# THE MAIN STAGES OF THE CONSTRUCTION OF AE89 — THE NUMERICAL EPHEMERIS OF THE PLANETS AND THE MOON

M.L. Belikov, V.N. Boyko, N.I. Glebova, G.I. Eroshkin, L.I. Rumyantseva, M.L. Sveshnikov, E.S. Sveshnikova, R.I. Smekhacheva, A.A. Trubitsyna, M.A. Fursenko, L.I. Chunaeva, and A.A. Shiryaev
*Institute for Theoretical Astronomy, USSR Academy of Sciences*
*10 Kutuzov Quay*
*191187 Leningrad*
*USSR*

The realization of theoretical and applied researches in the domain of ephemeris astronomy, connected with analysis of precision of existing planetary and lunar theories, the construction of an inertial coordinate system and investigation of physical properties of space-time, necessitated the elaboration in ITA of the numerical theory of the motion of heavenly bodies suitable for calculation of high-precision ephemerides at large time-spans, and fit also for the maintenance of space experiments.

In the course of construction of this theory, named AE89, the tasks to be solved are as follows:

a) the construction of the dynamically consistent model of the orbital motion of the planets and the orbital-rotational motion of the Moon;
b) the elaboration of an effective numerical integration method fit to the development of the ephemerides;
c) the working out of a base of astrometric solar, lunar and planetary data;
d) the determination of the dynamical parameters of the Solar system from the observations.

## 1. Mathematical model

The adequate mathematical model of the motion of the Solar system bodies constitutes the framework of the numerical ephemeris. This model is accomplished in the form of a system of differential equations describing the orbital motion of 9 major planets, 5 of the most massive asteroids, and the orbital-rotational motion of the Moon, in the barycentric ecliptic reference system defined by the ecliptic and equinox of the epoch J2000.0.

The orbital motions of the heavenly bodies considered as point masses, are presented by Einstein-Infeld-Hofmann equations. In the equations concerning the Earth and the Moon, the perturbations caused by their gravitational interaction as nonspherical rotating rigid bodies were added; the terrestrial zonal harmonics through 4-th degree and all the lunar harmonics through 4-th degree were also included. The rotation of the Moon about its centre of masses is described in terms of Rodrigues-



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Hamilton's parameters, defining the position of the lunar principal axes of inertia with respect to the ecliptical reference frame defined earlier.

The position of the Earth's true equator is defined by the precession parameters of Lieske and the theory of nutation of IAU (1980). The independent variable of the equation is barycentric dynamical time TDB. The system of constants adopted in this model (planetary and Moon's masses, geo- and selenodynamical parameters etc.) coincide with that of the DE200/LE200 numerical ephemeris. The initial conditions of the orbital motion of the planets and the Moon are taken from the same ephemeris; those of the asteroids are calculated by means of programme used in preparation of the *Ephemerides of minor planets*. The initial values of Rodriques-Hamilton parameters are defined by the series which represent the components of the lunar physical libration for the values of the DE200/LE200 selenodynamical constants [1].

## 2. The numerical integrator

For the integration of the equations the integrator RA15 [2] was used, as well as the integrator INCH7 [3] elaborated in ITA especially for this work. The integration and the comparison of the results with DE200/LE200 and with the series [1] was carried out at the time-span 1960–1990.

The deviations of the coordinates of AE89 from those of DE200/LE200 for the 1980–1990 time-span are shown in the table. For the planets in most cases they don't exceed tens of meters and 1.5 meters for the Moon (single precision integration: 12 digits). For double precision integration the deviations diminish considerably.

In view of the difference between the models adopted in AE89 and in DE200/LE200, one may consider these results as satisfactory. The comparison also made obvious the advantages of the INCH7 over RA15 with respect to the precision and speed of itegration. Moreover, in INCH7 the original method is employed for the construction of the coefficients of Chebyshev's polynomials, representing the coordinates of the heavenly bodies in the ephemeris by means of the coefficients of the interpolation polynomials used in the process of numerical integration.

## 3. Treatment of observations

The treatment of the observations for the improvement of the Solar system parameters will be performed by means of data base DVA (Disk Version of Archives) and Planetary Data Management System (PDMS). At present the construction of this system is completed, and so are three specialized archives of the observations, *viz*.:

a) the archive of optical angular observations of the Sun and major planets, which contains 66000 observations made at various observatories from 1774 to 1988.
b) the archive of planetary radar observations (7500 measurements) made in USSR and USA from 1964.
c) the archive of lunar laser observations (5500 measurements) made in USA, France and USSR from 1969 to 1985.

**Table.** The comparison with DE200 / LE200 and semianalytic theory of the physical libration of the Moon [1] at 10-years time-span from JD 2444 400.5
(Maximum and minimum deviations for the single precision integration are indicated)

| | $\Delta X(m)$ | $\Delta Y(m)$ | $\Delta Z(m)$ | $\Delta R(m)$ | $\Delta\lambda(1'' \times 10^6)$ | $\Delta\beta(1'' \times 10^6)$ |
|---|---|---|---|---|---|---|
| Mercury | +650.86 | +562.66 | +60.84 | +124.60 | – | +201 |
| | –431.93 | –624.51 | –86.80 | –121.50 | –3040 | –338 |
| Venus | +28.78 | +32.45 | +1.87 | +1.75 | +1 | +4 |
| | –32.64 | –30.11 | –1.86 | –0.46 | –68 | –4 |
| Earth | +14.85 | +24.25 | +0.53 | +3.89 | +5 | +1 |
| | –28.80 | –22.00 | –0.56 | –2.38 | –40 | –1 |
| Mars | +431.51 | +346.57 | +4.74 | +73.23 | +19 | +6 |
| | –398.35 | –550.70 | –8.57 | –52.85 | –561 | –8 |
| Jupiter | +172.43 | +54.10 | +1.61 | +48.53 | – | +1 |
| | –68.29 | –171.45 | –2.80 | –23.76 | –53 | –1 |
| Saturn | – | +3.24 | +6.54 | +70.78 | – | +1 |
| | –71.42 | –107.38 | – | – | –15 | – |
| Uranus | – | +3.31 | +5.26 | +32.54 | – | – |
| | –41.18 | –34.56 | – | –0.79 | –3 | – |
| Neptune | – | +3.33 | +5.66 | +21.77 | – | – |
| | –41.56 | –29.13 | – | –2.68 | –2 | – |
| Pluto | – | +3.33 | +7.12 | +48.73 | – | – |
| | –45.24 | –28.76 | – | – | –1 | – |
| Moon | +1.30 | +1.35 | +0.25 | +0.12 | +303 | +140 |
| | –1.59 | –1.31 | –0.25 | –0.14 | –914 | –139 |

The physical libration of the Moon

| $\Delta\tau$ | $\Delta\rho$ | $\Delta I_\sigma$ |
|---|---|---|
| +0.″231 | +0.″050 | +0.″266 |
| –0.″153 | –0.″476 | –0.″160 |

## References


1. Fursenko, M.A.: 1989, "The physical libration of the Moon. M.Moons' 1985 theory for the Stokes constants DE200/LE200", In press.
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