.6962	60.5130
2.40	31.4157	60.4688	31.3053	60.4705	31.2320	60.4716	31.1206	60.4732	31.0305	60.4746	31.2065	60.4719
2.60	33.9660	60.4337	33.8555	60.4351	33.7819	60.4361	33.6694	60.4375	33.5752	60.4388	33.7215	60.4369
2.80	36.5150	60.4036	36.4044	60.4048	36.3305	60.4056	36.2171	60.4069	36.1192	60.4080	36.2400	60.4066
3.00	39.0628	60.3773	38.9521	60.3784	38.8780	60.3791	38.7637	60.3802	38.6629	60.3812	38.7613	60.3802
3.20	41.6096	60.3543	41.4987	60.3552	41.4245	60.3559	41.3095	60.3569	41.2058	60.3579	41.2840	60.3571
3.40	44.1554	60.3339	44.0445	60.3348	43.9702	60.3353	43.8544	60.3362	43.7484	60.3370	43.8102	60.3365
3.60	46.7005	60.3158	46.5895	60.3165	46.5150	60.3170	46.3987	60.3178	46.2905	60.3186	46.3370	60.3182
3.80	49.2448	60.2995	49.1338	60.3002	49.0591	60.3006	48.9423	60.3013	48.8322	60.3020	48.8650	60.3018
4.00	51.7885	60.2848	51.6774	60.2854	51.6027	60.2858	51.4854	60.2865	51.3735	60.2871	51.3930	60.2870
4.20	54.3316	60.2715	54.2204	60.2721	54.1456	60.2725	54.0279	60.2730	53.9144	60.2736	53.9236	60.2736
4.40	56.8742	60.2594	56.7629	60.2599	56.6880	60.2603	56.5699	60.2608	56.4550	60.2613	56.4540	60.2613
4.60	59.4162	60.2483	59.3050	60.2488	59.2300	60.2491	59.1115	60.2496	58.9953	60.2501	58.9840	60.2501
4.80	61.9579	60.2382	61.8466	60.2386	61.7715	60.2389	61.6527	60.2393	61.5353	60.2398	61.5164	60.2399
5.00	64.4991	60.2288	64.3877	60.2292	64.3126	60.2295	64.1935	60.2299	64.0750	60.2303	64.0482	60.2304
5.20	67.0399	60.2201	66.9286	60.2205	66.8533	60.2208	66.7340	60.2212	66.6145	60.2215	66.5804	60.2217
5.40	69.5804	60.2121	69.4690	60.2125	69.3937	60.2127	69.2741	60.2131	69.1537	60.2134	69.1128	60.2136
5.60	72.1206	60.2047	72.0092	60.2050	71.9338	60.2052	71.8140	60.2055	71.6927	60.2059	71.6455	60.2060
5.80	74.6605	60.1977	74.5490	60.1980	74.4736	60.1982	74.3535	60.1985	74.2314	60.1989	74.1784	60.1990
6.00	77.2001	60.1912	77.0885	60.1915	77.0131	60.1917	76.8928	60.1920	76.7699	60.1923	76.7115	60.1924
6.20	79.7394	60.1851	79.6278	60.1854	79.5524	60.1856	79.4319	60.1859	79.3083	60.1861	79.2447	60.1863
6.40	82.2784	60.1794	82.1669	60.1797	82.0914	60.1798	81.9707	60.1801	81.8464	60.1804	81.7781	60.1805
6.60	84.8173	60.1741	84.7057	60.1743	84.6302	60.1745	84.5093	60.1747	84.3844	60.1750	84.3115	60.1751
6.80	87.3559	60.1690	87.2443	60.1692	87.1687	60.1694	87.0477	60.1696	86.9222	60.1699	86.8451	60.1700
7.00	89.8943	60.1643	89.7827	60.1645	89.7071	60.1646	89.5859	60.1649	89.4599	60.1650	89.3787	60.1652
7.20	92.4325	60.1597	92.3209	60.1599	92.2452	60.1601	92.1240	60.1603	91.9974	60.1605	91.9125	60.1606
7.40	94.9706	60.1555	94.8589	60.1557	94.7832	60.1558	94.6618	60.1560	94.5347	60.1562	94.4462	60.1563
7.60	97.5084	60.1514	97.3968	60.1516	97.3210	60.1517	97.1995	60.1519	97.0719	60.1521	96.9800	60.1523
7.80	100.0461	60.1476	99.9344	60.1478	99.8587	60.1479	99.7370	60.1481	99.6090	60.1483	99.5139	60.1484
8.00	102.5837	60.1440	102.4720	60.1441	102.3962	60.1442	102.2744	60.1444	102.1460	60.1446	102.0478	60.1447
8.20	105.1210	60.1405	105.0093	60.1406	104.9335	60.1407	104.8116	60.1409	104.6828	60.1411	104.5817	60.1412
8.40	107.6583	60.1372	107.5466	60.1373	107.4707	60.1374	107.3487	60.1376	107.2195	60.1377	107.1157	60.1379
8.60	110.1954	60.1340	110.0837	60.1342	110.0078	60.1343	109.8857	60.1344	109.7561	60.1346	109.6496	60.1347
8.80	112.7324	60.1310	112.6206	60.1311	112.5447	60.1312	112.4225	60.1314	112.2926	60.1315	112.1836	60.1317
9.00	115.2692	60.1281	115.1575	60.1283	115.0816	60.1283	114.9593	60.1285	114.8290	60.1286	114.7176	60.1287
9.20	117.8060	60.1254	117.6942	60.1255	117.6183	60.1256	117.4959	60.1257	117.3653	60.1258	117.2516	60.1260
9.40	120.3426	60.1227	120.2308	60.1228	120.1549	60.1229	120.0324	60.1231	119.9015	60.1232	119.7855	60.1233
9.60	122.8791	60.1202	122.7673	60.1203	122.6913	60.1204	122.5688	60.1205	122.4376	60.1206	122.3195	60.1208
9.80	125.4155	60.1178	125.3037	60.1179	125.2277	60.1180	125.1051	60.1181	124.9736	60.1182	124.8535	60.1183
10.00	127.9518	60.1154	127.8400	60.1155	127.7640	60.1156	127.6413	60.1157	127.5096	60.1158	127.3875	60.1160

V-INFINITY = 60.0 KM/S

	Q = .1 AU		Q = .3 AU		Q = .5 AU		Q = 1.0 AU		Q = 2.0 AU		Q = 5.2 AU	
T - YRS	RAD	VEL	RAD	VEL	RAD	VEL	RAD	VEL	RAD	VEL	RAD	VEL
10.00	127.9518	60.1154	127.8400	60.1155	127.7640	60.1156	127.6413	60.1157	127.5096	60.1158	127.3875	60.1160
11.00	140.6320	60.1050	140.5201	60.1051	140.4441	60.1052	140.3210	60.1053	140.1881	60.1054	140.0573	60.1055
12.00	153.3102	60.0964	153.1983	60.0964	153.1221	60.0965	152.9988	60.0966	152.8648	60.0966	152.7268	60.0967
13.00	165.9866	60.0890	165.8747	60.0891	165.7985	60.0891	165.6750	60.0892	165.5402	60.0893	165.3960	60.0893
14.00	178.6617	60.0827	178.5497	60.0828	178.4735	60.0828	178.3498	60.0828	178.2142	60.0829	178.0648	60.0830
15.00	191.3355	60.0772	191.2235	60.0773	191.1472	60.0773	191.0233	60.0774	190.8871	60.0774	190.7331	60.0775
16.00	204.0082	60.0724	203.8962	60.0725	203.8199	60.0725	203.6959	60.0725	203.5591	60.0726	203.4011	60.0726
17.00	216.6800	60.0682	216.5680	60.0682	216.4917	60.0683	216.3675	60.0683	216.2302	60.0683	216.0687	60.0684
18.00	229.3510	60.0644	229.2389	60.0645	229.1626	60.0645	229.0383	60.0645	228.9006	60.0646	228.7359	60.0646
19.00	242.0212	60.0611	241.9091	60.0611	241.8327	60.0611	241.7083	60.0611	241.5702	60.0612	241.4027	60.0612
20.00	254.6907	60.0580	254.5786	60.0581	254.5022	60.0581	254.3777	60.0581	254.2393	60.0581	254.0692	60.0582
21.00	267.3596	60.0553	267.2475	60.0553	267.1711	60.0553	267.0465	60.0553	266.9077	60.0554	266.7354	60.0554
22.00	280.0280	60.0528	279.9159	60.0528	279.8394	60.0528	279.7147	60.0528	279.5757	60.0529	279.4013	60.0529
23.00	292.6958	60.0505	292.5837	60.0505	292.5072	60.0505	292.3825	60.0505	292.2432	60.0506	292.0669	60.0506
24.00	305.3632	60.0484	305.2511	60.0484	305.1746	60.0484	305.0498	60.0484	304.9102	60.0485	304.7322	60.0485
25.00	318.0302	60.0465	317.9181	60.0465	317.8416	60.0465	317.7167	60.0465	317.5769	60.0465	317.3973	60.0466
26.00	330.6968	60.0447	330.5846	60.0447	330.5081	60.0447	330.3832	60.0447	330.2432	60.0448	330.0621	60.0448
27.00	343.3630	60.0430	343.2508	60.0431	343.1743	60.0431	343.0493	60.0431	342.9091	60.0431	342.7267	60.0431
28.00	356.0289	60.0415	355.9167	60.0415	355.8402	60.0415	355.7151	60.0416	355.5748	60.0416	355.3910	60.0416
29.00	368.6944	60.0401	368.5823	60.0401	368.5057	60.0401	368.3806	60.0401	368.2401	60.0401	368.0552	60.0402
30.00	381.3597	60.0388	381.2476	60.0388	381.1710	60.0388	381.0459	60.0388	380.9052	60.0388	380.7191	60.0388
31.00	394.0247	60.0375	393.9126	60.0375	393.8360	60.0375	393.7108	60.0375	393.5700	60.0376	393.3829	60.0376
32.00	406.6895	60.0363	406.5773	60.0364	406.5007	60.0364	406.3755	60.0364	406.2346	60.0364	406.0465	60.0364
33.00	419.3540	60.0352	419.2418	60.0353	419.1652	60.0353	419.0400	60.0353	418.8989	60.0353	418.7100	60.0353
34.00	432.0183	60.0342	431.9061	60.0342	431.8295	60.0342	431.7043	60.0342	431.5631	60.0343	431.3732	60.0343
35.00	444.6824	60.0332	444.5702	60.0332	444.4936	60.0333	444.3683	60.0333	444.2270	60.0333	444.0363	60.0333
36.00	457.3462	60.0323	457.2341	60.0323	457.1575	60.0323	457.0321	60.0323	456.8907	60.0324	456.6993	60.0324
37.00	470.0099	60.0314	469.8978	60.0315	469.8211	60.0315	469.6958	60.0315	469.5543	60.0315	469.3621	60.0315
38.00	482.6735	60.0306	482.5613	60.0306	482.4846	60.0306	482.3593	60.0306	482.2177	60.0307	482.0248	60.0307
39.00	495.3368	60.0298	495.2246	60.0298	495.1480	60.0299	495.0226	60.0299	494.8809	60.0299	494.6874	60.0299
40.00	508.0000	60.0291	507.8878	60.0291	507.8112	60.0291	507.6857	60.0291	507.5439	60.0291	507.3499	60.0291
41.00	520.6630	60.0284	520.5508	60.0284	520.4742	60.0284	520.3487	60.0284	520.2069	60.0284	520.0122	60.0284
42.00	533.3259	60.0277	533.2137	60.0277	533.1371	60.0277	533.0116	60.0277	532.8696	60.0277	532.6744	60.0278
43.00	545.9886	60.0271	545.8765	60.0271	545.7998	60.0271	545.6743	60.0271	545.5323	60.0271	545.3365	60.0271
44.00	558.6513	60.0265	558.5391	60.0265	558.4624	60.0265	558.3369	60.0265	558.1948	60.0265	557.9985	60.0265
45.00	571.3138	60.0259	571.2016	60.0259	571.1249	60.0259	570.9994	60.0259	570.8572	60.0259	570.6604	60.0259
46.00	583.9761	60.0253	583.8639	60.0253	583.7873	60.0253	583.6617	60.0253	583.5195	60.0253	583.3222	60.0253
47.00	596.6384	60.0248	596.5262	60.0248	596.4495	60.0248	596.3239	60.0248	596.1816	60.0248	595.9840	60.0248
48.00	609.3005	60.0243	609.1883	60.0243	609.1116	60.0243	608.9860	60.0243	608.8437	60.0243	608.6456	60.0243
49.00	621.9625	60.0238	621.8503	60.0238	621.7737	60.0238	621.6481	60.0238	621.5057	60.0238	621.3071	60.0238
50.00	634.6245	60.0233	634.5123	60.0233	634.4356	60.0233	634.3100	60.0233	634.1675	60.0233	633.9686	60.0233
51.00	647.2863	60.0228	647.1741	60.0228	647.0974	60.0228	646.9718	60.0228	646.8293	60.0229	646.6300	60.0229
52.00	659.9481	60.0224	659.8358	60.0224	659.7591	60.0224	659.6335	60.0224	659.4909	60.0224	659.2913	60.0224
53.00	672.6097	60.0220	672.4975	60.0220	672.4208	60.0220	672.2951	60.0220	672.1525	60.0220	671.9525	60.0220
54.00	685.2713	60.0216	685.1590	60.0216	685.0824	60.0216	684.9567	60.0216	684.8140	60.0216	684.6137	60.0216
55.00	697.9327	60.0212	697.8205	60.0212	697.7438	60.0212	697.6181	60.0212	697.4754	60.0212	697.2748	60.0212
56.00	710.5941	60.0208	710.4819	60.0208	710.4052	60.0208	710.2795	60.0208	710.1368	60.0208	709.9358	60.0208
57.00	723.2555	60.0204	723.1432	60.0204	723.0665	60.0204	722.9408	60.0204	722.7980	60.0205	722.5968	60.0205
58.00	735.9167	60.0201	735.8045	60.0201	735.7278	60.0201	735.6021	60.0201	735.4592	60.0201	735.2576	60.0201
59.00	748.5779	60.0197	748.4656	60.0198	748.3889	60.0198	748.2632	60.0198	748.1203	60.0198	747.9185	60.0198
60.00	761.2390	60.0194	761.1267	60.0194	761.0500	60.0194	760.9243	60.0194	760.7814	60.0194	760.5793	60.0194

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