PLANETARY EPHEMERIDES

Interplanetary Mission Design

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INTRODUCTION

The positions and velocities of the planets must be known on desired dates to compute interplanetary trajectories. There are various methods to determine the location of a planet for a given date. Currently, the most accurate method is to use the planetary ephemerides provided by JPL's Horizons system or from the Navigation and Ancillary Information Facility (NAIF) website (http://naif.jpl.nasa.gov/naif/). The NAIF website also provides several software packages for reading ephemerides. For the purposes of this class, the position of the planets in a heliocentric frame will be computed as a function of time using an algorithm given by Meeus.[1] Although not as accurate as ephemerides such as the DE421, it is a good approximation.

In Meeus' algorithm, the orbital elements of the planets are expressed as polynomials of the form:

$$\text{Element} = a_0 + a_1 T + a_2 T^2 + a_3 T^3$$

where T is time measured in Julian centuries of 36525 ephemeris days from the epoch J2000.0 = JDE 2451545. T may be computed as:

$$T = \frac{\text{JDE} - 2451545.0}{36525}$$

Meeus provides coefficients for the following elements:

$L =$ Mean longitude of the Planet
$a =$ Semimajor axis of the orbit
$e =$ Eccentricity of the orbit
$i =$ Inclination of the orbit
$\Omega =$ Longitude of the Ascending Node
$\Pi =$ Longitude of the Perihelion

The longitude of perihelion, Π should not be confused with the argument of perihelion, ω. Π is related to Ω and ω as follows:

$$\Pi = \Omega + \omega$$

The planet's mean anomaly, M, is given by:

$$M = L - \Pi$$

The true anomaly can be found as:

$$\nu = M + C_{cen}$$

where

$$C_{cen} = \left(2e - \frac{e^3}{4} + \frac{5}{96}e^5\right)\sin M + \left(\frac{5}{4}e^2 - \frac{11}{24}e^4\right)\sin(2M) + \left(\frac{13}{12}e^3 - \frac{43}{64}e^5\right)\sin(3M) + \frac{103}{96}e^4\sin(4M) + \frac{1097}{960}e^5\sin(5M)$$

The traditional orbital elements (a, e, i, Ω, ω, ν) are now known, and the position and velocity of the planet can be calculated. Tables 1-8 shows the coefficients for the planets and Pluto for the standard J2000.0 equinox.

Table 1. Coefficients for the Orbital Elements of Mercury

Orbital Elements	a_0	a_1	a_2	a_3
L (deg)	252.250906	149472.6746358	-0.00000535	0.000000002
a (AU)	0.387098310			
e	0.20563175	0.000020406	-0.0000000284	-0.00000000017
i (deg)	7.004986	-0.0059516	0.00000081	0.000000041
Ω (deg)	48.330893	-0.1254229	-0.00008833	-0.000000196
Π (deg)	77.456119	0.1588643	-0.00001343	0.000000039

Table 2. Coefficients for the Orbital Elements of Venus

Orbital Elements	a_0	a_1	a_2	a_3
L (deg)	181.979801	58517.8156760	0.00000165	-0.000000002
a (AU)	0.72332982			
e	0.00677188	-0.000047766	0.0000000975	0.00000000044
i (deg)	3.394662	-0.0008568	-0.00003244	0.000000010
Ω (deg)	76.679920	-0.2780080	-0.00014256	-0.000000198
Π (deg)	131.563707	0.0048646	-0.00138232	-0.000005332

Table 3. Coefficients for the Orbital Elements of Earth

Orbital Elements	a_0	a_1	a_2	a_3
L (deg)	100.466449	35999.3728519	-0.00000568	0.0
a (AU)	1.000001018			
e	0.01670862	-0.000042037	-0.0000001236	0.00000000004
i (deg)	0	0.0130546	-0.00000931	-0.000000034
Ω (deg)	174.873174	-0.2410908	0.00004067	-0.000001327
Π (deg)	102.937348	0.3225557	0.00015026	0.000000478

REFERENCES

[1] J. Meeus, *Astronomical Algorithms*. Richmond, VA: William-Bell, Inc., First English ed., 1991.

Table 4. Coefficients for the Orbital Elements of Mars

Orbital Elements	a_0	a_1	a_2	a_3
L (deg)	355.433275	19140.2993313	0.00000261	- 0.000000003
a (AU)	1.523679342			
e	0.09340062	0.000090483	- 0.0000000806	- 0.00000000035
i (deg)	1.849726	- 0.0081479	- 0.00002255	- 0.000000027
Ω (deg)	49.558093	- 0.2949846	- 0.00063993	- 0.000002143
Π (deg)	336.060234	0.4438898	- 0.00017321	0.000000300

Table 5. Coefficients for the Orbital Elements of Jupiter

Orbital Elements	a_0	a_1	a_2	a_3
L (deg)	34.351484	3034.9056746	-0.00008501	0.000000004
a (AU)	5.202603191	0.0000001913		
e	0.04849485	0.000163244	-0.0000004719	-0.00000000197
i (deg)	1.303270	-0.0019872	0.00003318	0.000000092
Ω (deg)	100.464441	0.1766828	0.00090387	-0.000007032
Π (deg)	14.331309	0.2155525	0.00072252	-0.000004590

Table 6. Coefficients for the Orbital Elements of Saturn

Orbital Elements	a_0	a_1	a_2	a_3
L (deg)	50.077471	1222.1137943	0.00021004	-0.000000019
a (AU)	9.554909596	-0.0000021389		
e	0.05550862	-0.000346818	-0.0000006456	0.00000000338
i (deg)	2.488878	0.0025515	-0.00004903	0.000000018
Ω (deg)	113.665524	-0.2566649	-0.00018345	0.000000357
Π (deg)	93.056787	0.5665496	0.00052809	0.000004882

Table 7. Coefficients for the Orbital Elements of Uranus

Orbital Elements	a_0	a_1	a_2	a_3
L (deg)	314.055005	429.8640561	0.00030434	0.000000026
a (AU)	19.218446062	-0.0000000372	0.00000000098	0.0
e	0.04629590	-0.000027337	0.0000000790	0.00000000025
i (deg)	0.773196	0.0007744	0.00003749	-0.000000092
Ω (deg)	74.005947	0.5211258	0.00133982	0.000018516
Π (deg)	173.005159	1.4863784	0.0021450	0.000000433

Table 8. Coefficients for the Orbital Elements of Neptune

Orbital Elements	a_0	a_1	a_2	a_3
L (deg)	304.348665	219.8833092	0.00030926	0.000000018
a (AU)	30.110386869	-0.0000001663	0.00000000069	0.0
e	0.00898809	0.000006408	-0.0000000008	-0.00000000005
i (deg)	1.769952	-0.0093082	-0.00000708	0.000000028
Ω (deg)	131.784057	1.1022057	0.00026006	-0.000000636
Π (deg)	48.123691	1.4262677	0.00037918	-0.000000003

Table 9. Coefficients for the Orbital Elements of Pluto

Orbital Elements	a_0	a_1	a_2	a_3
L (deg)	238.92903833	145.20780515	0.0	0.0
a (AU)	39.48211675	-0.00031596	0.0	0.0
e	0.24882730	0.00005170	0.0	0.0
i (deg)	17.14001206	0.00004818	0.0	0.0
Ω (deg)	110.30393684	-0.01183482	0.0	0.0
Π (deg)	224.06891629	-0.04062942	0.0	0.0