7. CELESTIAL MECHANICS (MÉCANIQUE CÉLESTE)

PRESIDENT: G. N. Duboshin.
VICE-PRESIDENT: P. J. Message.
ORGANIZING COMMITTEE: G. A. Chebotarev, A. Deprit, M. Davis, G. E. Giacaglia, Y. Hagihara, J. Kovalevsky, Y. Kozai, V. G. Szebehely, F. Zagar, J. Schubart.

INTRODUCTION

Up to the recent past, approximately to the first half of the 20th century, celestial mechanics represented a rather unpopular field of astronomy and an even less popular field of science in general.

The few experts in celestial mechanics were occupied almost exclusively with the motion of celestial bodies in the solar system, spending a lot of their time and trouble on cumbersome and time-consuming mathematical calculations with logarithms and primitive hand-arithmometers.

Problems of primary importance on celestial mechanics at that time were those of creating the tables of planetary, lunar and satellite motions and also that of the stability of the solar system.

The first problem was always significant for applications, whereas the second was of general interest.

Searcely anybody attempted the study motions of stars and stellar system, and if so, then only as abstract systems of mass points with arbitrary masses, which represented a purely mathematical problem related to the study of properties of solutions of certain sets of differential equations. In the second half of the 20th century the situation, as is well known, has radically changed. Launchings of artificial satellites round the Earth and later on round the Moon, Mars and Venus, flights of spacecraft and space stations in part of the solar system, and also future space flights to the stars required from celestial mechanics the immediate solution of totally different new problems which, in turn, brought about a rapid development in this field of astronomy as well as in theoretical mechanics.

Due to the high degree of accuracy required for space flight computations the classical solutions of the problems of the motions of the Earth, Moon, and other planets proved to be insufficient and this circumstance called for new, more precise theories of the motion of these natural bodies. On the other hand, the newly obtained data concerning the motions of artificial satellites and space vehicles offered opportunities of developping our knowledge about the dimensions, shapes and structure of celestial bodies, particularly of the Earth and the Moon, and at the same time to determine different astronomical constants with a high degree of accuracy.

The solution of the above problems was greatly aided by the use of electronic computers, which not only enabled one to carry out the high speed calculations needed for the solution of astrodynamical and celestial mechanics problems but also allowed one to advance and successfully solve entirely new problems which could not be solved by classical celestial mechanics at all (for instance, problems concerning the motion of a very great number of stars constituting a stellar system, including our own galaxy).

Finally, laser methods have recently been advanced and developed, providing direct determination of the distances from the Earth (later on from the Moon and other planets) to different artificial and natural celestial bodies, which required numerous observations and cumbersome calculations in the past.

This has resulted both in the increase of the amount of research in the field of celestial mechanics and in the number of scientific publications in different periodicals dealing with various aspects of this field of science.

The increase of the number of researchers in celestial mechanics can well be traced from the

https://doi.org/10.1017/S0251107X00024354 Published online by Cambridge University Press

number of the members of IAU *Comission 7* which is continuously uncreasing with each successive General Assembly.

At present Comission 7 has 80 members and this number will most likely reach 100 at the XVth Assembly in Sydney.

It should also be borne in mind that apart from IAU members many other scientists and researchers with backgrounds other than celestial mechanics are fascinated by and concerned with the problems of celestial mechanics. The number of these is extremely high and quite obviously greatly outnumbers the memebership of Commission 7.

The number of scientific publications on celestial mechanics and related branches of science (Astrodynamics, Theoretical Mechanics, Mathematics) is certainly very numerous and can hardly be appreciated accurately. It should be noted, however, that some years ago, on the initiative of a group of researchers in celestial mechanics from different countries, a special journal was established – *Celestial Mechanics*. The aim of the journal was to publish manuscripts concerned with the mathematical, physical and computational aspects of this branch of science and related fields. During the four years of its existence six volumes have appeared, each containing 4 issues. The total number of scientific contributions published therein is nearly 300.

At the same time, publications on celestial mechanics appear regularly in several other journals on astronomy, mathematics, mechanics, physics and so forth.

It is therefore impossible to cite all authors concerned with celestial mechanics or indicate all the publications relating to this domain even for the last three years.

Thus, only a general account of recent advances in the field of celestial mechanics for the above period is given here, together with a list of scientific publications which, being far from complete, is based mainly on information sent at my request by the members of the Organizing Committee of Commission 7. I take the opportunity of expressing my deep gratitude to all those who kindly rendered me their essential assistance in compiling the report. At the same time, I regret the incompleteness of the report which is explained both by the fact that some members of the Organizing Committee were apparently unable to send in the required materials on time, and because I myself could not collect them for some reason or an other.

For the sake of convenience, the contents of the present Report falls into 3 parts, each with its own title. The first is entitled 'Analytical Celestial Mechanics' and deals with publications and methods providing an analytical solution of the problem, that is, by means of finite or infinite expressions of mathematical formulae in literal form enabling one to calculate the necessary quantities for any value of an independent variable (certainly at some interval) for predetermined numerical values of parameters of importance for a given problem.

The second part is named 'Qualitative Celestial Mechanics'. It discusses investigations of general properties of motion either in the absence of, or without considering the solutions of differential equations. These are, for instance, stability problems of particular solutions of the equations of motion, problems concerning the existence of periodic, asymptotic, collision or recessing solutions, as well as the problems of the desintegration of a material system, and so forth.

The third part, 'Numerical Celestial Mechanics', deals with both semi-analytical and purely numerical problems and methods requiring the use of electronic computers and giving numerical results.

It goes without saying that this division is rather arbitrary, as it is impossible to draw a clear distinction between these three parts, first, essentially, and secondly because many scientific investigations require a combination of methods falling into different parts in the above classification. Thus, the division proposed here should not be ascribed any methodological significance: it simply appeared to me to be the most rational one.

It is also noteworthy, that I do not at all deal with publications pertaining to the competence of other related IAU Commissions, such as 17, 19 and 20. The report would have otherwise been too lengthy and would have contained a repetition of parts of other reports. This report gives separately a list of monographs on which I have been able to obtain information, and which have appeared in the course of the last three years.

https://doi.org/10.1017/S0251107X00024354 Published online by Cambridge University Press

The list may prove to be incomplete and in this case I apologize to the authors of the books which have been missed out in advance.

The list of references is given a similar code as the list given by the late President of Commission 7, W. J. Eckert, but slightly simplified and abbreviated.

The code gives first the number of the Journal according to the list published in the Report for 1970, then follows the last digit of the year of publication, and then designation of the volume which contains the paper. For instance, the code 58 2 6 indicates that the article appeared in the journal *Celestial Mechanics* in the year 1972, Volume **6**.

1. ANALYTICAL CELESTIAL MECHANICS

Analytical methods for the investigation of motion of celestial bodies have been developped for theories of the motions of the major planets, of the Moon, of artificial satellites round the Earth, Moon, and other planets, as well as for other theoretical investigations.

Chapront (1) in association with a group of associates at the Bureau des Longitudes (Paris) is preparing the development of a literal planetary theory. Thus the theory may be applied to large values of the ratio of the semi-major axes, and is constructed with an accuracy up to the first degree of the masses of the four major planets. The secular terms have been obtained with an accuracy of the second order. In cooperation with Brumberg (1), Chapront has been constructing an analytical theory of the motions of the four major planets in purely trigonometrical form.

Morando has been carrying out a study of the long periodal terms of the Jupiter-Saturn system.

The important problem of critical inclinations and eccentricities in the general n-body problem has been investigated by Krassinsky (1). A new method of regularization relating to the integration of the equations of the major planets motions has been devised by Miachine (1). The effects in planetary motions caused by the application of the scalar-tensor theories of gravitation were treated by Finkelstein (1).

In constructing a unique analytical theory of planetary motions an algorithm for the computation of the first order inequalities in orbital elements has been devised with an accuracy of up to the 10th degree of eccentricities and inclinations (Krassinsky, 2; Pius, 1).

A comparison of Hori's theory with von Zeipel's to terms of the second order has been conducted by Hori (1).

Yusa (1) extended this comparison to the third order terms. Musen carried out a detailed investigation of secular perturbations in the motions of the major planets using a modification of Hill's method (Musen, 1). Henrard has developed a perturbation theory based on Lie's method (Henrard, 1).

Broucke presented the solution of the n-body problem by means of a power series technique analogous to that of Steffensen (Broucke, 1). Investigations by Petrovskaya in which the new expansions of the perturbing function are given, valid for any orbits including the intersecting ones, are also related to the planetary motion problem in the solar system (Petrovskaya, 1, 2). The properties of the above expansions have undergone detailed study. Danby devised a matrix technique for the perturbation theory utilizing regularization coordinates (Danby, 1). Garfinkel has carried out a complete study of an ideal resonance problem, given its general solution and applied it to some particular problems (Garfinkel, 1, 2, 3).

To this field may also be related investigations on the influence of the instability of the proportionality factor in Newton's law (Finkelstein, 1; Vinti, 1). The researchers cited below dealt with analytical investigations of separate celestial bodies in the solar system. Laubscher (1) investigated the motion of Mars. Nacozy (1) studied the theory of Pluto's motion. The theory of the Moon's motion was treated by Musen (2), Griffiths (1) and Bourne (1). Analytical theories of the motion of natural satellites of major planets have been developed by Orlov (1, 2, 3) for the remote satellites of Jupiter, by Elmabsout (1) for the satellites of Saturn, by Saguier (1) and Mello (1) for the Galilean satellites of Jupiter, by Duncomb (1) for Uranus, and so forth.

It is appropriate to note that at present the construction of theories of motion for the natural satellites of major planets is closely connected with some astrodynamical problems.

https://doi.org/10.1017/S0251107X00024354 Published online by Cambridge University Press

Indeed, the investigation of interplanetary space, natural planetary satellites included, by means of automatic space stations, demands sufficiently precise information concerning the motion of planetary satellites. On the other hand, observations obtained by space stations yield a more exact definition of our knowledge both about planetary satellites and their motions.

Consequently, astrodynamics, that is the part of celestial mechanics dealing with the study of the motion of artificial bodies launched from the Earth, is of utmost importance in modern celestial mechanics and the number of investigations in this field is rapidly increasing. In the above field we should like to emphasize first of all the investigations concerned with the theory of the gravitation potential of the Earth and the Moon since the main force governing the motion of artificial satellites is that of the gravitation of an inhomogenous non-spherical body. Here the expansion of the perturbing function of a non-spherical body for an arbitrary reference plane has been derived by Brumberg (25), Evdokimova (1), Kochina (1). Investigations of properties of the classical expansion of a three-dimensional body potential into spherical functions were carried out (Kholshevnikov, 1).

Kholshevnikov (2) has also continued his investigations on the representation of the gravitational potential of the Earth by means of the field of the system of points.

Vinti's study (1) also pertains to the investigation of the gravitational potential of the Earth. It should also be noted that several investigations related to the represention of the potential of a gravitational body by expansion into Lame's functions have appeared (Walter, 1, 2). This will undoubtedly be of great importance for astrodynamics in the future.

Many investigations concerned the construction of analytical theories of motion of artificial satellites in the gravitational field of an oblate planet (either the Earth or the Moon).

Batrakov (1) derived analytical expressions for the perturbations of orbital elements from zonal harmonics of the Earth's potential with an arbitrary index and for any eccentricity. Analytical expressions of perturbations from tesseral harmonics have been obtained by Batrakov (2) and Filenko (1, 2). Deprit (1) and Rom (1) have developed a detailed analytical perturbation theory for the motion of an artificial satellite from the second harmonics of the Earth's potential.

Kovalevsky and his associates have also greatly contributed to the above problem (Kovalevsky, 1; Morando, 1; Challe, 1; Laclaverie, 1; Berger, 1, 2; Cazenave, 1).

Fominov (1) investigated the motion of artificial satellites in the atmosphere of the Earth and constructed analytical theories of motion. Noskov (1, 2) treated the combined problem of the non-sphericity of the Earth and its atmosphere.

Nasonova (1) studied the influence of the third order terms on the second harmonic.

An investigation of long-period inequalities was carried out by Aksenov (1) and Noskov (3). Uralskaya (1) and Domozhilova (1) were also involved in the above-mentioned investigation.

A whole series of investigations have dealt with the study of the influence of solar radiation pressure taking into account the Earth's shadow effect on the motion of artificial satellites (Eremenko, 1; Polyakhova, 1; Vashkoviak, 1; Mello, 2; Moraes, 1; Kunitsyn, 1; Isaev, 1).

Remote satellites of the Earth have been investigated and analytical theories have been constructed; an appreciable effect of lunar or solar perturbations being considered (Batrakov, 3; Sokolov, 1; Uralskaya, 2; Chepurova, 1). Much research has been engaged in the problem of resonance in satellite motion (Batrakov, 3; Orlov, 1; Rappaport, 1; Garfinkel, 1; Allan, 1; Mello, 2; Martins, 1). In all cases the authors constructed analytical theories applying the new mathematical methods.

Analytical theory of interplanetary flight for the Earth-Moon case has been derived by Nacozy (2) who used Chebyshev's polynominals for this purpose. (Yarov-Yarovoy, 1 and Lancaster, 1) Yarov-Yarovoy based his investigations on Bernstein's polynomial theory (polynomials of best approximation). Some other influences affecting the motion of artificial satellites, for instance the tidal effect, have been treated by Musen (3) and Estes (1). In concluding this section, I should like to briefly refer to developments concerned with the analytical theory of the rotational motion of a satellite about the center of gravity as well as the theory of the translational-rotational motion, that is the simultaneous treatment of the translational motion of a satellite along its orbit and its rotation about the center of the masses.

https://doi.org/10.1017/S0251107X00024354 Published online by Cambridge University Press

It should be noted that the above branch of astrodynamics is not very popular amongst celestial mechanicians whereas scientists in the adjacent fields have contributed greatly to the subject.

The review of these developments will be confined here to listing the contributions by Brackwell (1, 2), Hitzl (1), Nahon (1), Lange (1), relating to the theory of the rotational motion of satellites both along circular and elliptical orbits, (Cohran's, 1) investigation on the theory of a satellite's rotation along an elliptical orbit, and some papers on the theory of the translational rotational motion, concerned mainly with the treatment of the most ordinary special cases when a moving body is of a simple structure and shape (Pascal, 1, 2; Osipov, 1; Shinkarik, 1) being, for instance, a one-dimensional spindle, a dumbbell, a disk and so on.

2. QUALITATIVE CELESTIAL MECHANICS

In the domain of qualitative studies on celestial mechanics the restricted circular problem of three bodies (which is the simplest after the classical two-body problem) dominates the field.

The problem, which was without any practical value till the second half of the twentieth century, later received extraordinary attention from theorists and mathematicians who were concerned with the problem of stability (in Lyapunov's sense) of the well-known libration points and from those engaged in the problem of the existence of periodic solutions, mainly in the plane restricted problem. At present, the restricted three-body problem is widely adapted in important practical applications to astrodynamics in connection with the study of the motion of artificial celestial bodies in the Earth-Moon and Earth-Sun systems. In view of the above, interest in this problem, as well as the number of investigations, has significantly increased. After the appearance of the famous investigations of Siegel, Kolmogorov, Arnold, Moser and Leontovich, the problem of stability of the triangle points of libration for the plane circular case was completely solved by Markeyev in 1969. Markeyev pointed out that for any value of the parameter μ, satisfying the condition $\mu(1-\mu)<1/27$ the triangle libration points are stable but for two special values of μ for which the above libration points are unstable. Subsequently, Markeyev (1) has shown that this result is valid for the spatial circular problem too. Thus, the problem for the circular restricted case of three bodies is solved completely.

Consequently, it became possible to turn to the investigation of the libration points in the elliptic problem (in the case of rotating coordinate axes, utilizing pulsating coordinates). The problem had already been solved by Lyapunov in linear treatment but till now many theorists were unaware of that fact. Later on the problem attracted the attention of many other researchers. For the period under review Szebehely (1), Giacaglia (1), Kinoshita (1), Tshauner (1), Vinti (1) continued to study the problem. The transition from the linear approach to the problem of stability of the triangle libration points to a non-linear one and especially to the non-linear spatial problem, proved to be more complicated, and though considerable primary results have already been obtained (Alfriend, 1; Markeyev, 1, 2) the problem as a whole, remains unsolved.

It is also of interest to note that no one but Lyapunov, who used the linear approach, investigated the problem of the stability of Lagrange's triangular motions in the general three-body problem.

Another problem of primary importance in this field (that is in the restricted problem of three bodies) is that of the search for and the proof of the existence and the analytical construction of various periodic solutions. The classical results in that field are presented and analyzed in the well-known book *Periodic Orbits* by Szebehely published in 1967. Since then, and especially for the last three years, various new original results of practical value have appeared. New families of periodic solutions of the first and second kind have been discovered and investigated by Giacaglia (2, 3), Shelus (1), Message (1), Tshauner (1), Alfriend (1), Meyer (1), Bruno (1).

In some of these papers a combination of numerical and qualitative methods is used.

Periodic solutions were also dealt with in some other problems of celestial mechanics that are of importance to astrodynamics. Thus, Delmas (1) established the existence and investigated the stability of periodic orbits in the problem of the motion of a satellite around a spheroid. Periodic and quasi-periodic solutions in the general plane three-body problem were attacked by Lieberman

(1). Modi (1) and Williamson (1) treated periodic solutions of the rotational satellite motion. Kinoshita (3) treated the problem of the motion of an axissymmetrical body under the attraction of a sphere and analyzed stationary solutions of the above problem. Žuravlev (1) was engaged in the investigation of the stability of the libration point of a homogenous triaxial ellipsoid and that of the existence of periodic orbits in the vicinity of such points.

In the *n*-body problem (mass points) mainly the stability questions of a given material system after Lagrange were treated as well as those related to the problem of the integral existence and the general characteristic of sets of differential equation in Hamiltonian form.

Kholshevnikov continued to study the stability problem of the solar system but the investigation is not yet completed and the results are yet to be published.

Merman (1) developed a method for the investigation of the stability of the Hamiltonian system with many degrees of freedom.

The general topological investigation of a differential equation set applicable to the three-body problem was published by Marchal (1). In another publication the above author (Marchal, 2) derived a sufficient condition for the complete disintegration (instability after Lagrange) of the *n*-body system. Szebehely (2) presented a precise classification of motions in the plane restricted problem of three bodies. Sperling (1) treated various collisions of binaries and multiples in the general *n*-body problem. Waldvogel (1) pointed out the possibility of a new regularization in the plane problem of three bodies. Irigoyen (1) and Nahon (1) treated the zero-energy case of the plane three-body problem. Henon (1) performed an extensive investigation, involving numerical methods of constructing the solutions of differential equations of celestial mechanics, in particular, for Hill's problem. Froeschle carried out a systematic investigation of the surface section method and studied also the nature of some solutions of the system with two degrees of freedom. Danby (2) treated transformations extending the domain of convergence of power series representing the solutions of celestial mechanics equations. Yoshida (1) improved Hilmi's and Merman's criterions for the case of hyperbolic-elliptical motion in the general 3-body problem. The dynamic evolution in the general many-body problem was investigated by Saari (1) and Wielen (1).

Finally, a few comments will be added bearing on Duboshin's investigations which may be related to analytical and qualitative celestial mechanics and which deal with the generalized problem of three- and *n*-bodies (material points and dimensional bodies) when the operating forces depend not only on the mutual distances but also on their derivative and on time. Here the conditions of the existence of the Lagrangian and Eulerian solutions are derived (Duboshin, 1) as well as those of the existence of the first integrals analogous to the classical ones (Duboshin, 2).

Duboshin had also investigated the Lagrangian and Eulerian solutions in the three-rigid-body problem (in press).

3. NUMERICAL CELESTIAL MECHANICS

By means of numerical integration of differential equations for a time interval of considerable length Duboshin and his associates have investigated the problem of the dynamical stability of Orion Trapezium (Duboshin, 3; Rybakov, 1, 2; Kalinina, 1, 2; Kholopov, 1, 2) and have discovered that the system is stable in Lagrange's sense, the latter being at variance with the known Ambartsumyan's conception.

Solovaya (1) has investigated the stellar problem of three-bodies for the case when one of the stars is very distant from the two others. Eneyev and his associates have studied numerically the evolution of a system containing a considerable number of stars (galaxies) due to the transition of a large star (Eneyev, 1; Kozlov, 1). Szebehely (4) has investigated numerically the influence of three material point masses on their motion.

In the study of the solar system numerical methods are generally combined with analytical ones. for which reason such methods are called semi-analytical. Below some results of the application of these methods will be given. Brumberg and Chapront have developed an algorithm for the electronic computation of the first order inequalities for the major planets in rectangular coordinates. This computational work is supposed to be completed in 1973.

The second order corrections relative to planetary masses to the Leverier-Laplace theory have been obtained (Brumberg, 3; Yegorova, 1). A computational method has been derived for obtaining the planetary perturbations of the first and second orders on electronic computers (Boudnikova, 1). A new version of Gylden's and Hansen's methods of specific anomalies has been worked out (Skripnichenko, 1) as well as a long-range modification of Brouwer's planetary method.

A method for the numerical integration of the equations of celestial mechanics based on Encke's conceptions has been derived (Batrakov, 4; Makarova, 1).

Krasinsky (3) has performed numerical integrations of the averaged motion equations of the major planets for 2000 years ahead. A joint integration of the motion equations of eight major planets has been carried out by Miachin (2).

The programming of the literal theory of the Moon's motion by Kovalevsky's method has been accompolished. The first computations with an accuracy up to the ninth order relative to the small values have been carried out (Kovalevsky, 2; Meyer, 1; Bec, 1).

A semi-analytical theory of the Moon's motion has also been constructed (Chapront-Tousé, 1). A numerical theory of the motion of Jupiter's ninth satellite has also been derived (Bec, 2; Edelman, 1; Polavieja, 1). Utilizing numerical methods and basing himself on a comparison with observational data, Bec (3) has defined more exactly the parameter values in the system of Saturn's satellites. Griffith (1) calculated the perturbations in the motions of the four inner planets caused by the five outer ones.

Oesterwinter (1) and Cohen (1) obtained a new system of orbital elements for the Moon and the major planets. Numerical methods are widely applied in the theory of motion of artificial objects but the majority of the investigations of that kind are beyond the scope of celestial mechanics and therefore they are not listed and analyzed in this Report.

Within the limits of celestial mechanics numerical methods are applied to astrodynamical problems mainly for checking the results obtained by means of analytical formulae as well as for finding the numerical values of the parameters of the systems under investigation by comparing analytical formulae with numerous observational data. On the other hand, numerical methods may also be applied in the numerical study of solutions of specific problems in celestial mechanics, such as the restricted problem three bodies in its astrodynamical aspect. In this respect, Kozai's publications are noteworthy.

He investigated numerically both stationary and periodic solutions in the restricted problem (Kozai, 1) and suggested a new semi-analytical method for computing the lunar perturbations in the motion of an Earth's satellite.

Kinoshita found numerically new types of periodic solutions both for the circular and elliptical problems of three bodies. Numerical methods were also applied widely by Bruno, Guillom and Markeyev in qualitative investigations reviewed in the second part of the present Report. Giacaglia (1) developed a semi-analytical theory of the motion of a lunar satellite. The collision orbits in the restricted three-body problem were derived numerically by Standish (1).

Finally, numerical integration has found a considerably wide application in the theory of the rotational motion of artificial satellites.

4. BOOKS

Абалакин, В. К., Аксенов, Е. П., Гребеников, Е. А., Рябов, Ю. А. 1971, *Справочное руководство по небесной механике и астродинамике*, Москва.
Anderle, P. 1971, *Zaklady Nebeske Mechaniky*, Praha.
Белецкий, В. В. 1972, *Очерки о движении космических тел*, Москва.
Брумберг, В. А. 1972, *Релятивистская небесная механика*, Москва.
Giacaglia, G. 1971, *Periodic Orbits, Stability, Resonance*, New York.
Гребеников, Е. А., Рябов, Ю. А. 1971, *Новые качественные методы в небесной механике*, Москва.
Hagihara, Y. 1970, *Theories of Equilibrium Figures of a Rotating Homogeneous Fluid Mass*, Washington.
Hagihara, Y. 1970, *Celestial Mechanics*, Vol. **1**, 'Principles and Transformation Theory', New York.

Hagihara, Y. 1972, *Celestial Mechanics*, Vol. **2**, 'Perturbation Theory', New York.
Herrick, S. 1971, *Astrodynamics*, Vol. **1**, 'Orbit Determination, Space Navigation, Celestial Mechanics', New York.
Herrick, S. 1972, *Astrodynamics*, Vol. **2**, 'Orbit Correction, Perturbation Theory, Integration', New York.
Siegel, C. L., Moser, J. K. 1971, *Lectures on Celestial Mechanics*, New York.
Stiefel, E. L., Scheifel, G. 1971, *Linear and Regular Celestial Mechanics*, Berlin.
Stumpf, K. 1973, *Himmelsmeckaniks*, Vol. **3**, in press, Berlin.
Thiry, Y. 1970, *Les fondaments de la mécanique céleste*, Paris.
Яров-Яровой, M. C. 1973, *Небесная механика и теория приближения функций*, Москва.

BIBLIOGRAPHY

Aksenov, E. P.	54 2 49 45 2 5
Altfriend, K.	53 0 3; 53 2 5
Allen, R. R.	53 0 2
Babadjanian, L. K.	49 1 5
Barrar, R, B.	53 0 2
Batrakov, Y. V.	49 1 12; 49 2 13; 53 2 6
Bec A.	41 0 2
Berger, K.	51 2 5; 51 2 5
Bettis, D. G.	48 1 14; 71 2 1
Bohme, S.	43 0 35
Boudon, Y.	51 2 5
Bourne, S.	53 2 6
Breakwell, J.	53 0 3; 53 0 1
Bretagnon, P.	51 2 2
Broncke, R.	53 2 5
Broucke, B.	53 0 3
Brumberg, V. A.	53 3 Pr; 53 1 3; 49 1 62
Bruno, A. D.	65 0 83
Budnikova, N. A.	49 1 62
Cazenave, A.	41 1 5
Challe, A.	41 0 3
Chapront, J.	41 0 7; 41 2 19
Chapront-Touzé	Pr.
Chepurova, V. M.	49 0 12
Chong-Hung Zee	53 2 5
Cohen, C.	53 2 5
Cohran, J.	53 2 6
Danby, M. J. A.	53 0 2; 53 2 5
Delmas, J.	40 – –
Deprit, A.	53 0 2; 53 0 3
Duboshin, G. N.	53 0 2; 53 1 4; 53 2 5; 53 2 6; 54 1 175
Edelman, C.	41 1 13
Egorova, A. V.	49 1 62
Elmabsout, B.	49 0 5
Eremenko, A. V.	90 1 28
Estes, R.	53 2 6
Evdokivova, L. S.	53 1 3; 49 3 62
Faintich, M. B.	53 2 6
Ferraz-Mello, M. B.	53 2 4; 52 2 274
Filenko, L. L.	49 2 13
Finkelstein, A. M.	49 1 62; 53 0 2
Fominov, A. M.	49 2 14
Garfinkel, B. M.	53 1 2; 53 2 5; 53 2 6
Garsia de Polavieja	41 1 16
Giacaglia, G.	42 9 74; 53 0 3; 53 1 4
Griffith, J.	53 1 4; 53 0 3; 53 2 6
Henon, M.	41 0 9
Henrard, M.	53 0
Hitzl, D.	53 0 3; 53 2 5
Hori, G.	80 0 22; 80 1 23
Hughes, P.	53 1 4
Irogoyen, M.	41 2 17
Isaev, V. N.	53 2 6
Jupp, A.	53 2 5
Kalinina, E. P.	54 1 173; 45 1 48
Kane, T. R.	53 1 4
King-Hele, D.	53 2 5
Kinoshita, H.	80 0 22; 80 2 24; 53 2 3
Kozai, Y.	53 2 3; 87 2 295
Kholopov, P. N.	54 1 175; 45 1 48
Kholchevnikov, C. V.	53 2 6
Kotchina, I. G.	53 1 3
Kovalevsky, J.	53 1 4
Krasinsky, G. A.	53 2 6
Kunitsyn, A. L.	53 2 6
Laclaverie, J.	41 9 3
Lancaster, J. E.	53 0 2
Lange, B.	53 2 5
Laubscher, R.	41 1 13
Lieberman, B.	53 0 3
Lubowe, A. G.	53 0 2
Marchal, Ch.	53 1 4; 41 1 10
Markeev, A. P.	45 1 48; 49 2 15
Marsh, E.	53 1 4
Martins, R. V.	52 2 274
Merman, G. A.	49 1 12
Meassage, P.J.	53 0 2
Meyer, K.	53 1 4
Miachin, V. F.	49 2 14
Modi, V.	53 2 5
Mulholland, J. D.	42 0 75; 53 2 –
Musen, P. V.	53 0 2; 53 1 4; 53 2 6
Nacozy, P.	48 1 14; 38 2 10
Nahon, F.	41 2 17
Neilson, J.	53 2 2
Noskov, B. N.	45 2 49
Nasonova, L. P.	45 2 49
Oesterwinter, C.	53 2 5
Orlov, A. A.	49 0 12; 54 2 63

https://doi.org/10.1017/S0251107X00024354 Published online by Cambridge University Press

Olszewski, J.	53 1 4
Osipov, G. F.	45 0 67
Pascal, M.	52 1 272; 52 2 274
Petrovskaya, M. S.	53 0 3; 53 2 4; 49 1 12
Pius, L. Y.	49 1 12
Polyakhova, E. N.	90 1 28
Rappaport, A. I.	41 2 –
Rabe, E.	53 0 2
Rom, A.	53 0 2
Rybakov, A. I.	54 1 175; 45 1 48
Saari, D. G.	53 0 2
Sagnier, J. L.	40 0 –
Schubart, J.	53 1 4
Seidelman, P. K.	53 0 2
Shelus, P.	53 2 5
Shinkarik, T. K.	49 1 12; 49 2 13
Sinclair, A. T.	53 0 2
Skripnitchenko, V. I.	49 1 62
Sokolov, V. G.	53 2 6
Solovaya, N. A.	54 2 43
Sperling, H. J.	53 1 2; 53 2 5
Standish, Jr.	53 1 4
Stellmacher, J.	53 2 5; 53 2 6
Stiefel, E.	53 0 2
Szebehely, V.	53 0 2; 53 1 4; 53 2 6
Tapley, B. D.	53 0 2
Thuring, B.	53 0 2
Tshauner, J.	53 0 3
Uralskaya, V. S.	54 0 175
Vangers, J.	53 0 2
Vashkoviak, S. N.	54 0 160; 91 2 –
Vilhena de Moraes, R.	40 2 –
Vinh, N.	53 0 2; 53 0 3
Vinti, J.	53 1 4; 53 2 5
Volkov, M. S.	49 1 10
Waldvogel, J.	53 2 6
Walter, H.	53 0 2; 53 1 4
Wielen, R.	53 0 2
Williamson, W. E.	53 2 6
Yoshida, J.	80 2 24
Zhuravlev, S. G.	53 2 4

G. N. DUBOSHIN

President of the Commission

https://doi.org/10.1017/S0251107X00024354 Published online by Cambridge University Press