THE SPECIFICATION OF NUTATION IN THE IAU SYSTEM OF ASTRONOMICAL CONSTANTS

G. A. Wilkins
Royal Greenwich Observatory

SUMMARY

The principal purpose of the IAU system of astronomical constants is to provide a self-consistent set of constants for use in the computation of the international ephemerides of the Sun, Moon, planets and stars and in the reduction of observations of these bodies. At present nutation is computed from a theory of the rotation of the Earth as a rigid body and only the coefficient of the principal term in obliquity is specified in the system of constants. Such a simple specification will not be adequate for use with the more precise observations that are becoming available, and it appears that it will be necessary to adopt a new model of the Earth and to develop a new theory of nutation which will take into account the elastic properties of the Earth. The new model should be consistent with other constants of the IAU system, and with the model used in other branches of geophysics. The new specification of nutation should be formally adopted by the IAU in 1979 so that it can be used in the published ephemerides for 1984 onwards.

INTRODUCTION

This paper is intended to provide a general introduction to IAU Symposium No 78 on "Nutation and the Earth's Rotation". One of the purposes of this symposium is to provide for the discussion of the problems involved in the development and adoption for international use of a new theory of the nutation of the Earth's axis of rotation under the action of perturbing forces. This paper attempts to outline the problems rather than to solve them; it is arranged in three parts: firstly, the purposes, development and structure of the IAU system of astronomical constants are reviewed; secondly, the technical requirements for the development of a new specification of nutation are discussed; and thirdly, possible procedures for the formal adoption of a new specification are suggested.

At the IAU General Assembly at Grenoble last year (IAU, 1977) the

E. P. Fedorov, M. L. Smith and P. L. Bender (eds.), Nutation and the Earth's Rotation, 1–7.

system of astronomical constants was revised, but the value of the constant of nutation was left unchanged. It was, however, recognised that there is a requirement for a new theory of nutation to be based on a new standard non-rigid model for the Earth, but that as a temporary measure it may be desirable to apply observationally-determined correction terms to the current series for the nutation, which is based on Woolard's theory (1953). The correction terms, and the new model and theory, would take into account the elastic properties of the Earth. Furthermore it was agreed that the nutation should be computed for an axis that differs slightly from that now in use. There was, however, no dissent from the suggestion that the recommendations concerning nutation should be amended later if the discussions at this Symposium indicate that this is desirable. Any proposals for such amendments and for the adoption of a new standard model for the Earth and a new theory of nutation will, however, need to be carefully drafted and circulated for comment before being submitted for adoption at the next IAU General Assembly in 1979.

THE IAU SYSTEM OF ASTRONOMICAL CONSTANTS

The development of the IAU system of astronomical constants is described in the Explanatory Supplement to the A.E. (NAO, 1977). Its origin lies in an agreement in 1896 to adopt certain values for a small set of fundamental constants for use in the computation of the international ephemerides of the Sun, Moon, planets and stars. The value 9ʺ.21 for the constant of nutation is still in use. It is not possible to define nutation unambiguously by a single constant, but it was decided by the IAU in 1948 to adopt the new series then being developed by Woolard at the US Naval Observatory. The number of recognised constants gradually increased but the theoretical relationships between them were not always satisfied.

At the IAU General Assembly in Hamburg a formally defined system of constants was adopted (IAU, 1965). In this system a distinction was made between defining constants, whose values are conventional or arbitrary, primary constants, for which exact values are adopted, and derived constants, for which the values are obtained by calculation from the defining and primary constants using known theoretical relationships. The previously adopted values of the constants of precession and nutation were confirmed since neither observation nor theory could then provide significantly better values of either constant.

At last year's IAU General Assembly at Grenoble it was decided that the IAU system of astronomical constants should be revised in readiness for the preparation of the new fundamental catalogue FK5 and of new improved ephemerides for publication in the almanacs for the years 1984 onwards. The 1976 system contains more accurate values of many of the constants and differs from the 1964 system in several other respects. Firstly, it gives explicitly the relationships between the astronomical units of length, mass and time and the units (metre, kilogram and second) of the international system (SI). Secondly, the choice of defining constants, primary constants and derived constants differs in a few cases. Thirdly, several constants for the orbit of the Moon have been omitted since they are no longer relevant to the determination of other constants of the system. In addition the IAU adopted several recommendations on related topics (the new standard epoch, the basis of FK5, the procedures for the computation of apparent places, time-scales for dynamical theories and ephemerides) and also a list of other values for use in the preparation of ephemerides.

In the 1976 system the astronomical unit of time is defined to be an interval of one day of 86400 seconds, where the second is defined in the SI system in terms of the frequency of a certain transition of the caesium atom. The day is no longer defined by the rotation of the Earth (mean solar day, as in 1896) nor even in terms of the revolution of the Earth around the Sun (ephemeris day, as in 1964). Correspondingly, the time scales to be used for the new ephemerides will be related explicitly to International Atomic Time (TAI) and will not be defined by either the apparent diurnal motion or the apparent orbital motion of the Sun.

The astronomical unit of mass continues to be the mass of the Sun, and the 1976 system gives as a derived constant the mass of the Sun in kilograms. This constant is only known to low accuracy since the constant of gravitation in SI units is not known accurately. It does, however, mean that a consistent value for the mass of the Earth in kilograms can be derived.

The astronomical unit of length (or distance) is expressed in metres as a derived constant in the 1976 system since it was considered that the observed value of the light time for unit distance should be a primary constant. The speed of light is also given as a primary constant, but it has a special significance since it is understood that its value will not be changed if the definition of the metre is changed.

The system contains the principal parameters of the size, shape and gravity field of the Earth. The values are new since the 1964 constants are no longer sufficiently accurate for use in, for example, the analysis of the lunar-laser-ranging observations; they are the currently representative estimates of geodetic parameters as recommended by the International Association of Geodesy in 1975. No attempt has been made to introduce a full set of parameters to define a standard model for the Earth, but we need a larger set of parameters to define an adequate model for use in the development of a new theory of nutation.

The system also contains the principal constants that define the relative orientation of the equatorial and ecliptic reference frames for use in astrometry and dynamical astronomy. These are the general precession in longitude, the obliquity of the ecliptic, and the constant of nutation, and all are given for the new standard epoch of

https://doi.org/10.1017/S0074180900031715 Published online by Cambridge University Press

2000. These constants are not sufficient to define unambiguously the motions of the equator, ecliptic and equinox, but a full set of formulae (with precise numerical values) for the precessional motions has been developed for this purpose by Lieske in collaboration with Fricke, Lederle and Morando (1976). We shall similarly need a formal statement of the results of the development of any new theory of nutation that is to be used in ephemerides and reductions. The new series for precession and nutation will be used for the re-reduction of past observations, but I doubt whether it will be worthwhile to publish the results of the evaluation of the series as was done in Nutation, 1900-1959 (NAO, 1961) when Woolard's theory was introduced.

The system includes new values for the masses of the Sun, Moon and planets, and these have been used in the development of the series for the precession of the equinox and the mean obliquity of the ecliptic.

One of the recommendations that was adopted in the new system was that in future the Julian century of 36525 days should replace the tropical century as the unit of time in the series for precession etc, and that correspondingly we should use a new system of Julian epoch in place of the Besselian solar year. A Julian epoch is to be denoted by a letter J followed by a numerical designation in the form of year and decimal of year and is to be given by

$$J2000.0 + (JD - 245\ 1545.0)/365.25$$

The new standard epoch J2000.0 will be used for the epoch from which time intervals in the new dynamical theories will be measured as well as for the epoch of the fundamental reference frame of the FK5 catalogue. It is the instant 2000 January $1^{d}.5$ in the Gregorian calendar. It was generally agreed that the convenience of making the epoch exactly one Julian century after Newcomb's epoch of 1900 January $0^{d}.5$ will outweigh the inconvenience of using noon rather than midnight.

THE REQUIREMENTS FOR A NEW THEORY OF NUTATION

The theory of nutation that is in current use in the international ephemerides is that of Woolard (1953). It assumes that the Earth is a rigid body whose rotational motion is disturbed by the gravitational actions of the Sun and Moon. The direction of the largest of the principal moments of inertia of the Earth is referred to as the axis of figure, and the other two principal moments are taken to be equal in the numerical development. The series that are taken to represent the nutations in longitude and obliquity are those given by Woolard for (a) the quasi-periodic motion in longitude of the true equinox of date with respect to the mean equinox of date and (b) the quasi-periodic variations of the obliquity of the true ecliptic of date with respect to the mean ecliptic of date. In effect this gives the nutation of the true pole of rotation with respect to the mean pole of rotation which has the smooth precessional motion. There is, however, considerable controversy as to whether the true pole should be the point chosen by Woolard or whether a different point should be adopted. At the IAU at Grenoble in 1976 it was recommended that: "the tabular nutation shall include the forced periodic terms listed by Woolard for the axis of figure in place of those given for the instantaneous axis of rotation, and the two calibrations performed by him shall be revised accordingly, taking account of the change in the adopted precession". The maximum change is less than 0".01 and is only of concern to a small number of specialists, but it appears to me that the new procedure will require changes in the meanings of terms that are commonly used in text books of astronomy. This meeting should therefore consider whether it can find suitable definitions for such terms as the pole of rotation, the true pole, nutation (forced and free), polar motion etc, that will accord with the new procedure and yet will not confuse non-specialists. It is important that all should be clear about the meanings of these terms and the significance of the ephemerides and observational results.

The second step is to adopt a set of parameters that will define a suitable model for the Earth. Ideally these parameters should define a standard model that will be used in all relevant branches of geodesy and geophysics. It may not however, be possible to wait until there is general agreement on the form and parameters of such a standard model. Instead, we may have to adopt a new model that will be sufficient only for the purpose of providing an adequate representation of the observed nutations. I hope, however, that any inconsistencies between this model and the full standard model will not be significant in the context of the study of nutation.

It is unlikely that we will be able to agree here about all the details of this model of the Earth, but it is desirable that we should attempt to specify the form of the model. For example, should we represent the distribution of mass directly, or indirectly by specifying the corresponding moments of inertia? How should we specify the elastic properties of the Earth? Is it sufficient to adopt a set of Love numbers?

The third step is to adopt new theories of the Sun and Moon that are responsible for the forced nutation. (I assume that the effect of the planets is quite negligible.) Woolard's theory is based on Newcomb's theory of the Sun and Brown's theory of the Moon. It is probable that these theories will be sufficiently accurate for this purpose, but it is desirable that the theories used for nutation should be formally the same as those used for the principal ephemerides.

Finally there remains the major task of developing the new theory of forced nutation on the basis of the new model Earth and new theories of the perturbing bodies. It is not clear to me whether or not this will have to be an iterative process. For example, we may need to compare the results of the new theory with observation before we can decide on the parameters of the model Earth. It seems desirable that the new theory should be free from empirical adjustments even if this means that the fit with observations is not as close as might otherwise be possible.

PROCEDURES FOR THE ADOPTION OF A NEW THEORY OF NUTATION

Before a new theory of nutation can be used in the international ephemerides we have to find the scientists who are willing and able to carry out the necessary technical developments and we have to obtain agreement to the adoption of the new theory. In the past it has often been the case that the availability of a new development has provided the impetus for its adoption as a new standard. We are now, however, faced with a situation in which the need for the new theory is clear and urgent since it is the intention that new and improved ephemerides of the solar system bodies shall be published in the principal astronomical almanacs for the year 1984 onwards. This in turn means that the ephemerides must be produced not later than 1980 so that they can be distributed for use in the computation of the other ephemerides that depend on them. The decision to adopt a new theory of nutation must therefore be taken at the IAU General Assembly which is to be held in Montreal in 1979. Detailed proposals must be ready for circulation to the members of the relevant commissions not later than the beginning of 1979 since it is desirable that there be real opportunities for comment and amendment before the formal vote is taken. The IAU (1976) system of astronomical constants and the related recommendations were the results of several successive improvements to circulated drafts. The proposals for nutation will not be so complex nor so far reaching in their consequences, but we should take all reasonable precautions to ensure that they are free from error and ambiguity and that they will stand the test of time.

The proposals should be prepared by a small working group and this group should aim to meet in the middle of 1978. This will allow a year for technical development and consultation by informal discussions and correspondence before the attempt is made to draft the specifications of the new model of the Earth and of the theory to be used. There will then be a few months for circulation of the draft to other experts before the proposals are circulated to all concerned.

It may not be possible to develop the new model and theory in the time available to us, since there may be unforeseen technical difficulties or scientists with the necessary expertise may not be able to devote sufficient attention to the problems during the next year. If this proves to be the case then it will be necessary to adopt empirical corrections to the present theory in order that the ephemerides may correspond more closely to reality. These corrections should be based on the results of a comparison of observations and ephemerides, but the form of the corrections should be such that the corrected series are likely to correspond closely to those that will be obtained from a new theory. I doubt whether this meeting will be able to come to a firm decision about whether it will be possible to develop a new theory in

https://doi.org/10.1017/S0074180900031715 Published online by Cambridge University Press

time, or whether it will be necessary to adopt empirical corrections. We must however, look at both options and give the working group the opportunity of a fall-back position.

CONCLUSION

In this paper I have tried to set the scene for the discussions that will take place during the next few days. I have deliberately avoided any attempt to put forward technical proposals since I know that there are many here who are much better fitted to do this. Similarly I have not attempted to review the physical interpretation of the observational data that are now available on nutation and the rotation of the Earth. Rather I look forward to hearing about your proposals and interpretations and I hope that by the end of this meeting we will be able to reach a consensus on how to proceed to the further improvement of the IAU system of astronomical constants so that it will better fulfil its purpose of providing a sound basis for new ephemerides and for the reduction of observations.

POSTSCRIPT

Preprints of this review paper were distributed at the Symposium, together with a copy of the summary of the IAU (1976) system of astronomical constants which had just been published in IAU Information Bulletin no. 37. A few minor changes have been made to the text. The oral presentation of the material was based on the use of some 20 viewgraphs which summarised the main points of the paper. The problems of the choice of reference axis and the adoption of a new series for the forced nutation were discussed intermittently during the following three days, but it was not until the last session that there was an extended discussion on these points. This discussion is reported on and the adopted resolutions are given at the end of this volume.

Since the paper was drafted Kinoshita (1977) has published a new theory of the rotation of the rigid Earth; although he uses a different approach he obtains results that are in substantial agreement with those of Woolard.

REFERENCES

IAU: 1965, "Trans. Int. Astron. Union", 12B (1964), pp. 95, 593-8.
IAU: 1977, "Trans. Int. Astron. Union", 16B (1976), pp. 53-64.
Kinoshita, H.: 1977, "Celestial Mechanics", 15, pp. 277-326.
Lieske, J.H., Lederle, T., Fricke, W. and Morando, B.: 1977, "Astron. Astrophys.", 58, pp. 1-16.
NAO: 1961, "Royal Observatory Annals", no. 1.
NAO: 1977, "Explanatory Supplement to the Astronomical Ephemeris ...", 4th impression, Her Majesty's Stationery Office, London.
Woolard, E.W.: 1953, "Astron. Papers. Amer. Ephemeris ...", 15, pp. 3-16

https://doi.org/10.1017/S0074180900031715 Published online by Cambridge University Press