ASTRONOMICAL AND "ASTRODYNAMICAL" VALUES OF CONSTANTS AND EPHEMERAL DATA (1)

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RÉSUMÉ. — L'auteur présente ses vues sur les diverses utilisations des constantes astronomiques par les services des éphémérides et dans les problèmes de calcul des trajectoires spatiales.

ABSTRACT. — The author comments upon the different needs of the astronomical constants in ephemeris work and space trajectory computations.

ZUSAMMENFASSUNG. — Verf. erläutert die verschiedenartigen Erfordernisse der astronomischen Konstanten in der Berechnung von Ephemeriden und von Raumbahnen.

Резюме. — Автор комментирует различные применения астрономических постоянных службами эфемерид и в вычислениях траекторий в пространстве.

Precision space navigation is developing a significant and ever-increasing need for better values of certain physical constants, and for better values of ephemeral data on planets and satellites, and also for better understanding of their use in conjunction with various systems of units. The needed values we shall refer to tentatively as " astrodynamical values " in order to distinguish them from " astronomical values " as follows :

In the construction of astronomical almanacs and ephemerides we are interested primarily not in what we may know to be currently the best theories, the best values of constants, or the best ephemeral data, but in a consistent set of theories, constants, and ephemerides that will make possible the use of many decades of observation in the ultimate

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determination of improved theories, improved constants, and improved ephemerides. In astrodynamics, on the other hand, we are concerned with both constants and ephemerides that agree with the most recent observational data. For the constants this concern implies a continual updating; for the ephemerides it implies the use — anathema to the astronomer — of empirical corrective terms. These should be designed to introduce recent observational data, however, without destroying the dependence of the mean motion, for example, upon long-term astronomical theories and observations.

Consistency is only a secondary problem to precision space navigation, as may be illustrated by the problem of navigating a vehicle to a specific point on the Moon. The trajectory calculation should employ the best available values of the geocentric gravitational constants and the best data on the motion of the Moon, without requiring that the gravitational constants and the positions of the Moon be consistent, although either may have contributed to improving the other. The last possibility makes it important, of course, that we reexamine periodically the basic relationships or constraints between the constants in which we are interested, with an eye both to improving any that will lead to an improved value of a constant, and to discarding those that are no longer important.

The needs of space trajectory work are closely akin to the needs encountered in the observational determination of an astronomical constant, as in the determination of the solar parallax or related quantities from radar observations of Venus. In both areas we are concerned with where the planet and the Earth are at specified times, without reference to the consistency between earlier positions and the current positions, except insofar as the former give information about the latter.

In fact, the Venus-radar determinations of the solar parallax are an excellent illustration of the need for attention to " astrodynamical values " of constants and ephemeral data as well as " astronomical values " thereof. In the phrase " determinations of the solar parallax " I include what have been called incorrectly " determinations of the astronomical unit " — incorrectly unless this phrase is recognized as loose usage for " determinations of the ratio of the astronomical unit to the kilometer " — and still further I include the probably even more important determinations of the ratio of the astronomical unit to the light-second. For the present, of course, we may speak conventionally of the " kilometer " and include in it the concept of the light-second, since the ratio of the latter two has been known far more accurately than the solar parallax or the two ratios it implies — but it should be remembered that, because of the nature of radar " range " and " range-rate " observations, the kilometer may cease to be useful as an intermediary and so in time may be replaced entirely by the light second.

Originally there were two extremes of thought on ways of utilizing radar observations for the related problems of navigation and determination of the solar parallax. One extreme, not now held seriously by anybody, I believe, maintained that the two problems could be solved totally by radar observations alone, without reference to astronomical tables. The other extreme, pointing out with justice that a short series of observations of whatever character cannot accurately determine the semi-major axis (or the related period or mean motion), or probably other long-period effects such as the coefficients of secular and long-period perturbations, for any of the objects involved, advocated a dependence upon astronomical ephemerides, and the improvement thereof. Thus R. L. Duncombe's excellent work on the correction of the ephemeris of Venus assumed immediate and well-merited importance.

I have been advocating for some time a compromise between these two extremes, for example at the Douglas Space Age Astronomy Symposium in Pasadena, 1961 August 7-9, and still earlier in informal discussions at JPL and elsewhere. In its simplest form such a compromise would involve the use of a selected set of recent observations, both radar and optical, to correct differentially and statistically the orbital elements of the objects involved, and other relevant constants, except such as are better determined in other ways, e. g., the velocity of light, the Gaussian gravitational constant, or especially the ratios of the semi-major axes of the planetary orbits to the astronomical unit. In short the compromise proposes to obtain positions and velocities of the objects involved that are based upon the best available sources of information, whether these be recent observations or long-term theories.

The history of the JPL reductions of Venus observations to values of the solar parallax, and associated developments, if we may omit details on the diameter of Venus, the reflection by its atmosphere, the electronic considerations, etc., goes somewhat as follows :

(1) The earliest JPL determinations were based upon the Newcomb ephemeris.

(2) These determinations were then improved by the introduction of Duncombe's corrections to the orbit of Venus.

(3) Because the " range-rate " observations required planetary velocities, which cannot be determined with high accuracy by numerical differentiation of position data from the almanacs, JPL elected to obtain these velocities from numerical integrations fitted to the planetary tables by least-squares. It is to be noted, also : (*a*) that this process had the very great virtue that it also corrected the ephemerides for errors in the coefficients of short-period terms arising from neglect or errors in the original computations, and (*b*) that short-arc integrations,

as over the several months of the observations, would actually down grade the accuracy of semi-major axes and other long-range effects.

(4) Recognizing point (3 *b*), JPL has extended its integrations to arcs of 10 or 20 years.

The next step in the reduction of these Venus radar observations, I believe (as you may infer from my foregoing remarks), is the least-squares adjustment of the JPL ephemerides to fit current observations rather than the astronomical ephemerides, but without discarding the long-term values thereof. This is the step that will produce " astrodynamical ephemerides " rather than " astronomical " ones.