A STUDY OF HIGH-PRECISION GEOCENTRIC AND INTERPLANETARY ORBITS

TECHNICAL STATUS REPORT

by

SAMUEL HERRICK

UNIVERSITY OF CALIFORNIA
DEPARTMENT OF ENGINEERING

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Grant No. AF-AFOSR-241-64

Applied Mathematics Division
AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
OFFICE OF AERO SPACE RESEARCH
WASHINGTON, D. C. 20333

Department of Engineering
Astrodynamics Laboratory
University of California
Los Angeles, California 90024

June 30, 1965

Report to:

Major B. R. Agins
Applied Mathematics Division
Air Force Office of Scientific Research
Office of Aero Space Research
Temporary Building D
Fourth Street and Independence Avenue, S.W.
Washington 25, D. C.

From: Dr. Samuel Herrick, Principal Investigator

Subject: A Study of High-Precision Geocentric and Interplanetary Orbits

Contractor: The Regents of the University of California

Principal Investigator: Dr. Samuel Herrick

Grant Number: AF-AFOSR 241-64

Technical Status Report Number: 1965-1

Period: July 1, 1964 - June 30, 1965. (Extension was granted to June 30, 1966)

(Nothing patentable resulted from the research done under this Grant, which is to be continued for the period July 1, 1965 - June 30, 1966.)

CIRCULATION OF IDEAS - PUBLIC SERVICE:

We are in the process of revising our distribution list to include only libraries which over the years have requested our publications and recent or continuing participants as workers in the field of astrodynamics. We shall be glad to put any names your office may care to add to our list.

EDITORIAL WORK:

Because of the pressure of having to get ready his own material for publication, Dr. Herrick has cut down some participation in this aspect of public service. Dr. Robert M. L. Baker, however, continues his editing of the Journal of the American Astronautical Society, and reviews many papers.

CREDIT TO THE AIR FORCE GRANT

In all our publications and news releases we are being more careful to call attention to the fact that the work has been sponsored by the Air Force grant.

Recently we were gratified to learn that COMSAT chose Dr. Herrick's formula for the determination of the orbit of "Early Bird," as being the simplest and most accurate among those considered.

TECHNICAL STUDIES AND ARTICLES COMPLETED

Please note that for editorial reasons the numbers of the

Technical Studies have been changed from those in our report to you for the period May 1, 1963 to June 30, 1964.

1. "Single and Double Integration in the Method of Variation of Parameters." To be published in the Proceedings of I.A.U. Symposium No. 25, which took place in Thessalonike, Greece, August 19, 1964.

5. "Universal Variables". This has been published: Astronomical Journal, 70, No. 4, 309-315, May 1965.

8. "Quasilinearization", a study prepared by Mr. Robert S. Long while working under this contract, is being published in the proceedings of the IAU-COSPAR-IUTAM conference held in Paris, April 1965.

Minor Planets. Six ephemerides of minor planets were published last year by Ephemerides Minor Planets, M.P.C. and IAU Circulars. One of them led to the recovery of the minor planet 1948 OA, and its inclusion among the named planets (as "Toro"). This minor planet was found 11.9 million miles away from the Earth, but less than 11 seconds of arc from our ephemeris, by Dr. Elizabeth Roemer at Flagstaff, Arizona, in July 1964. Thanks to additional observation by Dr. Roemer and by Dr. J. Schubart at Heidleburg, Germany, its orbit is now well determined. Toro has been tagged by General Electric as a possibility for an asteroid capture in 1980. Ephemerides were also produced for (1566) Icarus, (1580) Betulia, and (1620) Geographos.

We are attempting to recover the minor planet 1948 EA which is still nameless. We computed an ephemeris which was published in IAU Circular No. 1904, and have not yet given up hope for its recovery.

TECHNICAL STUDIES IN PROGRESS

2. Differential Representation

Final editing of first paper not yet complete. Extension to the orbit methods of Lagrange, Gauss, Gibbs complete in theory and practical formulation; to be written for publication.

3. Orbits from Unassociated Observations

The Air Force SPADATS regularly receives observational data which cannot be readily associated with any known satellite orbit. The possibility has important consequences that these observations belonging to a heretofore unknown satellite. A method for analyzing such data has been developed to determine if some of it belongs to such an object. Only radar fix data (i.e. angular position and slant range) and circular orbits are considered in our first study.

The solution was divided into two parts. First the observations were separated for checking purposes according to their agreement with pre-selected orbit planes. Following the plane-check a longitude test was made in an attempt to determine if the observations that were lying close to the same plane might belong to the same object. Thus an effort was made to eliminate much of the data from consideration at the outset, leaving only a handful of points for more thorough final analysis. A special feature of the method is that it avoids giving priority to particular observations, since none are used as reference points.

We wrote a program for this method and made computations on the IBM 7094, which showed no errors for several cases using simulated data, and coincided with formerly made hand calculations. We have just completed the work involved in changing the unassociated observations program from Fortran II to Fortran IV. In the process, we revised the program with the objective of making it more efficient timewise. The program is meeting the primary requirements: simulated observations have been satisfactorily separated and associated with specific orbits. We are now attempting to obtain real SPADATS satellite observations for further testing of the theory.

4. Preliminary Orbits from Range and Range - Rate

The complete development of a theory for the determination of a preliminary orbit for an Earth satellite from single-pass range data or range-rate data has been fully developed. There will be added refinements in Dr. Herrick's final correction. Programming and computations are progressing satisfactorily.

5. Universal Variables

Additional studies are being formulated.

6. Reference Data for Space Trajectories

This extensive study is more than an updating of "Gravitational and Related Constants for Accurate Space Navigation" (paper presented by Dr. Samuel Herrick at the Proceedings at the 8th International Astronautical Congress in Barcelona in 1957)*. It is in addition a thoroughgoing development of a system for continuous

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* Herrick, S., Baker, R. M. L., Jr. and Hilton, C. G. (1958) Proceedings at the 8th International Astronautical Congress, Barcelona, pp.

updating of astrodynamical reference data, and of the bases therefor. The I.A.U. values of the astronomical constants are being adopted for reference values even though we judge that they were too timid in certain instances, in the light of modern determinations. The immediate problem of obtaining up-to-date values of these constants is solved by supplying correction formulae and also the best correction-and-uncertainty factor that can be estimated currently. The reports will also supply a solution to the further problem of providing a means for updating the I.A.U. values, which we estimate will be necessary in ten years, rather than the seventy-five anticipated by the committee.

Calculations thus far of the relative corrections and relative uncertainties (our "correction-and-uncertainty factors") of various astronomical constants, relative to values adopted in 1964 by the International Astronomical Union, include those for: the ratio of the astronomical unit to the kilometer, the velocity of light, the equatorial radius of Earth, the dynamical form -factor for Earth, the geocentric gravitational constants, the ratio of the masses of Moon and Earth, the solar parallax, the ratio of the astronomical unit to the light-second, the heliocentric gravitational constants, the ratio of the masses of Sun and Earth, and the ratio of mass of the Sun to that of the Earth-Moon system.

In the process compilations have been made of experimental values of the ratio of the astronomical unit to the kilometer, and of the velocity of light, in order to obtain weighted means of these values.

Special attention is being given to the several constants that describe the earth's size, shape, and gravitational field. Clairant's

equation and related formulae, some of them new, are being redeveloped, with increasing complexity, for the ellipsoid of revolution, the spheroid of revolution, and the general spheroid, in order to provide unambiguous relationships between the satellite gravitational field and terrestrial gravity surveys.

7. Numerical Analysis

The first study in this area is concerned with the Gauss-Jackson second-sum integration procedure, using both the backwards difference and the central difference equations. The purpose of the investigation is to determine the easiest and most accurate way to begin and continue a numerical integration table. Ease of programming, accuracy, and total computer running time will be compared and used as criteria of usefulness.

Investigations are being made to determine the best starting and re-starting procedures. Work is continuing satisfactorily, but is not yet completely ready for the computer. The completed portion of the program has been checked by integrating the sine function. The Runge-Kutta integration formulae are being included in the investigation of starting procedures, but, recognizing that existing such procedures are defective, we are developing corrective techniques that may be used with Runge-Kutta procedures as well as simpler ones. A subroutine to change the step size will also be incorporated with the integration program package.

After this work is completed, we anticipate writing the whole study in publishable form.

Other studies in this area will include the stability of integration formulae, and the smoothing of observed data.

8. Partial Differential Coefficients and Quasilinearization

Dr. Herrick and Ken Ford are working, independently of Mr. Long's efforts reported above, but utilizing them, to establish the relationship of quasilinearization to differential correction and to compare the processes. First indications are that quasilinearization is 6/7 identical with one of the differential correction processes, and that the remaining 1/7 is at least "provocative"!

9. Launch Dates for Flyby of Mars and Venus

A theory has been developed for the seeking of launch dates from the Earth that will permit a vehicle to fly-by both Mars and Venus on the same trip, and subsequently return to the Earth. The solution of the problem presented here differs from other approaches to the problem in that the turn-angles about Mars and Venus are included in the preliminary seeking of the launch dates. This approach to the problem will reveal heretofore undiscovered favorable launch dates for the dual planet flyby. The solution evolves into a parametric-type study.

After the initial thrusting phase at the Earth, the mission is carried out without further thrust. Coplanar orbits are assumed for the planets, as well as negligible time of planetary encounter for the vehicle, i.e., the time spent on the planetocentric hyperbolic orbit.

The entire theory has been programmed for the IBM 7094. The program produces the known flyby dates in 1971 and 1972, but no attempt has been made yet to extend the dates past 1972. We are planning during the first quarter of this year to extend fly-by dates past 1980.

10. Notation

This production of a reference list of astrodynamical notation, usage, and terminology has the philosophy that it should recognize usage, rather than attempt to legislate it, but should not hesitate to express opinions and make suggestions. The introduction has an essay on periselenopedantry, which should be welcome to those who can do without such clear-as-mud terms as cytherean, areodesy, and perichronian.

I. SUMMARY OF PUBLICATIONS (Samuel Herrick)

170. The geocentric gravitational constant from radar and angular observations of the Moon. Astrodynamics Research Report No. 17. Lockheed-California Company. July 1963.

171. Elements and 1964 ten-day ephemeris of 1580 Betulia. (With Mary P. Francis) Ephemerides Minor Planets, 1964, 41, 128. (Leningrad, 1963).

172. 1965 ten-day ephemeris of 1566 Icarus. (With Kenneth C. Ford) Ephemerides Minor Planets, 1965, 5, 12, 41 and 140. (Leningrad, 1964).

173. 1965 close-approach ephemeris of 1620 Geographos. (With Kenneth C. Ford) Ephemerides, Minor Planets, 1965, 5, 12, 42 and 140. (Leningrad, 1964). I.A.U. Circular No. 1889-90, January 22, 1965.

174. 1965 ten-day ephemeris of 1620 Geographos. (With Kenneth C. Ford). Ephemerides Minor Planets, 1965, 5, 12, 42 and 140. (Leningrad, 1964.)

175. Elements, ephemeris, and opposition of 1948 OA. (With Kenneth C. Ford). M.P.C. 2323, August 1, 1964; H.A.C. 1651, June 29,1964.

176. Ephemeris of 1566 Icarus. (With Kenneth C. Ford). M.P.C. 2323, August 1, 1964.

177. 1966 ephemeris of 1566 Icarus. (With Kenneth C. Ford). Ephemerides Minor Planets, 1966, 5, 102. (Leningrad, 1965).

178. 1966 elements of Icarus, Geographos, and Betulia. (With Kenneth C. Ford.) Ephemerides Minor Planets, 1966, 41 - 42. (Leningrad, 1965).

179. Ephemeris of 1580 Betulia. (With Kenneth C. Ford). M.P.C. 2345, February 15, 1965.

180. 1965 close-approach ephemeris of 1620 Geographos. (With Kenneth C. Ford). M.P.C. 2345-46, February 15, 1965. This ephemeris is an extension of #173.

181. Ephemeris of 1948 OA. (With Kenneth C. Ford). M.P.C. 2346-47, February 15, 1965. This ephemeris is an extension of #175.

182 Ephemeris of 1948 EA. (With Kenneth C. Ford). I.A.U. Circular 1904, April 26, 1965.

183. Ephemeris of 1566 Icarus. (With Kenneth C. Ford). I.A.U. Circular 1910, June 8, 1965.

184. Universal Variables. A.J., 70, No. 4, 309-315, May 1965; cf. errata in A.J., probably No. 6 or No. 7, July, August or September 1965.

Single and Double Integration in the method of Variation of Parameters. To be published in the Proceedings of I.A.U. Symposium No. 25, which took place in Thessalonike, Greece, August 19, 1964.

II. SUMMARY OF MEETINGS ATTENDED AND PAPERS PRESENTED

Dr. Samuel Herrick, Principal Investigator, attended the following scientific meetings and presented papers by special invitation:

August 14 - 17, 1964:

I.A.U. SYMPOSIUM No. 25, Thessalonike, Greece.

Dr. Herrick was an invited participant. He presented a paper on: "Single and Double Integration in the Method of Variation of Parameters." This paper will be published in the Proceedings of the I.A.U. Symposium No. 25.

August 25 - September 1, 1964:

I.A.U. XII Meeting of General Assembly. Hamburg, Germany.

April 20 - 23, 1965:

I.A.U.-COSPAR-IUTAM SYMPOSIUM, Paris, France on "Trajectories of Artificial Celestial Bodies as Determined from Observations."

Dr. Herrick presented a paper on: "Universal Variables", a summary of which was published in A.J., 70, No. 4, 309-315, May 1965.

Dr. Herrick also attended many of the meetings of the AIAA Board of Directors and the Technical Activities Committee while serving his term as member of the Board and of various committees.

III. ADDITIONAL INFORMATION

Personnel who have engaged in research work during the period of the Grant, from July 1, 1964 to June 30, 1965:

Dr. Samuel Herrick	Principal investigator (no financial compensation) July 1, 1964 to June 30, 1965.
Dr. Robert M. L. Baker, Jr.	Associate investigator (no financial compensation) July 1, 1964 to June 30, 1965.
Dr. Raimundo O. Vicente	Associate Research Astronomer (no financial compensation) May 17, 1965 to June 30, 1965.
Mr. Kenneth C. Ford	Research Assistant (50% time) July 1, 1964 to June 30, 1965. (From August 1964 paid by University laboratory account) (35% time).
Mr. Michael S. W. Keesey	Research Assistant (50% time) July 1, 1964 to June 30, 1965. (From August 1964 paid by University laboratory account 35% time).
Mr. Chu-chin Peng	Research Assistant (50% time) July 1, 1964 to June 30, 1965
Mr. James A. Adams	Research Assistant (50% time) July 1, 1964 to February 28, 1965.
Miss Keiko Watanabe	Secretary-Steno to the investigator July 1, 1964 to June 30, 1965.

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