THE EPHEMERIDES: PAST, PRESENT AND FUTURE

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Over the years there has been a continuing trend toward unification of both the annually printed volumes of ephemerides and the fundamental bases for the ephemerides. Thus, from many completely independent national and private publications, which were based on a multitude of theories, there has developed a continually improving agreement on accurate astronomical constants, planetary, lunar and satellite theories and cooperative methods of printing the annual ephemerides in different languages. This trend is continuing, currently, with the adoption of a new system of astronomical constants in 1976, consideration of revisions of nutation, the planned revision of the A.E. (American Ephemeris and Astronomical Ephemeris) for 1981, and the expected introduction in 1984 of new fundamental planetary and lunar ephemerides based on the new constants and on the FK5. Currently the differences between the printed ephemerides and observations sytematically exceed 2" for Mars at some times and 6$''\!.$ for Neptune at all times. It is anticipated that a new set of fundamental theories will be introduced which will be based on a consistent set of astronomical constants and in agreement with the available observational data to the printed accuracy.

INTRODUCTION

From earliest times man has been interested in the Sun, Moon, planets and stars and in determining their positions. Particularly, there has been an interest in being able to predict the positions of the solar system bodies and interesting phenomena, such as eclipses, planetary groupings and directions, and the times of rising and setting.

The results of these interests were numerous mathematical, or analog, approaches to the calculations, observations

R. L. Duncombe (ed.), Dynamics of the Solar System, 99–114.

of various types, some recorded but most of limited accuracy and not documented, and some attempts to predict the positions of the "wandering" objects.

Eventually national publications of the ephemerides appeared in the various countries in different years. The following are examples of such publications and their initial years of publication: from France the Connaissance des Temps in 1679, from England The Nautical Almanac and Astronomical Ephemeris in 1767, from Germany the Berliner Astronomisches Jahrbuch in 1776, from Spain the Efemerides Astronomicas in 1791, from the United States The American Ephemeris and Nautical Almanac in 1855, from the Union of Soviet Socialist Republics the Annuaire Astronomique in 1923, from Japan the Japanese Ephemeris in 1943, and from India the Indian Ephemeris and Nautical Almanac in 1958. Initially, these publications were based on various theories of the motions of the bodies, different astronomical constants, different geographical coordinate systems and different time scales.

INTERNATIONAL COOPERATION

Formal cooperation dated from the International Meridian Conference held in Washington, D. C. in October 1884, when the Greenwich meridian and the universal day were adopted. At the Conference Internationale des Etoiles Fondamentales in Paris in May 1896 the fundamental constants for nutation, aberration, solar parallax and lunisolar and planetary precession were adopted. Active cooperation between the preparers of the national ephemerides began in October 1911 with the Congres International des Ephemerides Astronomiques in Paris. The distribution of calculations between the principal ephemeris offices (France, Germany, Great Britain, Spain and the United States) was recommended and the constants for the flattening of the Earth and the semidiameter of the Sun at unit distance were adopted. In the United States the recommendation required official approval by an Act of Congress (37 Stat. L., 328, 342). In 1919 the International Astronomical Union (IAU) was founded, including Commission 4 for Ephemerides.

In the Draft Report for the Twelfth General Assembly, held in Hamburg in 1964, D. H. Sadler indicated that the functions of Commission 4 on Ephemerides are twofold: "firstly, to ensure that the published ephemerides fully meet the requirements of astronomers and other users; and secondly, to coordinate the work of the offices of the national ephemerides to ensure consistency, economy of effort, and efficiency." The history of cooperation in the IAU on ephemerides has been directed toward these functions, with the primary emphasis o the first function being on the constants used and the bases for the ephemerides. A brief review of the efforts in these two areas should be helpful.

The initial agreement concerning constants predated the IAU and has been mentioned previously. At a meeting on fundamental constants for astronomy that was held in Paris during March 1950 the definition of ephemeris time was recommended and the lunar ephemeris was brought into accordance with the solar ephemeris with respect to ephemeris time. These recommendations were adopted in 1952 by Commission 4 of the IAU at the Eighth General Assembly in Rome.

At the Twelfth General Assembly (Hamburg, 1964) it was reported that IAU Symposium No. 21 (Paris, May 1963) concluded that a change in the conventional IAU system of constants could no longer be avoided. The inconsistencies and inadequacies of the system of that time, the better values of some constants from recent determinations, and deficiencies revealed by discussions of high accuracy observations indicated the need for new constants. A list of constants proposed by the Working Group on the System of Astronomical Constants was adopted and recommended for use at the earliest practicable date in the national and international astronomical ephemerides. These constants were introduced in the ephemerides for 1968. It was also noted that the constants of precession and planetary masses had not been changed and that consideration should be given to their future improvement.

In August, 1970, IAU Colloquium No. 9 on the IAU System of Astronomical Constants was held in Heidelberg, and recommended the establishment of three Working Groups on Planetary Ephemerides, Precession, and Units and Time Scales. The recommendations were adopted and the Working Groups were established at the 1970 IAU General Assembly in Brighton, England. A Working Meeting on Constants and Ephemerides was held in October, 1974, in Washington, D. C. to draft a proposed report of the Working Groups. The chairmen of the Working Groups met in September, 1975, and June, 1976, in Herstmonceaux and Washington, respectively. The Report and Recommendations, known as the Joint Report of the Working Groups of IAU Commission 4 on Precession, Planetary Ephemerides, Units and Time Scales, were adopted by the IAU in August, 1976, at the meeting in Grenoble.

In 1976 a Working Group on Cartographic Coordinates and Rotational Elements of Planets and Satellites was established by IAU Commissions 4 and 16. In 1977 a Working Group on Nutation was established by Commission 4. These groups are expected to provide recommendations for consideration at the 1979 General Assembly in Montreal.

Concerning the second primary function of Commission 4 on ephemerides, specifically the coordination of the efforts of the offices, there has been a progression from the distribution of calculations among the various offices, which was out-dated by the advent of high speed computers, to the unification of printing and the exchange of reproduction proofs for printing by the various countries.

As early as 1932 at the Fourth General Assembly of the IAU in Cambridge, Mass., Dr. L. J. Comrie, Director of the British Nautical Almanac Office, suggested that duplicate printing in the national volumes of ephemerides be discussed, particularly with respect to the apparent places of stars. At that time Professor Herrero suggested that the ideal would be an international almanac. At the Fifth General Assembly (Paris, 1935) an agreement was reached for a single publication of the Apparent Places of Stars, initially to be printed in Great Britain and now printed in Germany.

At the Ninth General Assembly (Dublin, 1955) an International Fundamental Astronomical Ephemeris (IFAE) was discussed. The IFAE was to be a single publication, under the auspices of the IAU, containing the fundamental astronomical ephemerides to the fullest accuracy. The national ephemerides could then be much smaller and cater more directly to the practical astronomer. While there were many in favor of this proposal, there was the practical difficulty that the sales were not likely to cover the cost of printing, due to the anticipated, required, free distribution. Also, there was the difficulty for astronomers purchasing books published in other countries, the required cooperation of almost all national ephemerides and the loss of flexibility. Thus, full agreement and adoption was not possible. However, the use of reproduction proofs for the printing by various countries of material prepared by a single source was an attractive alternative. At the same time, it was announced that agreement had been reached for the unification of the American Ephemeris and Nautical Almanac and The Nautical Almanac and Astronomical Ephemeris beginning with the year 1960. It was hoped that other ephemeris offices would make use of the considerable saving of composition and proof reading by reproduction by photoligraphy.

At the Tenth General Assembly (Moscow, 1958) it was reported that the Astronomisch - Geodatisches Jahrbuch, introduced for the year 1949, had ceased publication after the 1957 edition and that the Berliner Astronomisches Jahrbuch, introduced for the year 1776, would cease publication after the edition for 1959. As a result of these savings of composition and printing costs the Astronomisches Rechen-Institut was able to take over composition and publication of the

Apparent Places of Fundamental Stars. Thus, while it was sad to see a publication of long standing cease, it indicated an increased international cooperation and permitted a beneficial transfer of functions.

G. M. Clemence and D. H. Sadler reported at the Eleventh General Assembly (Berkeley, 1961) that an important step towards unification of the National Ephemerides had taken place in the unification of the American and British volumes. They stated further that:

> "Many dearly-held, but essentially unimportant, standards and prejudices have had to be sacrificed on both sides; it is surprising how quickly these lose their former importance in the satisfaction of a comprehensive agreement. That same co-operation, goodwill and confidence exists between all the national ephemeris offices, and, although differences of language will introduce some further difficulties, there is no obstacle to complete unification that will not be overcome in course of time."

Between 1962 and 1964 the Japanese and Russian ephemerides began using the advanced proofs from the Astronomical Ephemeris.

In October 1974 plans were begun to revise the organization, content and basis for the American Ephemeris and Nautical Almanac/Astronomical Ephemeris. It was decided that a single unified printing in English will be made in the United States and that it will be available from both Her Majesty's Stationery Office in England and from the Superintendent of Documents in the United States. Since the United States legal code requires the title The American Ephemeris and Nautical Almanac, a bill was introduced into Congress to modify the legal code to permit a change in the name of the publication. Also, it was decided that the organization and content would be changed for the 1981 edition. A list of the principal modifications follows:

1. Replace the hourly apparent lunar ephemeris by daily short power series which permit the direct determination of the lunar position for any time.
2. Eliminate all 1st differences.
3. Eliminate Independent Day Numbers.
4. Eliminate fixed tables for unit conversions.
5. Give longitudes and latitudes of the Moon and planets to $0\overset{\circ}{.}01$ accuracy only.
6. Organize the volume into sections which have their own pagination.

7. Provide times of sunrise, sunset, moonrise, and moonset for southern latitudes.

8. Provide times of civil twilight in addition to astronomical twilight.

9. Expand the list of occultations to include lunar occultations of radio sources and planetary occultations of stars.

10. Include transformation matrices for reduction of apparent places.

11. Include an ephemeris of the barycenter of the solar system.

12. Include a BIH polar motion table.

13. Include physical ephemerides for all planets, commensurate with current knowledge.

14. Give satellite ephemerides to observing accuracy for all satellites, generally for the entire year.

15. Provide selected minor planet ephemerides to 1" accuracy.

16. Expand the star list to about 1600 stars.

17. Include standard lists of variable stars, radio sources, pulsars and x-ray sources.

18. Give locations of observatories to reduced precision in the annual Observatories List, and periodically publish for each observatory a list of accurate astronomical or geodetical locations of each instrument.

19. Introduce a rewritten explanation with a glossary of terms used in the volume.

20. Introduce tables of new values of astronomical constants as appropriate.

21. Introduce chapters for a new version of the Explanatory Supplement as supplements to the A.E. prior to the publication of the new volume.

Additionally, it is planned that the new constants, the reference system of the FK5, and new fundamental ephemerides based on the new constants will be introduced in the 1984 edition.

FUTURE FORM OF EPHEMERIDES

With the widespread use of computers, which began in the 1950's, ephemerides in machine readable form were required. Initially a cooperative arrangement was established so that duplicate copies of machine readable data were retained at and available from the Royal Greenwich Observatory, the Astronomisches Rechen-Institut and the U. S. Naval Observatory (USNO). As more data became available from numerous other sources, IAU Commission 4 established the International Information Bureau on Astronomical Ephemerides at the Bureau des Longitudes in Paris, France, to provide information on the availability of machine readable data.

The availability and common use of electronic calculators and mini-computers, particularly those that are programmable, has introduced a desire for ephemerides and astronomical data in the form of equations or polynomials instead of the tabular form. This interest stimulated the experimental publication of the Almanac for Computers (Kaplan et al 1976, Doggett et al 1977). This almanac contains Chebyshev polynomials, which can be truncated to any desired accuracy, for the apparent right ascension, declination, true distance, semi-diameter and ephemeris transit of the Sun, Moon and planets. These data are given to the accuracy of the A.E., but another section contains navigational data to the accuracy of 0!1. The Almanac for Computers also contains the mean positions of navigational stars and expressions for determining their apparent positions, Fourier series expressions for the planets, which provide limited accuracy for a period of several centuries, and expressions for various astronomical and navigational computations. Also, a useful collection of formulae for computing astronomical data with hand-held calculators has been prepared by B. D. Yallop (1978). This Technical Note includes methods for calculating the position of the Sun and Moon, and solving the navigational triangle.

To satisfy the requirements for ephemerides to limited accuracy for planning purposes prior to the annual publication of the national ephemerides, a new volume, Planetary and Lunar Coordinates, is being introduced. The initial volume for 1980-1984 continues the series of publications Planetary Coordinates but is broader in scope and includes heliocentric and geocentric planetary coordinates and lunar coordinates.

The annual publication, Astronomical Phenomena, is being revised, expanded and produced in cooperation with Her Majesty's Nautical Almanac Office. Among the material to be added are a diary of geocentric solar system phenomena, increased information on the visibility of the planets, a low-precision ephemeris of the Sun, and tables for computing times of moonrise and moonset for southern latitudes. The extensive tables of Polaris will be deleted; in their place will be a single table giving the daily position of Polaris and σ Octantis.

For archival purposes, microfiche can be stored in a minimum of space and readily accessed for astronomical data in the past. However, in most cases for current use, the inconvenience, equipment requirements and illumination conflicts make microfiche inferior to the published volumes.

For the forseeable future, there appears to be a continuing requirement for the published national ephemerides in addition to the machine readable and formulae or polynomial expression versions of astronomical data.

PRESENT FUNDAMENTAL EPHEMERIDES

Presently, the fundamental ephemerides forming the bases for the annually published astronomical data are based on the following sources: the ephemeris of the Sun is based on Newcomb's Tables of the Sun (1895); the ephemeris of the Moon is based on Brown's theory as given in the Improved Lunar Ephemeris (1954); the ephemerides of the inner planets are derived from Newcomb's tables of these planets (1895-8) with Ross's corrections applied for Mars (1917); and the outer planet ephemerides are based on a numerical integration by Eckert, Brouwer, and Clemence (1951), with inner planet perturbations by Clemence (1954). These ephemerides are, therefore, based on theories from thirty to eighty years old and on a heterogeneous combination of astronomical constants adopted over the same period of time. In addition, the theory of relativity and the variability of the rotation of the Earth have been discovered during this period.

New observational techniques have provided much more accurate observational data and a means of measuring the distance to some of the solar system objects. Thus, radar and laser ranging techniques have produced a requirement for more accurate ephemerides in order to make observations.

The optical observational data available also indicate discrepancies between the theories and the observed positions of the objects and these discrepancies are summarized in Table 1. Table 2 is a summary of some known characteristics of the differences between the published ephemerides and the observations. These variations are the symptoms of some known, and probably some unknown, theoretical problems. It is recognized that the basic constants used for the ephemerides do not represent the best current knowledge, particularly for planetary masses and for the precession constant. The Ephemeris Time Scale prior to the 1976 redefinition does not differentiate between coordinate and proper time and, while defined based on the Sun, it is determined from observations of the Moon. The location and motion of the equinox utilized for the different bodies varies and it is determined basically only from observations. The theory of nutation is recognized as having inadequacies which can cause periodic errors in the observations.

TABLE 1.

Current Average Observed Minus Ephemeris Differences

	Right Ascension s	Declination "
Mercury	+0.14	-0.3
Venus	+0.10	-0.1
Mars	-0.12	0.0
Jupiter	-0.03	+0.3
Saturn	0	-0.3
Uranus	+0.03	-0.2
Neptune	-0.48	+0.8
Sun	+0.10	+0.1

Note: These values are based on observations obtained with the Six-inch Transit Circle of the U. S. Naval Observatory during the 1975-6 period.

TABLE 2

Known Differences between Published Ephemerides and Observations

Planet	Discrepancy and References
Earth	The longitude may be in error by $0''.5$
Mars	Right ascension may be in error by as much as $0^{s}.2$ at opposition
Jupiter	Periodic errors reaching about $0''.3$ in longitude and $0''.5$ in latitude (Klepczynski et al, 1970)
Saturn	Periodic errors reaching about $0''.5$ in longitude and $0''.7$ in latitude (Klepczynski et al, 1970)
Uranus	$-0''.3$/century secular error in latitude (Duncombe & Seidelmann, 1978)
Neptune	Secular runoff in longitude, $-6''.0$ in 1975; periodic error in latitude (Duncombe & Seidelmann, 1978)

THE NEW FUNDAMENTAL EPHEMERIDES

Recognizing the current deficiencies in the published ephemerides, an effort was initiated to correct the fundamental ephemerides for the annual national publications. The first step in this effort was the determination and adoption of a new set of astronomical constants, representing the best values currently available; a revision of the ephemeris time scale, which acknowledges the availability of atomic clocks and the existence of relativistic theories; and a new definition of the standard epoch, equinox and fundamental reference frame, which is necessary for the preparation of the FK5. This step was accomplished at the Sixteenth General Assembly of the IAU (Grenoble, 1976; Duncombe et al, 1977).

It was recognized at that time that several other matters require correction and should be changed, if possible, with the introduction of the new system of constants, new ephemerides and the FK5. These matters include the theory of nutation, which is currently based on a rigid Earth model and has errors with respect to observations which can accumulate to $0^{s}.007$ in right ascension. For this purpose a Working Group on Nutation was established by Commission 4 and it is expected to submit a report and recommendations at the 1979 General Assembly of the IAU. Additionally, Commissions 4 and 16 have established a Working Group on Cartographic Coordinates and Rotational Elements of Planets and Satellites to recommend the definitions and values of the physical ephemerides for the Sun, planets and satellites. Also, it will be necessary for the IAU in 1979 to adopt the location of the equinox and equator for the FK5.

Given the new constants and definitions, new fundamental ephemerides can be prepared. Bearing in mind the widespread interest and participation in this work by such institutions as the Astronomisches Rechen-Institut, Bureau des Longitudes, Her Majesty's Nautical Almanac Office, Institute of Theoretical Astronomy, Japanese Hydrographic Office and the University of Tokyo, Jet Propulsion Laboratory, U. S. Naval Observatory, and others, several guiding principles have been established. First, we do not wish to have published ephemerides based on an isolated or single computation. Rather, we are seeking to have available several sources of the ephemerides, calculated by different methods and techniques so that intercomparisons can be performed to ensure the accuracy, rather than the internal precision, of the published ephemerides. While the different ephemerides may not agree completely, we should understand the cause of the difference and specify the assumptions and theory underlying the published values. Second, all available observational data with appropriate weighting should be utilized, directly or indirectly, in the preparation of the ephemerides. Third, the bases, constants, theories and reference frame for all the ephemerides should be consistent and specified. Fourth, in addition to the ephemerides that are published to the required accuracy, machine readable ephemerides of greater precision, covering extended periods of time, both in the past and in the future, should be available.

In pursuit of these new ephemerides and of the specified objectives, the following activities are in progress at the USNO:

(1) The occultation observations from 1830 to 1955 have been collected and placed in machine readable form. A corrected star catalog of the Zodiacal Zone has been prepared for the analysis of the occultation data. The analysis will determine the values of delta T, i.e. the difference between Universal Time and Ephemeris Time over the period 1830 to 1955. Her Majesty's Nautical Almanac Office is cooperating in this project and has analyzed the same occultation data, employing the N30 star catalog, and determined delta T values over this period. The two partially independent analyses will be compared to provide a best set of values for delta T over the period.

(2) All planetary observations are being collected and systematically reduced to the FK4 coordinate system. The assistance of the observatories still making planetary observations has been sought in order to distribute the effort required and to facilitate the use of knowledge that is only available at the observing site. Emphasis is being placed on collecting the observations of the inner planets, at least back to 1900, and the outer planets back to 1830. Currently, all observations of Mars, Neptune, and Pluto are available based on investigations by Laubscher (1970), Jackson (1974), and Cohen, Hubbard and Oesterwinter (1967), respectively. All observations of Uranus, except from Greenwich have been collected and reduced to the FK4 by Jackson (USNO). Many of the observations of Jupiter and Saturn were collected at the same time as the Uranus observations. The observations of the Sun, Mercury, and Venus are being collected.

(3) A program for integrating in terms of elliptical elements has been developed by George Kaplan (USNO) and, by carrying increased precision for the mean anomaly and argument of perihelion, the precision can be increased on the computer such that it is adequate for all solar system objects for the time period of interest.

(4) A program of numerical integration of the Moon and planets in heliocentric coordinates has been pursued in collaboration with Dr. Claus Oesterwinter at the Naval Surface Weapons Center in Dahlgren, Virginia.

(5) The most recent Jet Propulsion Laboratory Development Ephemeris covering an extended period of time is available for comparison and will be utilized as one of the possible sources of the ephemerides.

(6) A program to determine highly precise ephemerides over a fixed period of time by means of Chebyshev polynomials has been developed by LeRoy Doggett (USNO). This independent approach to calculating ephemerides has already proven to be a very effective means of detecting signatures of imprecision in the other methods of calculating ephemerides. The differences in the methods are such that truncation, round-off, interpolation, insufficient step size and other discrepancies can be detected at the precision of several parts in 10^{13}, although the causes are not always obvious.

(7) An analytical manipulation system has been developed by K. F. Pulkkinen and T. C. Van Flandern (USNO) which is capable of performing algebraic processes on terms involving numerous algebraic factors and trigonometric terms with many angular arguments. This manipulation system has been used to calculate expressions for positions of the planets to limited precision (1' of arc), for a period of several centuries, and it is being used to calculate analytical partial derivatives for determining the corrections to the initial conditions.

(8) Previous investigations concerning the ephemerides of the outer planets have indicated the presence of unexplained systematic trends in the observational residuals (Duncombe and Seidelmann, 1978). Since this could be due to catalog errors in the previous reduction of the observational data, or to an unresolved problem in the fitting of the ephemerides to the observations, an early comparison of the observations of Uranus and Neptune was initiated. Also, T. Corbin (1977) investigated a daily correction approach for the Uranus and Neptune observations from the Paris Observatory in order to see if a significant improvement in the observational residuals could be achieved by such a painstaking and detailed reduction procedure.

(9) Numerical general theories are being attempted by Seidelmann (1977) using the methods of Musen and Carpenter (1963) and Carpenter (1963, 1965, 1966, 1966). By a combination of iterative and ordered calculations, the general theories for the inner planets are currently being developed, but it is likely that these theories will not be available in time for inclusion in the new ephemerides.

(10) The algebraic manipulator mentioned previously will eventually be utilized in an attempt to develop im-

proved planetary theories by means of the Airy method, whereby, based on the specified equations of motion, corrections are determined to a given, or approximate, theory.

(11) It is also planned that the algebraic manipulator will be used to develop analytical expressions for the planetary part of the lunar theory.

CONCLUSION

The progress in international cooperation, as reviewed here, continues to proceed toward minimizing the duplication of effort in computations, composition and printing of astronomical data. Publication of a single international astronomical ephemeris might be the eventual goal of this cooperation.

Currently, preparations are being made for a revised version of the Astronomical Ephemeris/American Ephemeris and Nautical Almanac, which involves cooperation among Germany, France, Great Britain and the United States and which will be printed only in the United States.

The various steps necessary for the computation and production of new fundamental ephemerides are in progress. New astronomical constants have been adopted and other changes will be proposed to the IAU in 1979. It is our aim and hope to introduce the FK5 and the new fundamental ephemerides, based on new and improved theories, into the national ephemerides of 1984.

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Trans. I.A.U.,	Assembly	
I, 159, 207; 1923.	Rome	1922
II, 18-19, 178, 229; 1926.	Cambridge, England	1925
III, 18, 224, 300; 1929.	Leiden	1928
IV, 20, 222, 282; 1933.	Cambridge, Mass.	1932
V, 29-33, 281-288, 369-371; 1936.	Paris	1935
VI, 20-25, 336, 355-363; 1939.	Stockholm	1938
VII, 61, 75-83; 1950.	Zurich	1948
VIII, 66-68, 80-102; 1954.	Rome	1952
IX, 80-91; 1957.	Dublin	1955
X, 72, 85-99; 1960.	Moscow	1958
XI, A, 1-8; 1962. B, 164-167, 441-462; 1962.	Berkeley	1961
XII, A, 1-10; 1965. B, 101-105, 593-625; 1966.	Hamburg	1964
XIII, A, 1-9; 1967. B, 47-53, 178-182; 1968.	Prague	1967
XIV, A, 1-9; 1970. B, 79-85, 198-199; 1971.	Brighton	1970
XV, A, 1-10; 1973. B, 69-72; 1974.	Sydney	1973
XVI, A1, 1-7; 1976. B, 31, 49-67, 1977.	Grenoble	1976

DISCUSSION

Aoki: What kind of relativistic theory are you using to make up the ephemeris?
Duncombe: Einstein.

Aoki: Which method do you want to use for ephemeris calculations, the analytical method or the numerical integral?
Van Flandern: We hope that the results by both methods will agree with each other.

Aoki: If not, which do you prefer?
Van Flandern: We will keep working until they agree.

Everhart: Has some thought been given to publishing velocities as well as positions in the ephemeris? With both positions and velocities available, then an investigator may use his own numerical integrator for values at desired times. The tabular interval for such position-velocity data could be large, say 200 days (1950.0 frame).

Van Flandern: The printed ephemerides are in polar coordinates, and not intended to serve that purpose. The machine-readable ephemerides provide such position and velocity data. Consideration will be given to including such a table in the printed volumes as well. It would be based on the equinox and epoch J2000.