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SUBTABULATED LUNAR AND PLANETARY EPHEMERIDES

[6]

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SUBTABULATED LUNAR AND PLANETARY EPHEMERIDES[1]

In a joint JPL-STL effort the planetary ephemerides have been collected on IBM 704-709 magnetic tape, and a series of routines have been written to utilize these tapes. This paper describes the contents and preparation of the ephemeris tapes.

Two tapes are available, a geocentric tape containing the cartesian coordinates of the planets, the Sun, and the Moon tabulated at one-day intervals for the period J.D. 2437116.5 to 24441132.5 and a heliocentric tape containing the cartesian coordinates of the planets and the Earth-Moon barycenter tabulated at 4-day intervals for the period J.D. 2437116.5 to 2451716.5. Both coordinate systems are referred to the mean equator and equinox of 1950.0. All coordinates are in A. U. with the exception of the Moon, which is tabulated in Earth radii. The tape format is described in the Appendix.

Due to lack of source data the position coordinates of Mars and Mercury are replaced with zeros on the heliocentric tape after J.D. 2450996 and J.D. 2443880.5, respectively.

Table 1 indicates the source of the ephemerides used in preparing the tapes and gives the tabular interval (in days) of the data. With the exception of the Sun and Moon, which were obtained in geocentric coordinates, all ephemerides were in the heliocentric coordinate system, referred to the mean equinox and equator of 1950.0.

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[1]This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract No. NASw-6, sponsored by the National Aeronautics and Space Administration.

Table 1

Body	Interval	Source
Pluto	40	Astronomical Papers, Vol. XII
Neptune	40	"
Uranus	40	"
Saturn	40	"
Jupiter	40	"
Mars	20	U.S. Naval Proving Ground
Earth-Moon	4	Astronomical Papers, Vol. XIV
Moon	1/2	U.S. Naval Observatory
Venus	4	Astronomical Papers, Vol. XV, Part III
Mercury	5	Planetary Coordinates
Sun	4	Astronomical Papers, Vol. XIV

The data from the Astronomical Papers were obtained in the form of magnetic tape copies of the "Themis Tapes" which were prepared from the Astronomical Papers by the University of California Radiation Laboratory. The lunar ephemerides were obtained in geocentric rectangular coordinates for the period 1960-1970 in groups of approximately one year, each group referred to the equinox of nearest beginning of year. These data were then rotated so that the coordinate system was referred to the equinox of 1950.0.

Since the ephemerides were being prepared primarily for interplanetary trajectory computations, the tabular interval was chosen to be constant for each body to ease the programming required to use the tapes. Further, it was decided to carry second and fourth central differences so that an Everett method could be used to speed the interpolation process. With this in mind, the inclusion of the Moon dictated a maximum interval of one day for the geocentric tape, and the inner planets dictated a 4-day interval for the heliocentric tape.

Even though one day is an unnecessarily fine interval for the geocentric coordinates of the planets, it was found necessary to carry modified second and modified fourth differences for the Moon, in effect "throwing back" the sixth and eighth differences of the lunar position onto the second and fourth differences. A discussion of this technique can be found in References 1 and 2. The formulas for simultaneous throw-backs are

$$\delta_m^2 = \delta^2 - 0.01312\ \delta^6 + 0.0043\ \delta^8$$

$$\delta_m^4 = \delta^4 - 0.27827\ \delta^6 + 0.0685\ \delta^8$$

Representative samples of the source data were differenced to determine the optimum polynomial to use in subtabulating. The usual method of "eye balling" the differences to find which differences could be neglected was backed up by estimating the "noise" in the data and computing how the noise would propagate through the difference table. When the actual differences became smaller than the estimated propagation of the "noise" it was assumed that they, and higher differences, could be ignored.

Table 2 gives the order of the polynomial used to subtabulate each body. The differences were such that the same interpolating polynomial could be used for each position component of any given planet.

Table 2

Body	Polynomial Order
Pluto	3
Neptune	3
Uranus	3
Saturn	4
Jupiter	5
Mars	8
Earth-Moon	4
Venus	5
Mercury	6
Sun	5

The Mercury data were available only to three significant figures and the interpolation order chosen was completely arbitrary. Mercury was included solely for completeness.

The ephemerides were subtabulated to 1- and 4-day intervals using polynomials of the order indicated above. To obtain geocentric coordinates of the planets, the geocentric coordinates of the Sun were added to the heliocentric coordinates of the planets. The signs of the solar geocentric coordinates were changed to obtain the heliocentric coordinates of the Earth.

For each of the source ephemerides the first differences assumed to be negligible were listed for the period of interest and scanned for bad points. This procedure was not feasible in the lunar case due to the magnitude of the high order differences. The sixth central differences of the Moon's position were plotted and scanned to check for bad points.

To guard against gross errors in the subtabulation process the first negligible differences for each planet on the final tapes were again listed and scanned for bad points.

REFERENCES

1. H. M. Nautical Almanac Office, Interpolation and Allied Tables, H. M. Stationery Office, London, 1956.

2. Kopal, Zdenek, Numerical Analysis, John Wiley and Sons, New York, 1955.

3. Nautical Almanac Office, U.S. Naval Observatory, Astronomical Papers, Vol. XII, XIV, XV. U.S. Government Printing Office, Washington, 1951, 1953, 1955.

4. H. M. Nautical Almanac Office, Planetary Co-ordinates 1960-1980, H. M. Stationery Office, London, 1958.

APPENDIX

TAPE FORMAT

The formats of the geocentric tape and the heliocentric tape are identical. All data are written in the low density binary mode. The tape begins with one record describing the contents of the tape followed by one record per Julian day tabulated. An end-of-file mark follows the last record. Each record begins with the octal number 000000000001, and this number is not included in the checksum which follows each record. This is a dummy word included for compatibility with FORTRAN programs.

A. I. D. Record (length 2N+6)

PZE	1	(For FORTRAN compatibility)
PZE	0, 0, XXX	Table number
PZE	0, 0, N	Number of bodies tabulated
BCI	2, Sun	Name of central body
BCI	2, Mercury	
BCI	2, Venus	BCD names of tabulated bodies
BCI	2, Earth-Moon	(2 words per name)
⋮		
Check-sum		Does not include first word

B. General record (length 9N+3)

PZE	1	Dummy word
DEC	Julian Date	
DEC	X, Y, Z	1st tabulated body
DEC	δ^2X, δ^2Y, δ^2Z	
DEC	δ^4X, δ^4Y, δ^4Z	
DEC	X, Y, Z, etc.	2nd tabulated body
⋮		
Check-sum		Does not include first word