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HUNTSVILLE, ALABAMA

July 10, 1960 MNN-M-S&M-F-1-60

REVISED CALENDAR OF PLANETARY PHENOMENA FOR SPACE MISSION PLANNING

By Frank M. Cameron

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July 10, 1960 MNN-M-S&M-F-1-60

REVISED CALENDAR OF PLANETARY PHENOMENA FOR SPACE MISSION PLANNING

by
Frank M. Cameron

FUTURE PROJECTS DESIGN BRANCH
STRUCTURES AND MECHANICS DIVISION

ABSTRACT

Dates of opposition and conjunction of the Planets have been linearly interpolated from "Planetary Coordinates for the years 1960 - 80," prepared by the British Nautical Almanac Office. The planet Pluto has not been included.

For initial planning of space missions, dates of injection into Hohmann transfer ellipses during the period 1960 - 80 have been tabulated together with corresponding travel times and dates of arrival.

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INTRODUCTION

For planning missions into interplanetary space it is important to have relevant astronomical data available. Approximate dates of opposition for Mars and inferior conjunctions of Venus have been improved through the use of British Almanac Office data and have been tabulated for ease of reference.

Mission planning requires dates of launch and arrival. These cannot be determined with accuracy until the transfer orbit has been optimized. The selected orbit will not lie in the plane of the ecliptic nor in the orbit plane of the chosen planetary destination.

As a starting point, it will be convenient to know the "Hohmann" transfer dates. W. Hohmann (1925) studied the spaceship flight orbit with two basic assumptions regarding planetary orbits. These assumptions, though untrue, provide information realistic enough to produce close approximations for scheduling purposes. First, the orbits of the launching planet and the destination planet are assumed *circular; secondly, all orbits are assumed to be in the same plane. With these assumptions, orbital transfer is made along an ellipse tangent to both circles. This has been done in the present note. Corrections to these transfer ellipses, providing exact launch and arrival times, will be given later. Such corrections will be made using non-coplanar and non-circular elliptical planetary orbits.

*The radii of these circular orbits are the radii vectores of the launching planet and the target planet at instants of injection and arrival respectively.

ACKNOWLEDGMENTS

Mr. Walter H. Stafford was responsible for the design and layout of all diagrams in the report.

SP4 Forrest Leonard was responsible for much of the computation for the planet Mercury, using a Datatron 205 computer.

CONJUNCTION AND OPPOSITIONS OF THE PLANETS FOR THE YEARS 1960 - 1980

In this report, an inferior conjunction of an inner planet is defined as that configuration for which the heliocentric longitudes of Earth and the planet are identical. Thus, the Sun, the planet, and Earth are, respectively, in line with each other. The longitude is measured from the vernal equinox, eastward, along the ecliptic.

For the outer planets, opposition is defined as that configuration for which the heliocentric longitudes of Earth and the planet are identical. In this case, the Sun, the Earth, and the planet are, respectively, in line with each other.

Inferior conjunction dates for Mercury and Venus are listed in Tables 1 and 2. Positions of these planets at each inferior conjunction are shown in Figures 1 and 2.

Opposition dates for the outer planets are listed in Tables 3, 4, 5, 6, and 7. Positions of these planets at each opposition are shown in Figures 3, 4, 5, 6, and 7.

All of the tables of inferior conjunctions and oppositions were compiled by Mr. C. C. Dearman in his ABMA Report No. DSP-TN-2-60, dated 24 February 1960, except for Mercury.

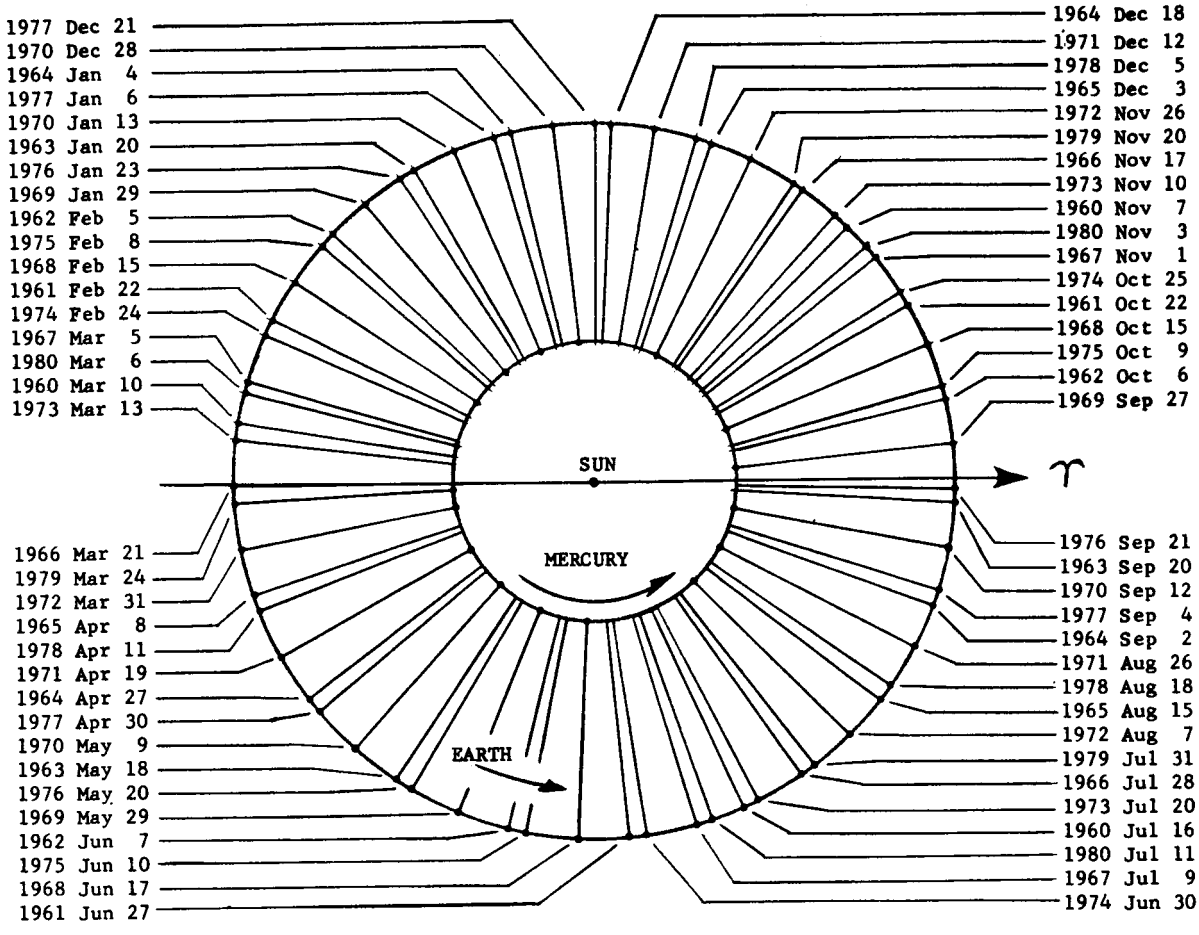

FIGURE 1

INFERIOR CONJUNCTIONS OF MERCURY

TABLE 1

INFERIOR CONJUNCTIONS OF MERCURY (1960 - 1980)

Calendar Date	Longitude*	Calendar Date	Longitude*
1960 Mar 10.4	170°.202	1970 Sep 12.0	349°.085
1960 Jul 16.4	294.173	1970 Dec 28.0	96.098
1960 Nov 7.1	45.064	1971 Apr 19.4	208.890
1961 Feb 21.6	153.048	1971 Aug 26.0	332.286
1961 Jun 26.8	275.290	1971 Dec 12.3	79.829
1961 Oct 22.2	28.928	1972 Mar 31.0	190.564
1962 Feb 5.1	136.109	1972 Aug 7.1	314.854
1962 Jun 6.7	255.849	1972 Nov 25.6	63.611
1962 Oct 6.0	12.610	1973 Mar 13.3	172.735
1963 Jan 19.9	119.471	1973 Jul 19.5	296.803
1963 Feb 6.6	236.256	1973 Nov 9.8	47.452
1963 Sep 19.5	356.167	1974 Feb 24.4	155.555
1964 Jan 4.1	103.070	1974 Jun 30.1	278.098
1964 Apr 26.9	216.974	1974 Oct 24.9	31.285
1964 Sep 1.7	339.559	1975 Feb 7.9	138.634
1964 Dec 18.3	86.743	1975 Jun 10.0	258.680
1965 Apr 8.1	198.311	1975 Oct 8.8	15.037
1965 Aug 15.1	322.324	1976 Jan 22.7	121.914
1965 Dec 2.6	70.510	1976 May 19.8	239.083
1966 Mar 21.1	180.259	1976 Sep 21.3	358.592
1966 Jul 28.0	304.690	1977 Jan 5.8	105.691
1966 Nov 16.9	54.339	1977 Apr 30.0	219.702
1967 Mar 5.2	169.211	1977 Sep 4.5	341.982
1967 Jul 8.8	286.194	1977 Dec 21.0	89.136
1967 Nov 1.1	38.191	1978 Apr 11.1	200.928
1968 Feb 15.2	145.811	1978 Aug 18.1	324.892
1968 Jun 17.0	267.013	1978 Dec 5.3	72.911
1968 Oct 15.0	21.964	1979 Mar 24.1	182.905
1969 Jan 28.8	128.986	1979 Jul 31.0	307.286
1969 May 28.8	247.454	1979 Nov 19.6	56.707
1969 Sep 26.7	5.644	1980 Mar 5.7	165.330
1970 Jan 12.8	112.466	1980 Jul 11.0	288.895
1970 May 8.7	227.861	1980 Nov 2.6	40.550

*Heliocentric longitude measured eastward along the ecliptic from the vernal equinox, ♈.

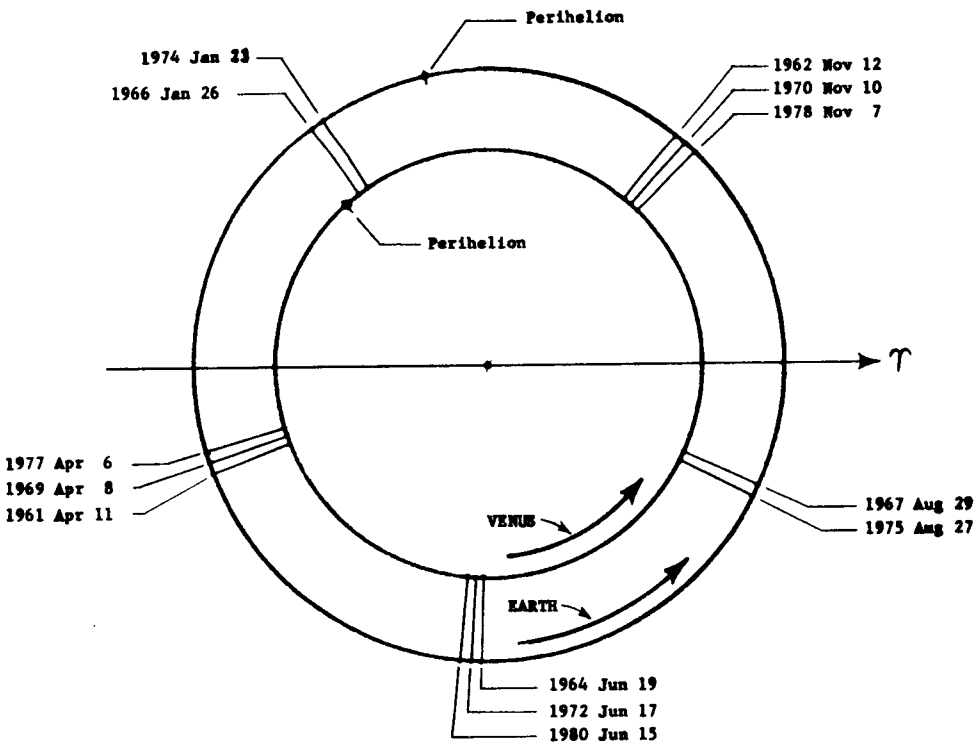

FIGURE 2

INFERIOR CONJUNCTIONS OF VENUS

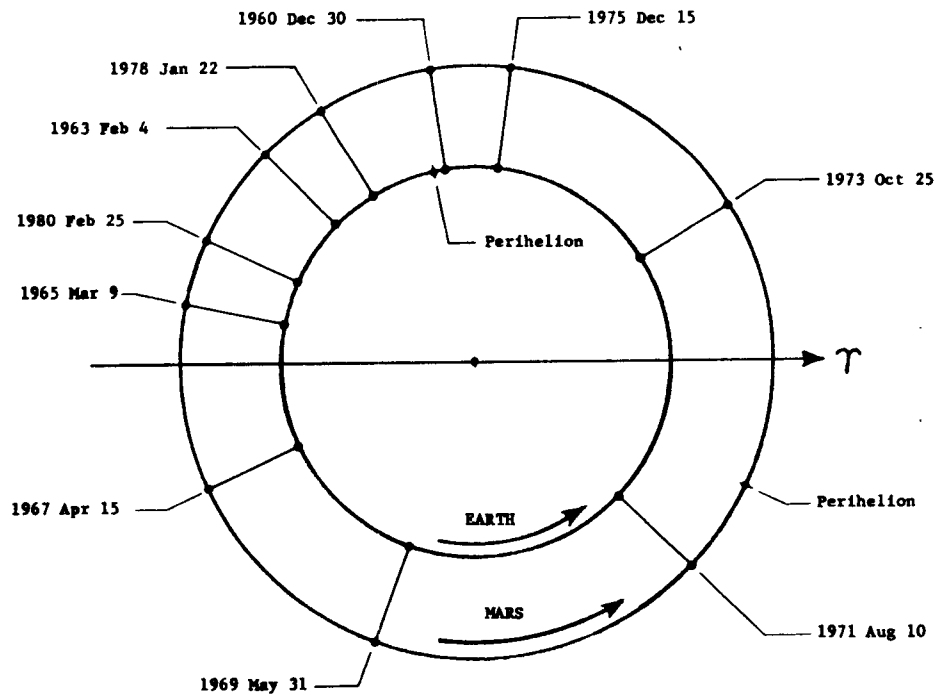

FIGURE 3

OPPOSITIONS OF MARS

TABLE 2

INFERIOR CONJUNCTIONS OF VENUS (1960 - 1980)

Calendar Date	Longitude*
1961 Apr 11.0	200°.71
1962 Nov 12.8	49.79
1964 Jun 19.9	268.44
1966 Jan 26.3	125.72
1967 Aug 29.9	335.62
1969 Apr 8.6	198.34
1970 Nov 10.4	47.25
1972 Jun 17.6	266.18
1974 Jan 23.8	123.16
1975 Aug 27.5	333.30
1977 Apr 6.2	195.96
1978 Nov 7.9	44.72
1980 Jun 15.3	263.92

TABLE 3

OPPOSITIONS OF MARS (1960 - 1980)

Calendar Date	Longitude*
1960 Dec 30.4	98°.58
1963 Feb 4.5	134.77
1965 Mar 9.5	168.53
1967 Apr 15.5	204.59
1969 May 31.7	249.75
1971 Aug 10.3	316.70
1973 Oct 25.1	31.24
1975 Dec 15.6	82.60
1978 Jan 22.0	121.22
1980 Feb 25.2	155.37

*Heliocentric longitude measured eastward along the ecliptic from the vernal equinox, ♈.

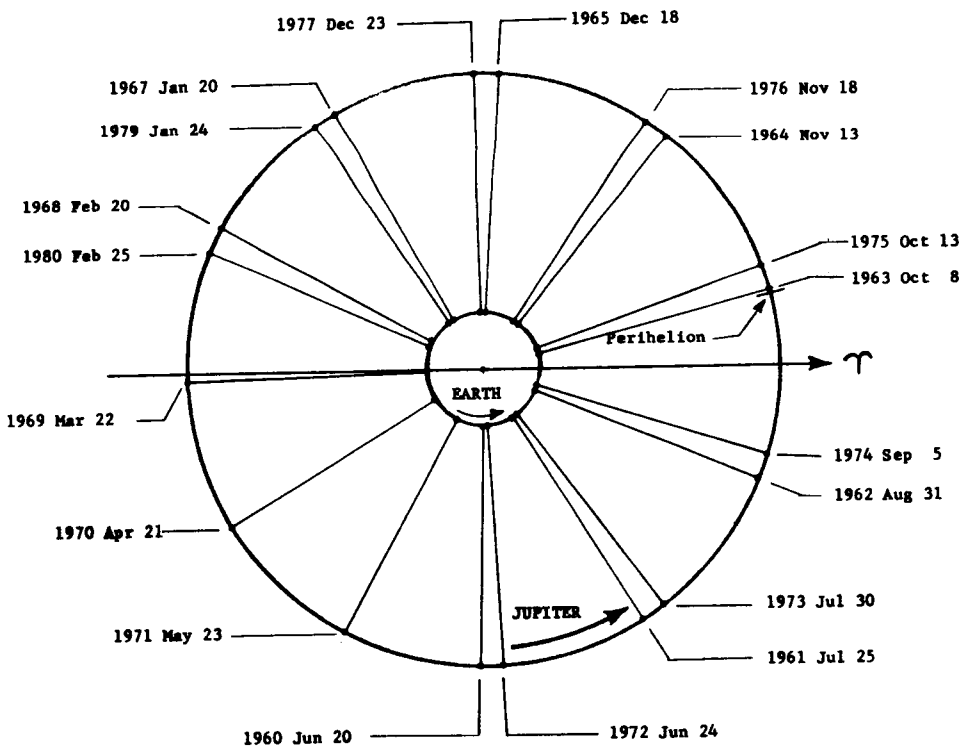

FIGURE 4

OPPOSITIONS OF JUPITER

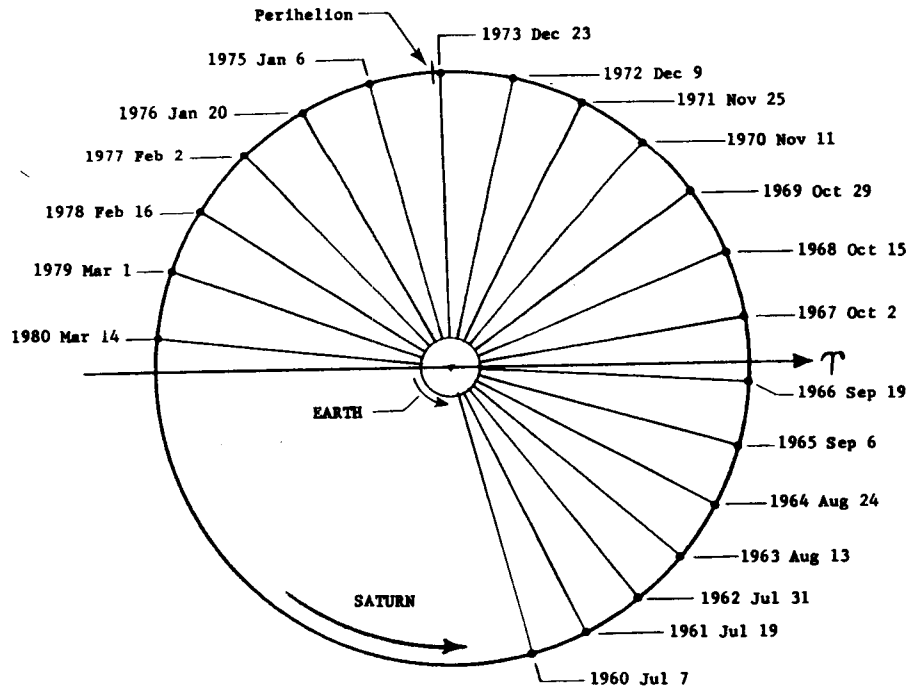

FIGURE 5

OPPOSITIONS OF SATURN

TABLE 4

OPPOSITIONS OF JUPITER (1960 - 1980)

Calender Date	Longitude*
1960 Jun 20.1	268°.59
1961 Jul 25.4	302.08
1962 Aug 31.6	337.54
1963 Oct 8.4	14.25
1964 Nov 13.4	50.84
1965 Dec 18.4	86.02
1967 Jan 20.2	119.22
1968 Feb 20.5	150.62
1969 Mar 22.0	180.88
1970 Apr 21.6	210.81
1971 May 23.4	241.29
1972 Jun 24.9	273.12
1973 Jul 30.5	306.84
1974 Sep 5.8	342.53
1975 Oct 13.6	19.29
1976 Nov 18.3	55.74
1977 Dec 23.0	90.68
1979 Jan 24.6	123.63
1980 Feb 25.6	155.70

TABLE 5

OPPOSITIONS OF SATURN (1960 - 1980)

Calendar Date	Longitude*
1960 Jul 7.2	284°.98
1961 Jul 19.4	296.38
1962 Jul 31.8	307.89
1963 Aug 13.2	319.57
1964 Aug 24.8	331.46
1965 Sep 6.6	343.60
1966 Sep 19.7	356.03
1967 Oct 2.9	8.77
1968 Oct 15.4	21.82
1969 Oct 29.0	35.18
1970 Nov 11.9	48.83
1971 Nov 25.9	62.72
1972 Dec 9.1	76.77
1973 Dec 23.2	90.92
1975 Jan 6.4	105.07
1976 Jan 20.4	119.14
1977 Feb 2.4	133.06
1978 Feb 16.5	147.11
1979 Mar 1.8	160.14
1980 Mar 14.1	173.23

*Heliocentric longitude measured eastward along the ecliptic from the vernal equinox, ♈.

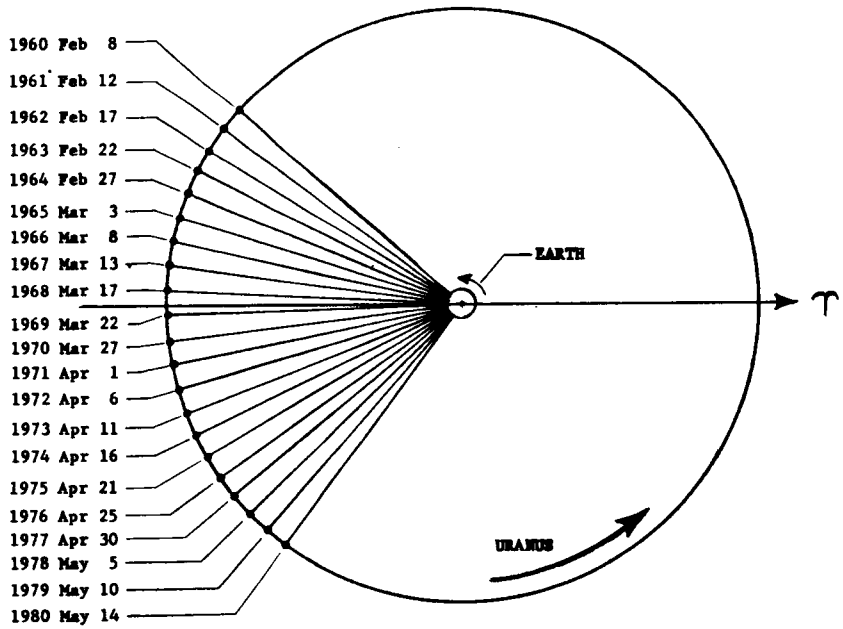

FIGURE 6

OPPOSITIONS OF URANUS

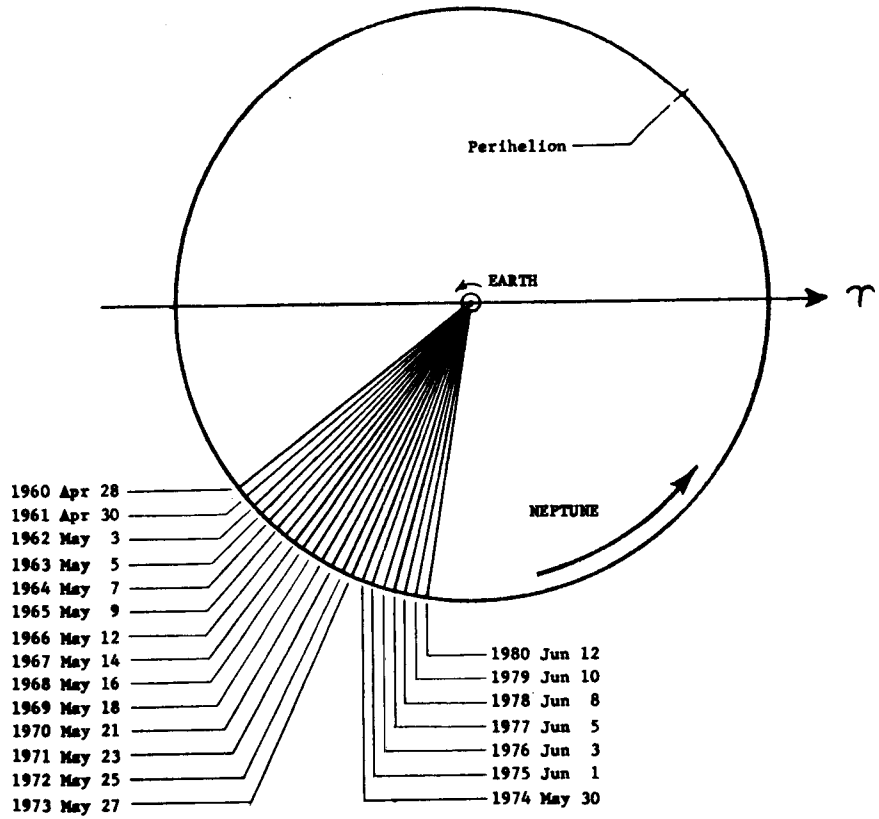

FIGURE 7

OPPOSITIONS OF NEPTUNE

TABLE 6

OPPOSITIONS OF URANUS (1960 - 1980)

Calendar Date	Longitude*
1960 Feb 8.8	138°.88
1961 Feb 12.8	143.60
1962 Feb 17.7	148.33
1963 Feb 22.6	153.07
1964 Feb 27.7	157.83
1965 Mar 3.7	162.59
1966 Mar 8.7	167.37
1967 Mar 13.7	172.15
1968 Mar 17.8	176.93
1969 Mar 22.8	181.70
1970 Mar 27.9	186.47
1971 Apr 1.9	191.23
1972 Apr 6.1	195.98
1973 Apr 11.2	200.70
1974 Apr 16.2	205.41
1975 Apr 21.2	210.09
1976 Apr 25.3	214.75
1977 Apr 30.3	219.38
1978 May 5.3	223.99
1979 May 10.2	228.58
1980 May 14.3	233.14

TABLE 7

OPPOSITIONS OF NEPTUNE (1960 - 1980)

Calendar Date	Longitude*
1960 Apr 28.1	217°.63
1961 Apr 30.7	219.79
1962 May 3.1	221.96
1963 May 5.5	224.11
1964 May 7.0	226.27
1965 May 9.5	228.43
1966 May 12.1	230.59
1967 May 14.5	232.75
1968 May 16.0	234.91
1969 May 18.5	237.07
1970 May 21.0	239.24
1971 May 23.5	241.40
1972 May 25.1	243.57
1973 May 27.6	245.74
1974 May 30.0	247.90
1975 Jun 1.5	250.06
1976 Jun 3.1	252.23
1977 Jun 5.7	254.39
1978 Jun 8.1	256.55
1979 Jun 10.7	258.71
1980 Jun 12.1	260.88

*Heliocentric longitude measured eastward along the ecliptic from the vernal equinox, ♈ .

MERCURY, VENUS, MARS, AND JUPITER: HOHMANN ELLIPSE TRANSFER TIMES, INJECTION DATES, AND ARRIVAL DATES FOR 1960 - 1980

Hohmann transfer ellipse characteristics were obtained in the following manner.

As a first approximation, the semimajor axis of the transfer ellipse was set equal to half the sum of Earth and Planetary semi-axes. The flight time, then, was half the sideral period; corresponding mean motions of the Earth and Planet were written down.

Continuing the first approximation, the sidereal mean motions used initially permit the estimation of Earth and Planet heliocentric longitudes at injection. Planet longitude at spaceship arrival time, of course, must be 180° greater than Earth longitude at injection. These longitudes, then, allow one to enter the tables for dates of injection and arrival, which in turn will determine more accurate mean motions for the particular intervals in which we are interested.

The new mean motions, then, produce more accurate determinations of the longitudes, new dates and so on. Basic reference dates and longitudes at all times are those for opposition or conjunction which have previously been interpolated with some accuracy.

Usually two or three iterations were sufficient to produce errors of less than half a day in the dates of injection.

Figures 8 and 9 illustrate typical transfer ellipses between Earth and Venus, and Earth and Mars, respectively. In Tables 9 through 14 are tabulated Dates of Injection, Transfer Times, and Arrival Times for Mercury, Venus, Mars, and Jupiter. The data for Mercury are those describing an Earth to planet transfer; the data for the remaining three planets include both Earth to planet and planet to Earth transfers.

The Earth to planet transfer ellipses for Venus, Mars, and Jupiter were computed by Mr. C. C. Dearman and appeared in his ABMA Report No. DSP-TN-2-60, dated 24 February 1960.

TABLE 8

MERCURY: HOHMANN INJECTION AND ARRIVAL DATES FOR EARTH TO PLANET TRANSFER

Injection Date (± 0.1 day)	Transfer Time (± 0.1 day)	Arrival Date (± 0.1 day)
1959 Dec 19.5	112.6	1960 Apr 10.1
1960 May 3.6	99.0	1960 Aug 10.6
1960 Aug 16.6	99.3	1960 Nov 23.9
1960 Nov 28.8	111.8	1961 Mar 20.6
1961 Apr 16.9	99.7	1961 Jul 25.6
1961 Jul 29.5	100.8	1961 Nov 7.3
1961 Nov 9.9	110.8	1962 Mar 31.7
1962 Mar 29.1	101.8	1962 Jul 8.9
1962 Jul 15.3	99.6	1962 Oct 22.9
1962 Oct 24.8	108.1	1963 Feb 9.9
1963 Jul 28.8	101.5	1963 Oct 8.3
1963 Oct 8.0	107.4	1964 Jan 23.4
1964 Feb 16.0	107.3	1964 Jun 2.3
1964 Jun 26.2	88.5	1964 Sep 22.7
1964 Sep 19.8	106.6	1965 Jan 4.4
1965 Jan 18.8	113.2	1965 May 12.0
1965 May 28.9	99.3	1965 Sep 5.2
1965 Sep 6.6	103.5	1965 Dec 19.1
1965 Dec 31.4	112.6	1966 Apr 23.0
1966 May 13.8	99.2	1966 Aug 21.0
1966 Aug 22.0	102.9	1966 Dec 2.9
1966 Dec 11.9	111.6	1967 Apr 2.5
1967 Apr 27.2	99.3	1967 Aug 4.5
1967 Aug 8.1	101.2	1967 Nov 17.3
1967 Nov 20.9	111.6	1968 Mar 11.5
1968 Apr 9.1	100.2	1968 Jul 18.3
1968 Jul 23.2	100.2	1968 Nov 30.4
1968 Nov 1.5	110.6	1969 Feb 20.1
1969 Mar 21.7	101.9	1969 Jul 1.6
1969 Jul 8.0	99.8	1969 Oct 5.8
1969 Oct 5.9	108.8	1970 Feb 1.6
1970 Mar 2.2	104.1	1970 Jun 14.3
1970 Jun 23.8	98.7	1970 Sep 30.5

TABLE 8 (CONTINUED)

MERCURY: HOHMANN INJECTION AND ARRIVAL DATES FOR EARTH TO PLANET TRANSFER

Injection Date (± 0.1 day)	Transfer Time (± 0.1 day)	Arrival Date (± 0.1 day)
1970 Sep 30.9	106.7	1971 Jan 15.6
1971 Feb 8.4	107.0	1971 May 26.4
1971 Jun 8.8	98.2	1971 Sep 15.0
1971 Sep 5.8	105.1	1971 Dec 29.9
1972 Jan 11.6	113.1	1972 May 3.7
1972 May 23.1	98.2	1972 Aug 29.3
1972 Aug 30.6	103.6	1972 Dec 12.2
1972 Dec 23.2	111.7	1973 Apr 13.9
1973 May 6.7	98.8	1973 Aug 13.5
1973 Aug 7.2	101.2	1973 Nov 26.4
1973 Dec 2.0	112.0	1974 Mar 24.0
1974 Apr 20.2	99.0	1974 Jul 28.2
1974 Aug 1.5	100.8	1974 Nov 10.3
1974 Nov 12.4	111.4	1974 Mar 3.8
1975 Apr 1.8	101.1	1975 Jul 11.9
1975 Jul 18.1	99.6	1975 Oct 25.7
1975 Oct 27.1	109.1	1976 Feb 13.2
1976 Mar 13.5	102.5	1976 Jun 24.0
1976 Jul 31.6	100.1	1976 Oct 8.7
1976 Oct 9.1	107.9	1977 Jan 25.0
1977 Feb 21.3	104.9	1977 Jun 6.2
1977 Jun 17.2	98.4	1977 Sep 13.6
1977 Sep 24.0	106.0	1978 Jan 8.0
1978 Jan 21.8	113.6	1978 May 15.0
1978 Jun 1.5	98.3	1978 Sep 7.8
1978 Sep 9.2	104.2	1978 Dec 22.4
1979 Jan 3.6	112.7	1979 Apr 26.3
1979 May 17.0	98.3	1979 Aug 23.3
1979 Aug 25.3	102.8	1979 Dec 6.1
1979 Dec 14.7	112.0	1980 Apr 4.7
1980 Apr 29.1	99.3	1980 Aug 6.4
1980 Aug 9.7	101.4	1980 Nov 19.1

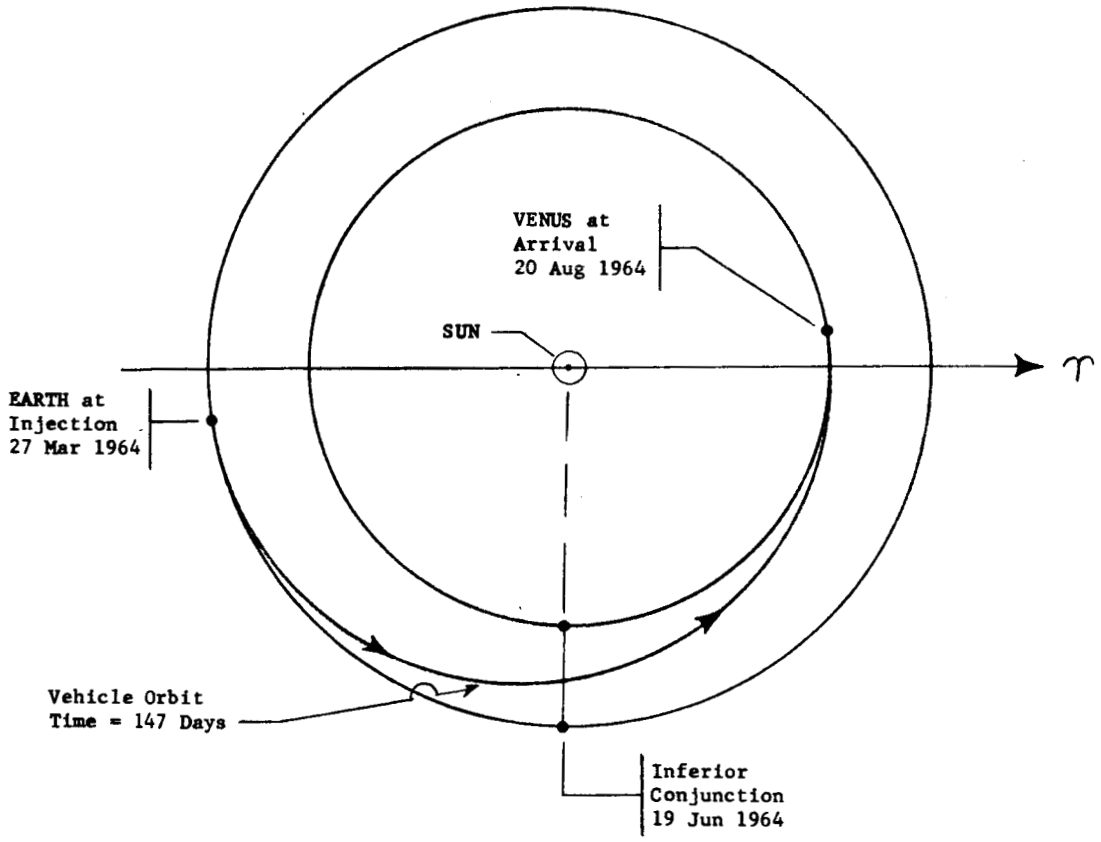

FIGURE 8

VENUS: HOHMANN INJECTION AND ARRIVAL FOR EARTH TO PLANET TRANSFER

TABLE 9

VENUS: HOHMANN INJECTION AND ARRIVAL DATES FOR EARTH TO PLANET TRANSFER

Injection Date (± 1 day)	Transfer Time (± 1 day)	Arrival Date (± 2 days)
1961 Jan 15	145	1961 Jun 9
1962 Aug 12	147	1963 Jan 7
1964 Mar 27	146	1964 Aug 20
1965 Oct 27	145	1966 Mar 21
1967 Jun 3	148	1967 Oct 29
1969 Jan 13	145	1969 Jun 7
1970 Aug 11	147	1971 Jan 5
1972 Mar 25	146	1972 Aug 18
1973 Oct 24	145	1974 Mar 18
1975 Jun 1	148	1975 Jul 19
1977 Jan 10	145	1977 Jun 4
1978 Aug 8	147	1979 Jan 2
1980 Mar 23	146	1980 Aug 16

TABLE 10

VENUS: HOHMANN INJECTION AND ARRIVAL DATES FOR PLANET TO EARTH TRANSFER

Injection Date (± 0.1 day)	Transfer Time (± 0.1 day)	Arrival Time (± 0.1 day)
1961 Feb 11.9	147.5	1961 Jul 9.4
1962 Sep 16.4	145.0	1963 Feb 8.4
1964 Apr 18.8	146.4	1964 Sep 12.2
1965 Dec 2.6	147.1	1966 Apr 28.7
1967 Jun 28.3	144.7	1967 Nov 20.0
1969 Feb 9.4	147.4	1969 Jul 6.8
1970 Sep 13.8	144.9	1971 Feb 5.7
1972 Apr 16.8	146.5	1972 Sep 10.3
1973 Nov 30.3	147.2	1974 Apr 26.5
1975 Jun 25.9	144.8	1975 Nov 17.7
1977 Feb 7.1	147.2	1977 Jul 4.3
1978 Sep 10.9	144.4	1979 Feb 2.3
1980 Apr 14.2	146.3	1980 Sep 7.5

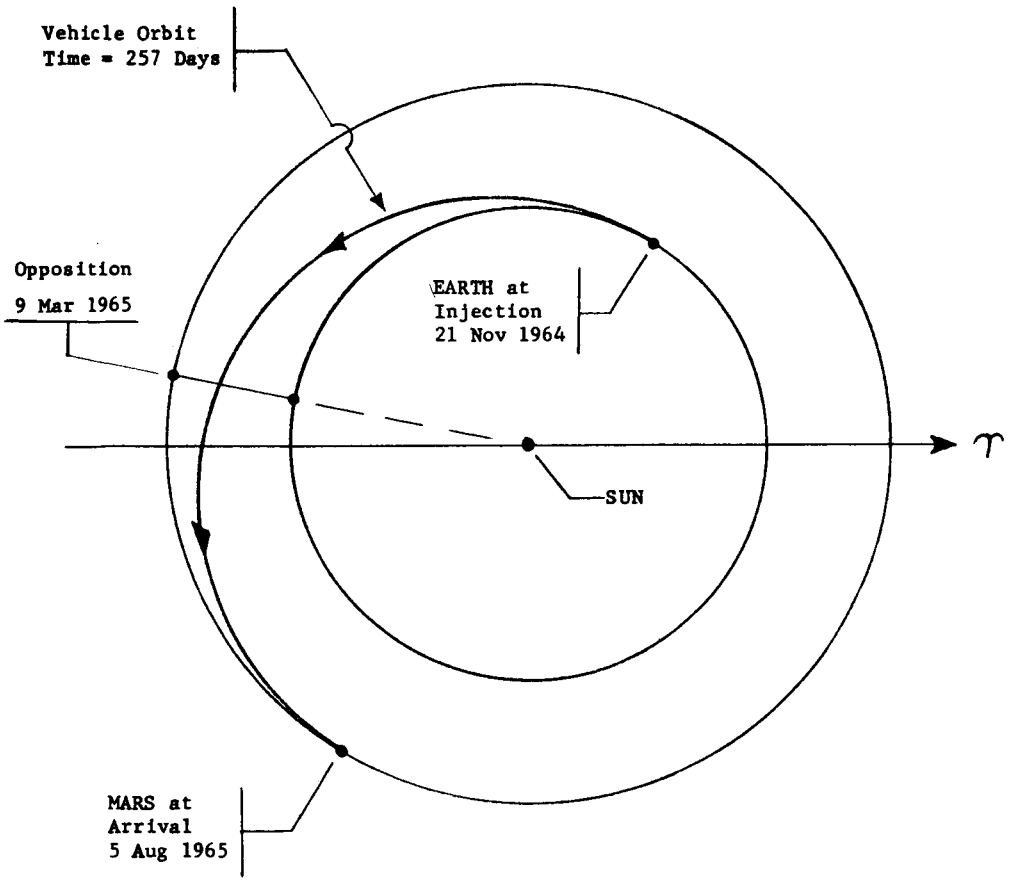

FIGURE 9

MARS: HOHMANN INJECTION AND ARRIVAL FOR EARTH TO PLANET TRANSFER

TABLE 11

MARS: HOHMANN INJECTION AND ARRIVAL DATES FOR EARTH TO PLANET TRANSFER

Injection Date (± 1 day)	Transfer Time (± 2 days)	Arrival Date (± 3 days)
1960 Sep 22	279	1961 Jun 28
1962 Oct 22	270	1963 Jul 19
1964 Nov 21	257	1965 Aug 5
1966 Dec 27	244	1967 Aug 28
1969 Feb 18	236	1969 Oct 12
1971 Jun 4	262	1972 Feb 21
1973 Aug 4	281	1974 May 12
1975 Sep 10	281	1976 Jun 17
1977 Oct 11	275	1978 Jul 13
1979 Nov 9	262	1980 Jul 28

TABLE 12

MARS: HOHMANN INJECTION AND ARRIVAL DATES FOR PLANET TO EARTH TRANSFER

Injection Date (± 0.1 day)	Transfer Time (± 0.1 day)	Arrival Date (± 0.1 day)
1960 Aug 13.1	244.1	1961 Apr 14.2
1962 Sep 9.3	258.4	1963 May 25.7
1964 Sep 30.1	271.4	1965 Jun 28.5
1966 Oct 23.8	280.5	1967 Aug 31.3
1968 Nov 25.7	282.2	1969 Sep 3.9
1971 Jan 24.0	270.3	1971 Oct 21.3
1973 May 17.3	239.8	1974 Jan 12.1
1975 Jul 19.8	239.3	1976 Mar 25.1
1977 Aug 30.9	252.8	1978 May 10.7
1979 Sep 22.7	266.7	1980 Jun 15.4

TABLE 13

JUPITER: HOHMANN INJECTION AND ARRIVAL DATES FOR EARTH TO PLANET TRANSFER

Injection Date (± 1 day)	Transfer Time (± 1 day)	Arrival Date (± 2 days)
1960 Mar 1	944	1962 Oct 1
1961 Apr 6	938	1963 Oct 31
1962 May 16	954	1964 Dec 24
1963 Jun 25	988	1966 Mar 9
1964 Aug 1	1025	1967 May 23
1965 Sep 5	1051	1968 Jul 22
1966 Oct 7	1059	1969 Aug 30
1967 Nov 5	1047	1970 Sep 17
1968 Dec 3	1021	1971 Sep 19
1969 Jan 2	993	1972 Sep 21
1971 Feb 1	961	1973 Sep 18
1972 Mar 5	942	1974 Oct 3
1973 Apr 11	939	1975 Nov 6
1974 May 21	955	1976 Dec 30
1975 Jun 30	992	1978 Mar 19
1976 Aug 6	1025	1979 May 28
1977 Sep 10	1052	1980 Jul 27
*1978 Oct 8	*1060	*1981 Sep 2
*1979 Nov 12	*1039	*1982 Sep 16

*Estimates

TABLE 14

JUPITER: HOHMANN INJECTION AND ARRIVAL DATES FOR PLANET TO EARTH TRANSFER

Injection Date (± 0.1 day)	Transfer Time (± 0.1 day)	Arrival Date (± 0.1 day)
1960 Mar 3.8	1013.0	1962 Dec 11.9
1961 May 14.1	977.6	1964 Jan 16.7
1962 Jul 21.0	947.4	1965 Feb 22.4
1963 Sep 5.6	938.6	1966 Apr 1.2
1964 Oct 1.1	948.9	1967 May 8.0
1965 Oct 14.2	970.9	1968 Jun 11.1
1966 Oct 8.6	1008.6	1969 Jul 13.2
1967 Oct 13.6	1034.9	1970 Aug 13.5
1968 Oct 23.5	1054.3	1971 Sep 12.8
1969 Nov 19.5	1057.7	1972 Oct 12.2
1971 Jan 2.6	1042.4	1973 Nov 13.0
1972 Mar 11.0	1010.7	1974 Dec 16.7
1973 May 23.8	973.0	1976 Jan 21.8
1974 Jul 28.5	945.1	1977 Feb 27.6
1975 Sep 11.4	938.1	1978 Apr 6.5
1976 Oct 3.6	951.4	1979 May 13.0
1977 Oct 10.3	979.0	1980 Jun 15.3

SATURN, URANUS, AND NEPTUNE: HOHMANN ELLIPSE TRANSFER TIMES, INJECTION DATES, AND ARRIVAL DATES FOR 1960 - 1980.

In Tables 14 through 19 are tabulated Dates of Injection, Transfer Times, and Arrival Times for Saturn, Uranus, and Neptune. Mean motions were determined only from the semimajor axes. Injection dates, accordingly, are in error by as much as 10 days, and the transfer times are in error by as much as 45 days. Reduction of these errors may be determined at a later date if required.

The data in the tables include both Earth to planet and planet to Earth transfers. The Earth to Planet transfers were computed by Mr. C. C. Dearman and appeared in ABMA Report No. DSP-TN-2-60, dated 24 February 1960.

TABLE 15

SATURN: HOHMANN INJECTION AND ARRIVAL DATES FOR EARTH TO PLANET TRANSFER
(Approximate transfer time: 2209 mean Solar days)

Injection Date	Arrival Date
1960 Mar 15	1966 Apr 3
1961 Mar 27	1967 Apr 15
1962 Apr 8	1968 Apr 27
1963 Apr 20	1969 May 9
1964 May 2	1970 May 21
1965 May 15	1971 Jun 3
1966 May 28	1972 Jun 16
1967 Jun 10	1973 Jun 29
1968 Jun 23	1974 Jul 12
1969 Jul 8	1975 Jul 27
1970 Jul 23	1976 Aug 11
1971 Aug 7	1977 Aug 25
1972 Aug 20	1978 Sep 7
1973 Sep 4	1979 Sep 21
1974 Sep 19	1980 Nov 6
1975 Oct 4	1981 Nov 21
1976 Oct 17	1982 Dec 4
1977 Oct 31	1983 Dec 18
1978 Nov 13	1984 Jan 1
1979 Nov 26	1985 Jan 14

TABLE 16

SATURN: HOHMANN INJECTION AND ARRIVAL DATES FOR PLANET TO EARTH TRANSFER
(Approximate transfer time: 2209 mean Solar days)

Injection Date	Arrival Date
1960 Jan 30	1966 Feb 17
1961 Feb 10	1967 Feb 28
1962 Feb 22	1968 Mar 11
1963 Mar 6	1969 Mar 23
1964 Mar 17	1970 Apr 4
1965 Mar 29	1971 Apr 16
1966 Apr 11	1972 Apr 28
1967 Apr 25	1973 May 12
1968 May 7	1974 May 25
1969 May 21	1975 Jun 8
1970 Jun 5	1976 Jun 22
1971 Jun 20	1977 Jul 7
1972 Jul 4	1978 Jul 22
1973 Jul 19	1979 Aug 6
1974 Aug 3	1980 Aug 20
1975 Aug 18	1981 Sep 4
1976 Aug 31	1982 Sep 18
1977 Sep 15	1983 Oct 3
1978 Sep 29	1984 Oct 16
1979 Oct 12	1985 Oct 29

TABLE 17

URANUS: HOHMANN INJECTION AND ARRIVAL DATES FOR EARTH TO PLANET TRANSFER
(Approximate transfer time: 5858 mean Solar days)

Injection Date	Arrival Date
1960 Oct 20	1976 Nov 3
1961 Oct 25	1977 Nov 8
1962 Oct 30	1978 Nov 13
1963 Nov 4	1979 Nov 18
1964 Nov 8	1980 Nov 22
1965 Nov 13	1981 Nov 27
1966 Nov 18	1982 Dec 2
1967 Nov 23	1983 Dec 7
1968 Nov 27	1984 Dec 11
1969 Dec 2	1985 Dec 16
1970 Dec 7	1986 Dec 21
1971 Dec 12	1987 Dec 26
1972 Dec 16	1988 Dec 30
1973 Dec 21	1989 Jan 4
1974 Dec 26	1990 Jan 9
1975 Dec 31	1991 Jan 14
1976 Jan 4	1992 Jan 19
1977 Jan 9	1993 Jan 24
1978 Jan 14	1994 Jan 29
1979 Jan 19	1995 Feb 3
1980 Jan 23	1996 Feb 7

TABLE 18

URANUS: HOHMANN INJECTION AND ARRIVAL DATES FOR PLANET TO EARTH TRANSFER
(Approximate transfer time: 5858 mean Solar days)

Injection Date	Arrival Date
1960 May 23	1976 Jun 6
1961 May 28	1977 Jun 12
1962 Jun 3	1973 Jun 18
1963 Jun 8	1979 Jun 22
1964 Jun 12	1980 Jun 26
1965 Jun 18	1981 Jul 2
1966 Jun 23	1982 Jul 7
1967 Jun 28	1983 Jul 12
1968 Jul 2	1984 Jul 16
1969 Jul 8	1985 Jul 22
1970 Jul 13	1986 Jul 27
1971 Jul 18	1987 Aug 1
1972 Jul 22	1988 Aug 5
1973 Jul 27	1989 Aug 10
1974 Aug 2	1990 Aug 16
1975 Aug 7	1991 Aug 21
1976 Aug 11	1992 Aug 25
1977 Aug 16	1993 Aug 30
1978 Aug 21	1994 Sep 4
1979 Aug 26	1995 Sep 9

TABLE 19

NEPTUNE: HOHMANN INJECTION AND ARRIVAL DATES FOR EARTH TO PLANET TRANSFER
(Approximate transfer time: 11,176 mean Solar days)

Injection Date	Arrival Date
1960 Jan 5	1990 Aug 10
1961 Jan 6	1991 Aug 11
1962 Jan 9	1992 Aug 14
1963 Jan 11	1993 Aug 16
1964 Jan 14	1994 Aug 19
1965 Jan 15	1995 Aug 20
1966 Jan 17	1996 Aug 22
1967 Jan 20	1997 Aug 25
1968 Jan 22	1998 Aug 27
1969 Jan 24	1999 Aug 29
1970 Jan 26	2000 Aug 31
1971 Jan 28	2001 Sep 2
1972 Jan 31	2002 Sep 5
1973 Feb 1	2003 Sep 7
1974 Feb 4	2004 Sep 10
1975 Feb 6	2005 Sep 12
1976 Feb 8	2006 Sep 14
1977 Feb 10	2007 Sep 16
1978 Feb 12	2008 Sep 18
1979 Feb 15	2009 Sep 21
1980 Feb 17	2010 Sep 23

TABLE 20

NEPTUNE: HOHMANN INJECTION AND ARRIVAL DATES FOR PLANET TO EARTH TRANSFER
(Approximate transfer time: 11,176 mean Solar days)

Injection Date	Arrival Date
1960 Jan 17	1990 Aug 23
1961 Jan 18	1991 Aug 25
1962 Jan 21	1992 Aug 27
1963 Jan 23	1993 Aug 29
1964 Jan 26	1994 Aug 31
1965 Jan 27	1995 Sep 3
1966 Jan 29	1996 Sep 4
1967 Jan 31	1997 Sep 7
1968 Feb 3	1998 Sep 9
1969 Feb 4	1999 Sep 11
1970 Feb 7	2000 Sep 13
1971 Feb 9	2001 Sep 15
1972 Feb 12	2002 Sep 18
1973 Feb 13	2003 Sep 20
1974 Feb 15	2004 Sep 21
1975 Feb 18	2005 Sep 24
1976 Feb 20	2006 Sep 26
1977 Feb 22	2007 Sep 29
1978 Feb 24	2008 Sep 31
1979 Feb 26	2009 Oct 2
1980 Feb 29	2010 Oct 5

SUMMARY

Dates of inferior conjunction for Mercury and Venus, as well as oppositions for Mars, Jupiter, Saturn, Uranus, and Neptune, have been tabulated and shown diagrammatically for convenient reference.

Hohmann transfer times, injection dates, and arrival dates have been tabulated for reference when planning space missions.

APPENDIX: COMPUTATION OF HOHMANN TRANSFER INJECTION AND ARRIVAL TIMES

The approximate space vehicle Transfer Time, T, in Solar days, is first determined from Kepler's law:

$$T = \pi \left[0.5 \left\{ r_1 (E) + r_3 (P) \right\} \right]^{\frac{3}{2}} / 0.01720210 \qquad (1)$$

In this equation, for the first approximation, r_1 (E) and r_3 (P) are set equal to the semimajor axes of Earth and Planet. The subscripts refer to positions 1 and 3, in Fig. 9. In all later approximations these subscripts will designate the newly interpolated values of the radii vectores at positions 1 and 3. The number 0.01720210 is the Gaussian constant.

Angles A, B, and C in Fig. 9 are next found from:

$$B + C = 0.5\ T \cdot n_3 (P) \qquad (2)$$

$$A = 180 - (B + C) \qquad (3)$$

$$B = A \cdot n_1 (P) \Big/ \left[n_1 (E) - n_1 (P) \right] \qquad (4)$$

$$C = (B + C) - B \qquad (5)$$

where n (E) and n (P) are the mean daily motions of Earth and Planet over the interval (subscripts) of interest. On the first approximation, we use the mean daily motions of Earth and Planet over a whole period.

The next step is to calculate the heliocentric longitudes, L (E) and L (P), of Earth and Planet in degrees measured counterclockwise from the vernal equinox to the positions in Fig. 9 indicated by the subscripts:

$$L_1 (E) = L_2 (E) - (A + B) \tag{6}$$

$$L_1 (P) = L_2 (P) - B \tag{7}$$

$$L_3 (P) = L_2 (P) + C \tag{8}$$

where the longitudes $L_2 (E) = L_2 (P)$ are those at opposition or conjunction.

Reference is next made to the planetary tables; from these, the "times," corresponding to the longitudes $L_1 (E)$, $L_1 (P)$, and $L_3 (P)$, are interpolated exactly. These "times," $t_1 (E)$, $t_1 (P)$, and $t_3 (P)$, are Julian dates (2436934.0 days for December 31, 1959, through 2444239.0 days for December 31, 1979). The radii vectores, $r_1 (E)$ and $r_3 (E)$, corresponding to longitudes $L_1 (E)$ and $L_3 (P)$ are also interpolated exactly.

On the first approximation,

$$t_1 (E) \neq t_1 (P) \tag{9}$$

On the next approximation (using Equations (1) through (8)), the following values must be calculated and used:

$$n_1 (E) = \frac{A + B}{t_2 (E) - t_1 (E)} \tag{10}$$

$$n_1 (P) = \frac{B}{t_2 (P) - t_1 (P)} \tag{11}$$

$$n_3 (P) = \frac{B + C}{t_3 (P) - t_1 (P)} \tag{12}$$

where $t_2 (E) = t_2 (P)$, obviously, for the inferior conjunction time or opposition time (given in Tables 1 through 7).

As the approximations are repeated, $t_1 (E) \rightarrow t_1 (P)$. The approximations are continued until the degree of equality between $t_1 (E)$ and $t_1 (P)$ is that which is desired. The final values of $t_1 (E)$ (P) and $t_3 (P)$ are then the injection time and arrival time; their difference is the flight time.

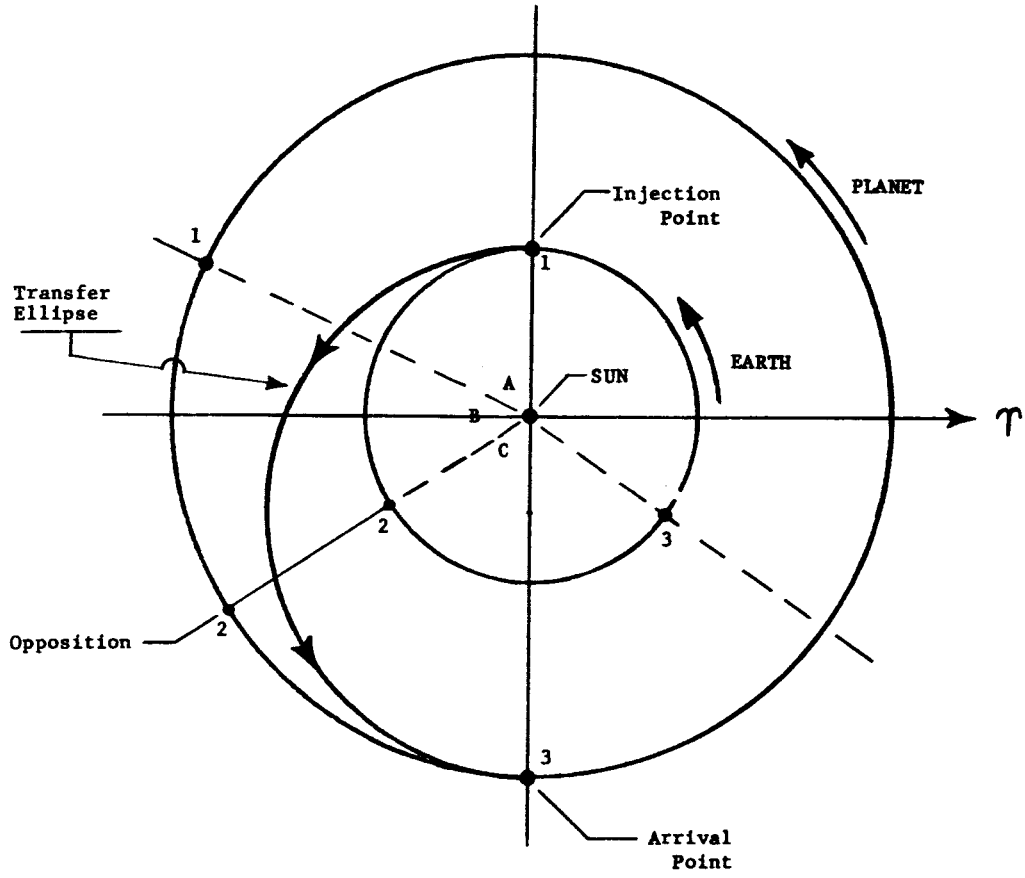

FIGURE 10

HOHMANN TRANSFER
FOR AN
OUTER PLANET

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